EXCURSION GUIDE

HIMALAYAN SEQUENCE OF DEHRA DUN-MUSSOORIE SECTOR

GEOLOGICAL SOCIETY OF INDIA
1988

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HIMALAYAN SEQUENCE OF DEHRA DUN-MUSSOORIE SECTOR

S. K. TANDON
Department of Geology, University of Delhi, Delhi

V. C. THAKUR, A. C. NANDA, R. J. AZMI, T. N. BAGATI,
V. C. TEWARI AND ROHTASH KUMAR
Wadia Institute of Himalayan Geology, Dehra Dun

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PREFACE

Direct observation in the field and mapping are the very essence of geology. Unfortunately this aspect has been neglected in recent years in preference to more sophisticated studies in laboratory. Funding agencies are more liberal in granting substantial amounts for importing costly equipment from abroad and apparently look with disfavour on field-oriented studies. There is also a dearth of literature and guides to geological treasures in the country.

In order to overcome this shortcoming in our geological education, the Geological Society of India has launched on a programme of bringing out a series of Excursion Guide Books with the objective of introducing students to areas of exceptional geological interest in the country, where they can learn at first hand geological processes.

We start this series with a guide to an easily accessible Himalayan terrain. The student will get a glimpse of the mighty Himalaya, and of the processes which have operated in moulding this highest mountain range. Since present is the key to the past, students will be introduced to Quaternary Geology, Neotectonics, Geomorphology and related fields.

S. K. Tandon of the Delhi University enthusiastically supported this idea of bringing out Field Guides and took on himself the responsibility of assembling the material for the first guide book. In this work, he has sought and obtained the assistance of his fellow workers in the Wadia Institute of Himalayan Geology who have willingly come forward to share their knowledge and experience in making the guide book more comprehensive.

The large number of illustrations have been specially redrawn by Sri B. G. Kulkarni and have substantially added to the usefulness of the Guide Book.

There are bound to be shortcomings, but these can be set right with experience. Grateful thanks of the Society are due to Dr. S. K. Tandon of the Delhi University and Dr. V. C. Thakur and his colleagues of the Wadia Institute of Himalayan Geology for the interest they have taken in the preparation of the Field Guide.

Messrs. Bookmakers Private Limited have composed the matter by the photo typesetting process in record time and our traditional printers, the B. B. D. Power Press, have executed the work maintaining their high standards of printing. The grateful thanks of the Society are due to them.

The Geological Society of India hopes that this new venture of bringing forth Excursion Guide Books will be welcomed by all those interested in promoting geological education in this country. We invite suggestions for improvement and for increasing the scope of this activity.

September 15, 1988 B. P. RADHAKRISHNA

INTRODUCTION

This guide attempts to present an overview of the stratigraphy, sedimentology and tectonic setting of the Sub-Himalayan and Lesser Himalayan sequences of Dehra Dun-Mussoorie sector of Garhwal region (Fig. 1). At least one stop in each of the major stratigraphic units (Fig. 2) is planned.

The focus of the trip is interpretation of sequences using stratigraphic relationships and primary sedimentary structures. The lithofacies and palaeoenvironments emphasised in the Siwalik Group are: sandstone-mudstone units of channelbar-flood plain origin (Stop 1), multistoried sandstone bodies of major channel belt (Stop 2), fining upward sandstone (channel bars) of sandy braided streams (Stop 3), sandstone-pebbly-sandstone-conglomerate sequences representing the transition from a sandy braided fluvial system to a gravel bedload braided fluvial system (Stop 4) and conglomerate-sandstone beds representing distal alluvial fan deposits (Stop 5).

In the Lesser Himalayan sequence, the lithofacies and paleo-environments emphasised are: very thinly laminated siltstone and sandstone of Chandpur Formation representing a muddy near-shore shelf sequence (Stop 6), cross-bedded and flaser-bedded quartzites of Nagthat Formation representing coastal sandbar complex of a shallow tidal sea (Stop 7), immature polymictic conglomerates of Blaini Formation representing debris flows in a shallow sea (Stop 8), interbedded siltstone and sandstone of Infra-Krol Formation representing near-shore shelf facies, thinly bedded marl and limestone of basal part of Krol Formation (Krol A) indicating predominantly carbonate flat facies (Stop 9), green and red shale of Krol B (Stop 10), Upper Krol

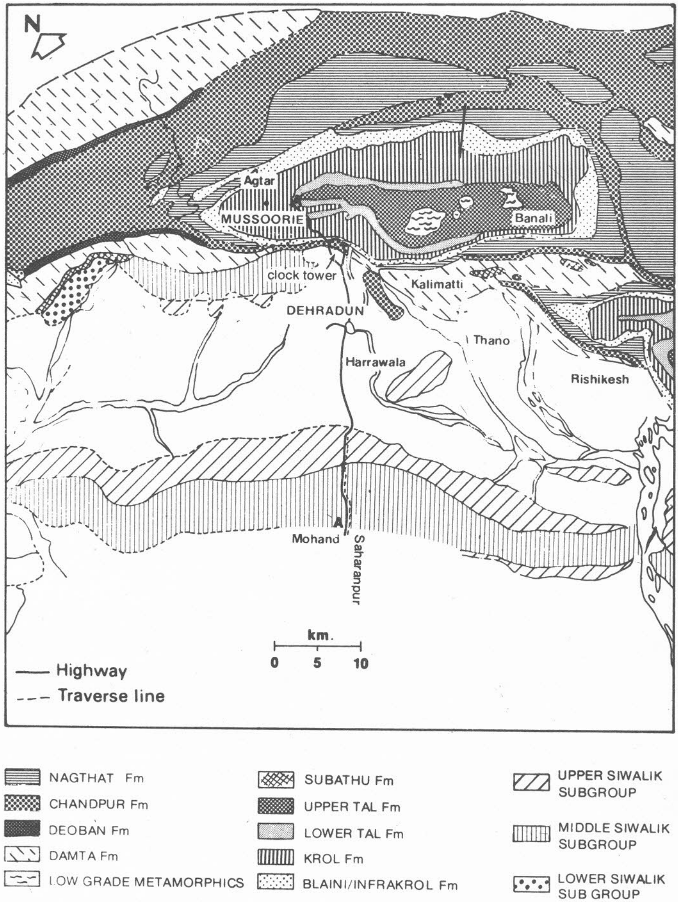

Fig. 1. Geological map of Dun Valley showing the major litho-stratigraphic units. The transect to be taken across the Sub-Himalaya and Lesser Himalaya is shown at A-A′ (After Rupke, 1974).

carbonates (Krol C, D and E) representing intertidal-Supratidal flats of a tidal sea (Stop 10–13) and siltstone-mudstone-sandstone and quartzite of the Tal Formation representing the deposits of a shallow tidal complex (Stop 14).

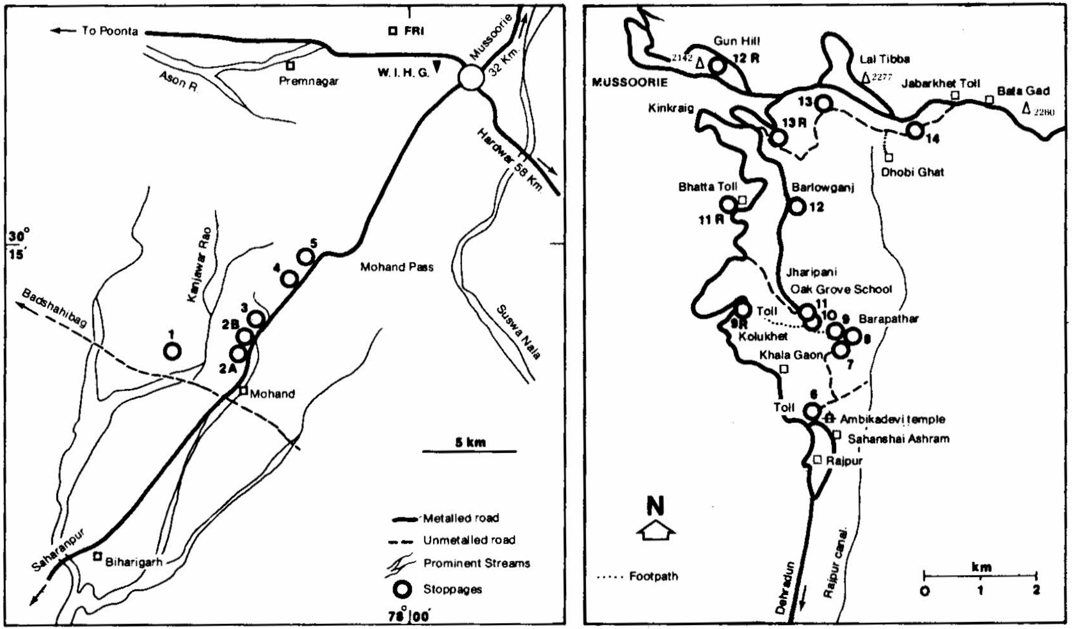

Fig. 2. Locality map of the field stops.

General Information about Dehra Dun for Planning Field Work:

Dehra Dun is situated in a flat spindle-shaped valley and supports a population of 4 lakhs. This valley experiences heavy rainfall during the monsoon months. Field work may be carried out in any part of the year excepting July–September. However, the ideal period for field work in this valley and the neighbouring hills is from October–December. The general information regarding climate, transport and accommodation in Dehra Dun and Mussoorie is given below:

DEHRA DUN

Altitude	640 metre (2100 ft)	
Climate	Average summer	max 36.6°
		min 16.7°
	Average winter	max 23.4°
		min 5.2°
Rainfall	77.8 cm to 228.6 cm per annum.	

Transport and Communications

Air	The nearest airport is Jolly Grant 24 km from Dehra Dun City.	
Rail & Road	Terminus of Northern Railway; direct transport from Calcutta, Bombay, Delhi; well connected with various places.	
	Delhi-Dehra Dun	255 km
	Hardwar-Dehra Dun	54 km

Accommodation

Hotels	Various classes
Dharamshalas	1) Shivaji Dharamshala Saharanpur Road Dehra Dun, Tel: 23528
	2) Agarwal Dharamshala Gandhi Road Dehra Dun, Tel: 26871
	3) Jain Dharamshala Gandhi Road, Dehra Dun, Tel: 25823, 26873

Other accommodation

1) Tourist Complex
(Drona)
45, Gandhi Road
Dehra Dun, Tel: 26894

2) P.W.D. Inspection House
Rajpur Road
Dehra Dun

3) Y.W.C.A.
4 New Cantt. Road
Y.W.C.A. Dehra Dun

MUSSOORIE

Altitude	2000.5 metres (6600 ft)		
Climate	Average summer	max	31.80°C
		min	7.2 °C
	Average winter	max	7.2 °C
		min	1.0 °C

Transport and Accommodation

Mussoorie is situated 32 km from Dehradun and is connected only by road. Frequent bus and taxi services are available from Dehra Dun Railway and Bus stations.

Accommodation

Hotels	Various classes
Other types	1) Tourist Complex The Mall Mussoorie, Tel: 2863
	2) P.W.D. Inspection House L.B.S. Academy Road Mussoorie
	3) C.P.W.D. Inspection House Castle Hills, Landour Mussoorie.
	4) Central Government Employee Holiday Home Library–Kingeraig Road, Mussoorie.
	5) Haryana P.W.D. B & R Rest House Kempty Fall Road Mussoorie.

Ideally, it is suggested that student parties may stay at one of the 'dharamashalas' located near the Railway and the Bus stations in Dehra Dun. Suitable places for eating are available near the dharamshalas. It is advisable to book accommodation well in advance.

There are several institutions of geological interest in Dehra Dun which may be visited by student parties by making prior arrangements. These include a) Keshav Dev Malaviya Institute of Petroleum Exploration (ONGC), b) Wadia Institute of Himalayan Geology, c) Indian Institute of Remote Sensing.

A visit to the museum of the Forest Research Institute will also be very rewarding.

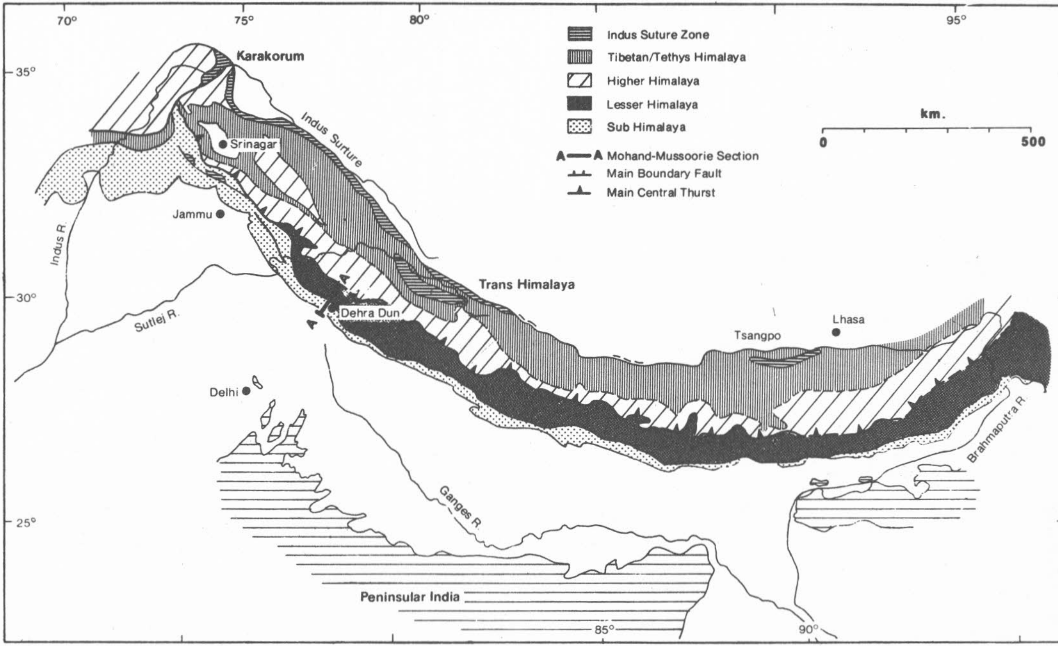

Fig. 3. Major structural zones of the Himalaya (modified after Gansser, 1964).

SUGGESTIONS FOR READING

The Dun Valley comprises features which are illustrative of Himalayan stratigraphy, sedimentation and tectonics. The student parties planning to carry out field visits in this area would be well advised to brush up their course materials in stratigraphy (*Geology of Himalaya* by Gansser, 1964; *Sedimentary Rocks* by Pettijohn, 1977; *Depositional Sedimentary Environments*, by Reineck and Singh, 1980; *Geology of Kumaun Lesser Himalaya* by Valdiya, 1980, and *Aspects of Tectonics* by Valdiya, 1984; *Principles of Sedimentary Basin Analysis* by Miall, 1984 and *Sedimentary Environments and Facies* by Reading, 1986). Other important references are listed in the bibliography and form part of the desirable reading for field visits to this area.

REGIONAL SETTING

The focus in this field trip is on the Sub- and Lesser Himalayan terrains. From south to north, the following sub-divisions of the Himalaya are generally recognized (Fig. 3).

1. Sub-Himalaya
2. Lesser Himalaya
3. Higher Himalaya
4. Tibetan Tethys Himalaya
5. Indus Suture Zone

Of these, the first two are of relevance to this field trip and are described below:

Sub-Himalaya

This refers to the southernmost part of the Himalaya and is demarcated to the south by the alluvial piedmont. To the

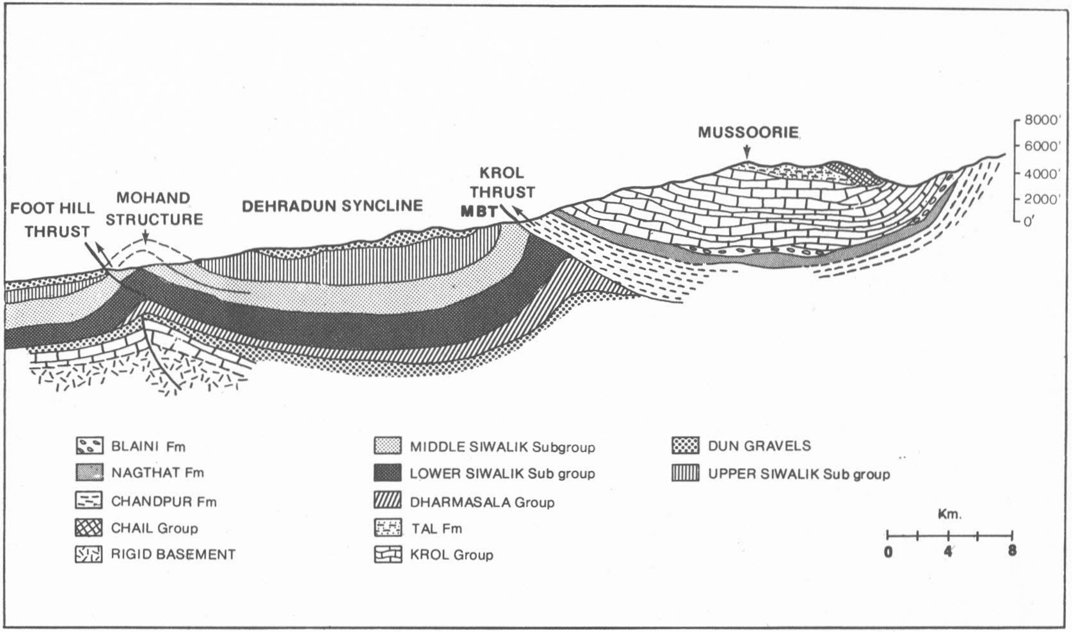

Fig. 4. Geological cross section across Mohand and Mussoorie area (compiled from Rao et al., 1974 and Shankar, 1975).

north, the Sub-Himalaya is delineated by a tectonic contact– the Main Boundary Thrust (MBT) (Figs. 3 and 4). The Sub-Himalayan belt consists predominantly of fluvial sequences which have been deposited in the Neogene. In stratigraphy, these rocks are referred to as the Siwalik Group.

The Siwalik Group represents one of the thickest fluviatile sequences of the world (Opdyke, et al., 1982). These occur along the Himalayan foothills from the Brahm-putra valley in the east to the Potwar Plateau and Bannu Plains in the West (Krishnan, 1982).

The stratigraphic framework of the Siwalik Group has been re-defined recently through intensive application of the magnetic reversal stratigraphy and radiometric dating of the zircon grains extracted from the interbedded volcanic ashes. Data on the classification of the Siwalik Group and the new temporal constraints provided by magnetic polarity stratigraphy are summarised in Table 1. The initiation of the Siwalik basin took place ~19 m.y. ago (Johnson et al., 1985). Prior to the commencement of the Siwalik sedimentation, extensive deposition took place in the basin in the Palaeogene. These units are referred to as the Dharamsala Group. Widespread sedimentation has taken place in most parts of the Siwalik basin until 1 m.y. ago. In view of the collision tectonics the result of continued northward convergence of India and the consequent crustal shortening (Stocklin, 1980), the Siwalik rocks occur as anticlines in the outermost belt. These anticlines have been dated in the Pabbi Hills, Pakistan (Keller et al., 1977) and are believed to have ceased to grow 400,000 years ago. In most of the sectors in India, the Siwalik Group occurs in tectonic slices (stacks of thrust sheets).

Sedimentation pattern: The Siwalik Group represents a sequence which consists of ~6000 m thick interbedded

Table 1. Chronostratigraphic Division of The Siwalik Group.

Geological Time Scale		Classification of the Siwalik Group	Standard European equivalent	Age calculated from reversal stratigraphy	*Continental equivalent
Pleistocene	*Upper Siwalik*	Boulder Conglomerate	Cromerian	1·5 to 0·5 m.y.	?
		Pinjor	Villafranchian	2·47 m.y.	Middle-Late Villafranchian
Pliocene		Tatrot	Astian	5·5 m.y.	Ruscinian-Early Villafranchian
	Middle Siwalik	Dhok Pathan	Pontian	8·5 m.y.	Turolian
		Nagri	Sarmatian	10·8 m.y.	Late Vellesian–Early Turolian
Miocene	*Lower Siwalik*	Chinji	Tortonian	14·3 m.y.	Oeningian–Vellesian
		Kamlial	Helvetian		18·3 m.y.
		Murree Group	Burdigalian		Pre-Oeningian

*After Berggren and Van Couvering (1974).

mudstones, sandstones and conglomerates and subordinate marls. These are the deposits of complex channel and fan systems which have varied considerably in their morphology in space and time.

The Lower Siwalik Subgroup largely consists dominantly of red mudstone with sand-poor intervals. These may be taken as deposits of transient streams. The style of sedimentation undergoes a dramatic change with the onset of big river systems (10 m.y). The Nagri lithofacies of Middle Siwalik consists predominantly of multistoried sandstone with deep orange and reddish-brown clays. Some of the argillic horizons of Nagri Formation of Haritalyanagar have been interpreted to be ferruginous tropical soils or low-grade oxisols developed on a typical floodplain toposequence (Johnson, 1977). Isochronous fluvial systems have been described from Pakistan by Behrensmeyer and Tauxe (1982). Detailed analysis of the Upper Siwalik Subgroup reveals a progressive change from anastomosed fluvial system through braided stream, distal alluvial fan and finally proximal alluvial fan deposits (Kumar and Tandon, 1985).

In the Dehra Dun-Mussoorie region, the significant tectonic features of the belt are the Mohand Anticline and the Dehra Dun Re-entrant. The Dun Re-entrant is fault-bound along its eastern and western margins by the Ganga and Yamuna Faults respectively (Fig. 5). The Krol Thrust (MBT) delineates its northern boundary. Stratigraphically, the Siwalik Group in this sector (Mohand Anticline) has been sub-divided into the Middle and the Upper Siwalik Subgroup (Table 2). The Middle Siwalik Subgroup consists of predominantly multistoried sandstones (Fig. 6) measuring upto 1800 m on the northern limb of the Mohand Anticline (Kumar and Nanda, *in press*). The upper part of the Middle

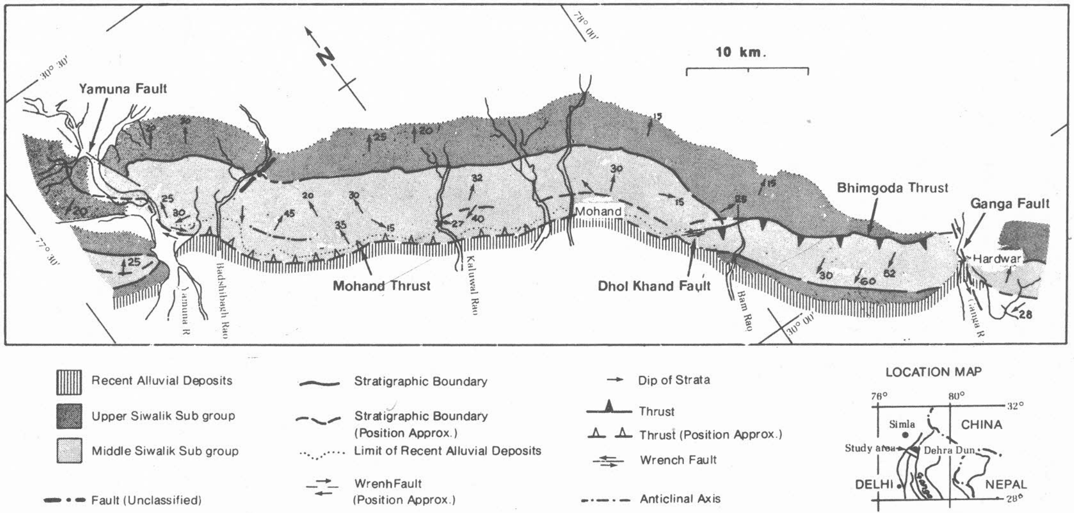

Fig. 5. Geological map of the Siwalik Range between Yamuna and Ganga Rivers (After Rao et al., 1974).

Table 2. Lithostratigraphy of Mohand Area.

Formation	*Lithology*	*Age*
Doon Gravel	Conglomerate–clast of limestone, quartzite, embedded into sandy matrix	Late Pleistocence
Upper Siwalik Subgroup	Conglomerate, clasts of quartzite, granite, limestone, phyllite, embedded in sandy and muddy matrix and lenses of sandstone and mudstone.	Pliocene to Middle Pleistocene
Middle Siwalik Subgroup	C. Alternation of brown mudstone and thickly bedded grey to greyish brown micaceous sandstone. B. Massive, thick grey multistoried sandstone with occasionally mud-pockets. C. Thickly bedded grey sandstone and grey mudstone.	Upper Miocene

Siwalik Subgroup, however, consists of alternations of sandstone and mudstone. Sandstones are predominantly grey in colour, medium-grained and rich in micaceous minerals. Pebbly sandstones are also common. In the lower part of this sequence, mudstones are scarce. But, wherever present, they are grey in colour. In the upper part of the sequence, the mudstones are predominantly red coloured suggesting the dominance of oxidising conditions and relatively well drained floodplains.

The Upper Siwalik Subgroup consists predominantly of polymictic conglomerate and subordinate grey micaceous sandstones. The conglomerates consist of well rounded to subrounded clasts of white, pink and grey quartzite, granite, phyllite and rare limestone.

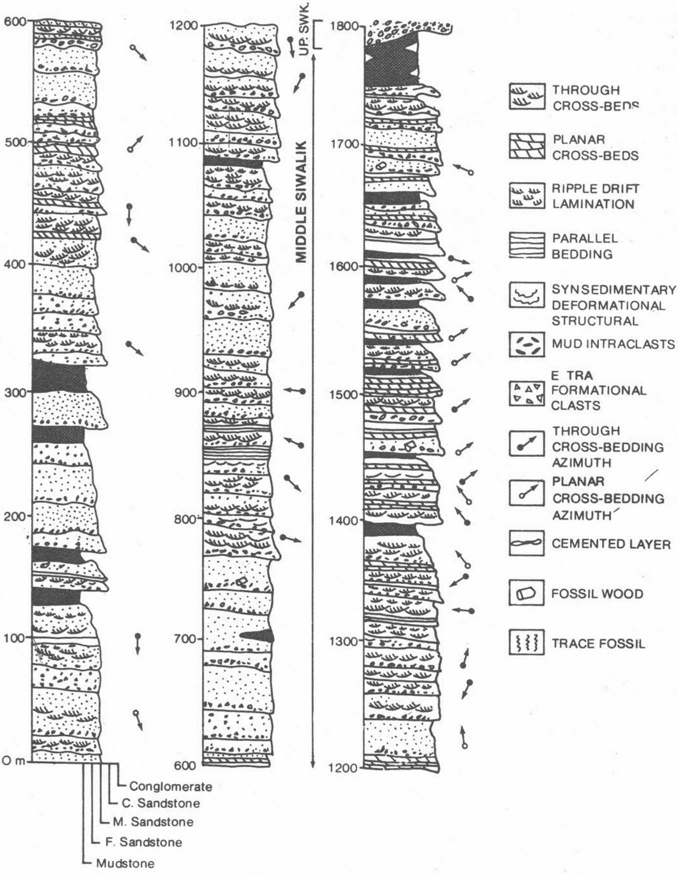

Fig. 6. Vertical log of the lithofacies occurring in the multistoried sandstone of the Middle Siwalik Subgroup of the Mohand Rao Section (After Kumar Nanda, *in press*).

The Upper Siwalik conglomerates conformably overlie the Middle Siwalik sandstone-mudstone sequences. In turn, the Upper Siwalik conglomerates are overlain by the Dun Gravels—a stratigraphic unit consisting of unconsolidated flat-lying gravel beds.

There is no data on the age of these sequences in this region. Fossil record is poor. A few vertebrate fossils (artiodactyl remains) have been collected. Similar multi-storied sandstone lithofacies have been reported to occur in the Nagri Formation (10 m.y. to 8 m.y.) in various parts of Potwar and in Haritalyangar in Himachal Pradesh (Opdyke *et al.*, 1982; Johnson *et al.*, 1983).

Dun Valley: The Sub-Himalaya and the Lesser Himalaya are separated by a depression referred to as Dun (Fig. 1). Coarse clastic deposits fill up this depression. The origin of the depression is poorly understood. In terms of contemporary knowledge, the Dun valley may be regarded as an unclassified structural depression.

Lesser Himalaya

This refers to the litho-tectonic province which is demarcated to the south by the Main Boundary Thrust (MBT) and is separated to the north by the Main Central Thrust (MCT) (Fig. 3). It predominantly consists of Proterozoic-Cambrian shelf to shallow marine sequences disposed in two main belts viz. the inner carbonate belt and the outer Krol belt.

The stratigraphy of the Mussoorie Syncline consists largely of sedimentary rocks of Krol belt (Figs. 1 and 7).

Field parties may find the stratigraphy of the Krol belt, especially the Blaini-Krol-Tal succession, interesting as it has recently been established to be a most significant

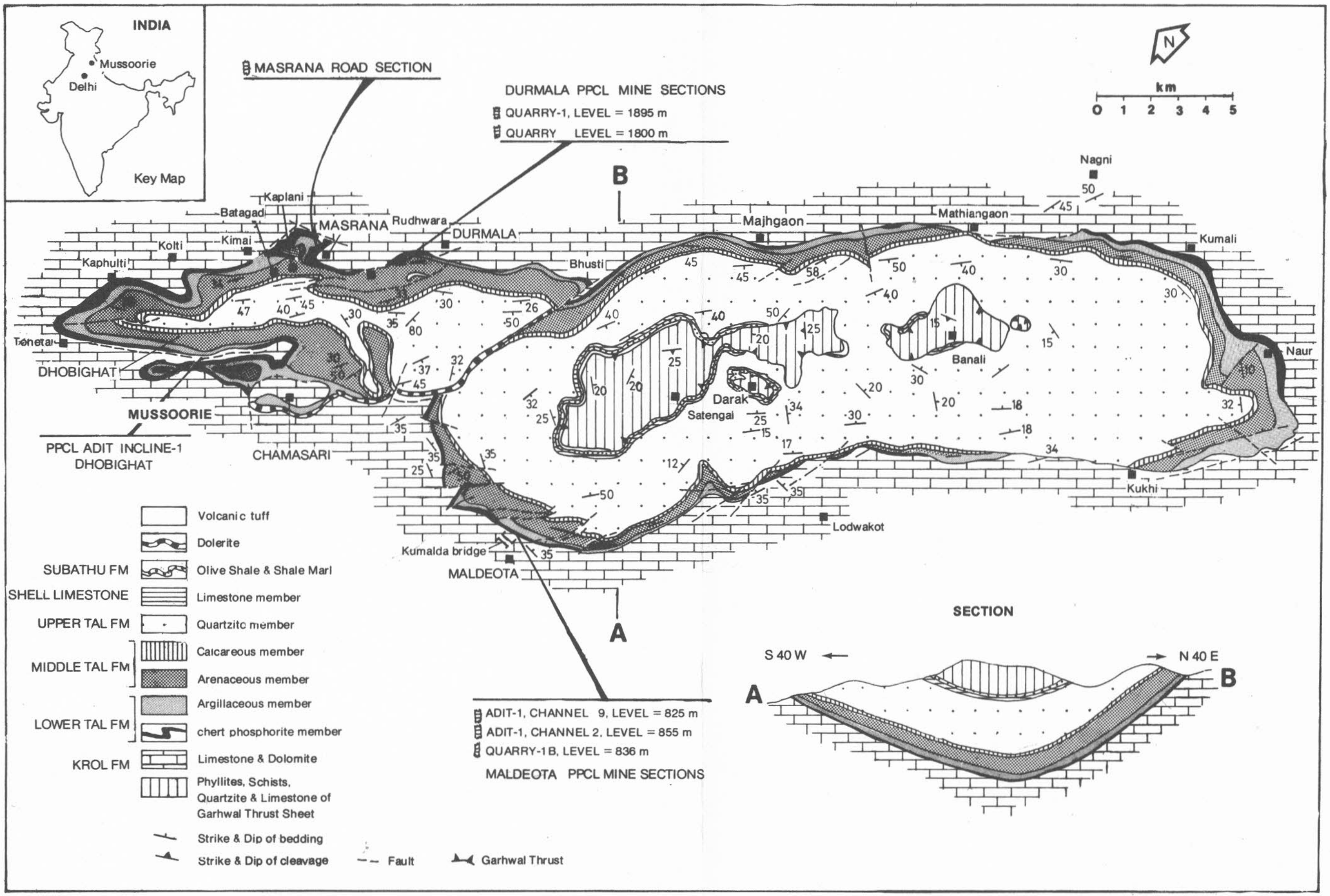

Fig. 7. Geological map of part of the Mussoorie Syncline after Ravi Shankar (1975). Locations of important measured sections yielding Precambrian-Cambrian boundary shelly microfauna are after Azmi (1983). Few other fossiliferous localities referred in the text are also shown.

succession of Late Precambrian-Cambrian, in contrast to the century old traditional belief of its Late Palaeozoic-Mesozoic age. A generalised litho-stratigrahic column of the Krol belt succession with revised time-stratigraphy is given in figure 8.

The late Palaeozoic-Mesozoic age of the Krol belt was deduced mainly on two criteria—

1. The occurrence of definite Upper Cretaceous marine fossils in the Shell Limestone unit capping the Upper Tal Quartzite in an apparently conformable manner.

2. The occurrence of Blaini Boulder Bed at the base of Infra Krol-Krol sedimentary rocks in a normal stratigraphy which was invariably equated with the glacigenic Upper Carboniferous-Talchir Boulder Beds of Indian Peninsula since the first proposition of this idea by Oldham (1888).

While a general consensus had emerged about the Upper Cretaceous age of the Shell Limestone, the status of the Blaini Boulder Bed as an Upper Carboniferous chronostratigraphic datum could not be confirmed mainly due to lack of any definite fossils. Contrary to this, it was Holland (1908) who first questioned the Blaini-Talchir correlation, and due to *unfossiliferous* nature of the Krol belt sequence, correlated it with the Purana Group of rocks (placing Blaini in the Late Precambrian). Incidentally, the proposal of Late Precambrian age for Blaini by Holland did not receive support although there were reports of algal oncolites (Gundu Rao, 1970) and algae resembling *Renalcis* (Gansser, 1974) from the Krol carbonates which, in general, indicated a Late Precambrian to Cambrian age. Instead, the notion of Late Palaeozoic– Mesozoic age got firmly rooted in Indian geology because of several fossil records pointing to

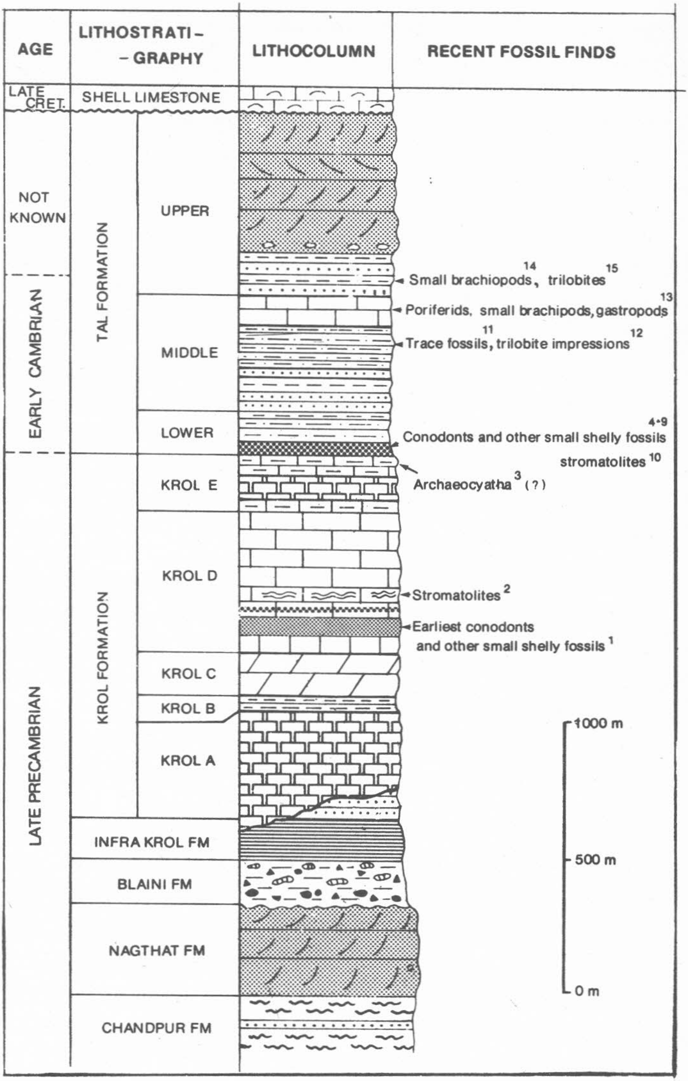
AGE
LITHOSTRATI- - GRAPHY
LITHOCOLUMN
RECENT FOSSIL FINDS
LATE CRET.
SHELL LIMESTONE
NOT KNOWN
EARLY CAMBRIAN
LATE PRECAMBRIAN
TAL FORMATION
UPPER
MIDDLE
LOWER
KROL FORMATION
KROL E
KROL D
KROL C
KROL B
KROL A
INFRA KROL FM
BLAINI FM
NAGTHAT FM
CHANDPUR FM
Small brachiopods 14, trilobites 15
Poriferids, small brachipods, gastropods 13
Trace fossils 11, trilobite impressions 12
Conodonts and other small shelly fossils 4-9
stromatolites 10
Archaeocyatha 3 (?)
Stromatolites 2
Earliest conodonts and other small shelly fossils 1
1000 m
500 m
0 m

Fig. 8

this age (Sitholey et al., 1954; Ghosh and Srivastava, 1962; Sah et al., 1968; Tiwari, 1969; Prasad and Bhatia, 1975; Sinha, 1975; Srivastava and Venkatraman, 1975; Valdiya, 1980; and several others). Singh (1981) and Azmi and Joshi (1983) after critically reviewing palaeontological validity of all such records pointed out that these data have no biostratigraphic significance. Earlier, Singh (1976, 1979 and 1980) had already attempted to resolve this enigma suggesting that the Krol belt represented a Late Proterozoic shallow marine basin instead of a Late Palaeozoic-Mesozoic basin. Further, Singh and Rai (1977) used the evidence of the occurrence of extensive stromatolitic carbonates to support this hypothesis. In addition, Singh (1979) also explained the occurrence of Permian, Late Cretaceous, and Eocene fossiliferous beds of the Krol belt as transgressive events corresponding to the three main similar events of the Indian shield.

The most significant palaeontological data input in the age controversy of the Krol belt was the discovery of conodonts from the Chert-Phosphorite Member of the basal Tal in Maldeota PPCL mine by Azmi et al., (1981) which indicated a latest Cambrian (straddling the Cambro-Ordovician boundary) age to this unit. This discovery led to the spontaneous record of many additional fossil finds from several levels of Krol-Tal succession (see Fig. 8). These

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Fig. 8. Revised time-stratigraphy of the Krol belt succession (after Azmi & Joshi, 1983; Kumar et al. 1983; Singh & Rai, 1983; Tewari, 1984 a & b). Recent fossil finds: 1, Azmi and Pancholi (1983); 2, Tewari (1984 c and 1987); 3, Singh and Rai (1983 a); 4, Azmi et al. (1981); 5, Azmi (1983); 6, Bhatt et al. (1983); 7, Bhat et al. 1985; 8, Kumar et al. 1987; 9, Brasier and Singh (1987); 10, Tewari (1984 a); 11, Singh and Rai (1983 b); 12, Rai and Singh (1983); 13, Kumar et al. (1983); 14, Tripathi et al. (1984); 15, Kumar et al. (1987).

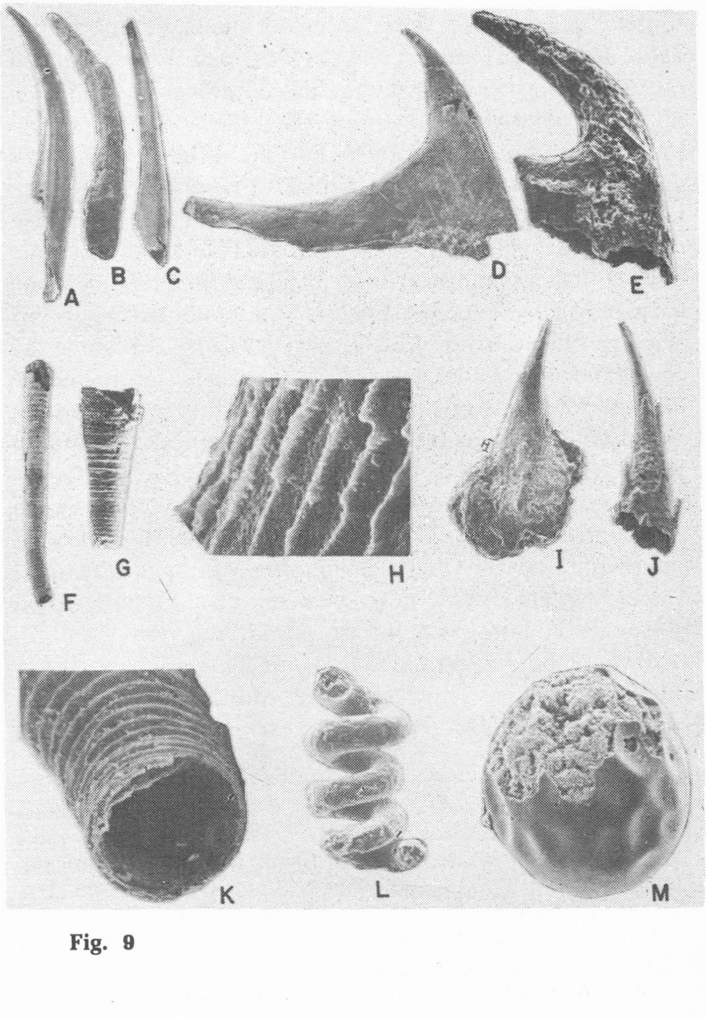

Fig. 9

are conodonts and other small shelly fossils (Fig. 9) (Azmi, 1983; Azmi and Pancholi, 1983; Bhatt et al., 1983; Bhatt et al., 1985; Brasier and Singh, 1987; Kumar et al., 1987), small brachiopods, gastropods and trace fossils (Kumar et al., 1983), various trace fossils (Singh and Rai, 1983), trilobite impressions (Rai and Singh, 1983), archaeocyatha (?) (Singh and Rai, 1984), stromatolites (Fig. 10) (Tewari, 1984a and 1984b), small inarticulate brachiopods (Kumar et al., 1987), and redlichiid trilobites (Tripathi et al., 1987), which firmly establish that except the Upper Cretaceous Shell Limestone, Blaini-Krol Tal succession belongs to a Late Precambrian-Cambrian interval in which the Blaini Formation attains a Late Precambrian position (Fig. 8). Of late, however, Tiwari and Kumar (1986) have recorded Late Permian-Early Triassic? miospores from the upper part of Upper Tal

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Fig. 9. A few selected Precambrian-Cambrian boundary conodonts (A–E, H–J) and other small shelly fossils from Krol-Tal succession of Mussoorie Syncline, Garhwal Lesser Himalaya (from Azmi, 1983 and Azmi and Pancholi, 1983 with some taxonomic amendments by Azmi). All specimens from Chert-Phosphorite Member of Lower Tal Formation except B from Upper Krol.

A, *Protohertzina anabarica* Missarzhevsky, × 35.
B, *Protohertzina unguliformis* Missarzhevsky, × 38.
C, *Protohertzina siciformis* Missarzhevsky, × 100.
D, *Mongolodus platybasala* (Yang and He), × 94.
E, *Mongolodus* cf. *rostriformis* Missarzhevsky, × 150.
F and K, *Hyolithellus annulatus* Meshkova; F, × 18; K, gently curved broken near end portion of F, × 170.
G, *Pseudorthotheca bistriata* Qian; G, × 20.
H–I, *Fomitchella infundibuliformis* Missarzhevsky, H, Surface detail at position indicated in I, × 100; I, × 85.
J, aff. *Salanacus* Grigorieva, E, × 100.
L, *Spirellus columnarus* Jiang, × 155.
M, *Olivooides multisulcatus* Qian, × 90.

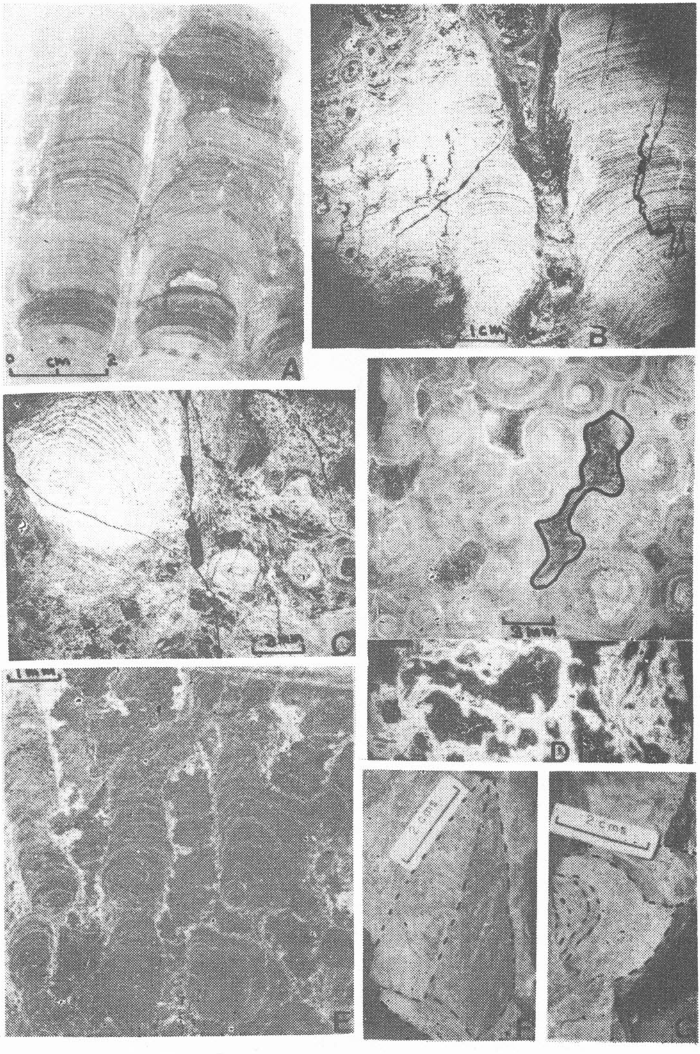

Fig. 10

Quartzite in Garhwal syncline which may correspond to the Permian transgression in the Lesser Himalaya. This find is significant but requires additional data before it is utilised for the time-stratigraphy of the Krol-belt. These recent fossil finds not only solved our long standing age controversy of the Krol belt succession but offered an unique opportunity to closely workout the international problem of Pre-cambrian/ Cambrian boundary in this succession which is primarily based on the stratigraphic concept of metazoan evolution. It is generally believed that the soft-bodied metazoans of Ediacarian/Vendian (Latest Proterozoic) time later acquired mineralized skeletons in their bodies during the course of their evolution. This evolutionary change is regarded as an important event in the evolutionary history of the metazoans, and therefore, should be taken for the

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Fig. 10. **A** Lower Cambrian (Tommotian) stromatolite form *Collumnaefacta vulgaris* Sidorov, from Chert Phosphorite Member, Lower Tal, PPCL Mine, Durmala.

B Lower Cambrian (Tommotian) stromatolite form *Aldania mussoorica* and oncolites from Chert Phosphorite Member, Lower Tal, PPCL Mine, Durmala.

C *Compactocollenia* Koroljuk, and *oncolites* from Chert-Phosphorite Member, Lower Tal, PPCL Mine, Durmala.

D Photomicrograph showing development of fenestral fabric in algal mat carbonate facies of Upper Krol (Krol D). Upper part of the photograph shows fenestral fabric and oncolites.

E Photomicrograph of microstromatolites from Upper Krol (Krol D) algal mat facies.

F Photograph of *Conophyton* Maslov from Krol D Member of Mussoorie syncline, Chamasori area. (Upper Krol algal mat (Krol D) facies) showing conical shape tapering towards the top.

G Photograph of *Conophyton* Maslov showing transverse section and concentric laminae (same specimen as in Fig. F).

Proterozoic-Phanerozoic boundary delineation. Evidence of such an interpretation for evolutionary change is available from the sections of Siberian and Russian Platforms, South China, Southwest Africa, Newfoundland and South and central Australia (see Dawn of Animal Life by M. F. Glaessner, 1984).

The Krol or Infra Krol units hold promise of containing the Ediacarian-type soft-bodied metazoan impressions. A lucky hunter may herald this discovery soon.

The biostratigraphic utility of the stromatolites has been a debatable question in India and other continents for a long time. Valdiya (1969) attempted the correlation of Lesser Himalayan carbonates and Vindhyans. Singh and Rai (1977) and Tewari (1984b, and 1984c), on the basis of occurrence of stromatolites from the Upper Krol stressed a Late Precambrian age. Tewari (1984a, b) also discovered lower Cambrian (Tommotian) stromatolite taxa *Collumnaefacta vulgaris* and *Aldania mussoorica* from the Chert Phosphorite Member of the Lower Tal Formation exposed at PPCL Mine, Durmala (Fig. 10a, b and c). Tewari (1988) assessed the biostratigraphic usefulness of the stromatolite taxa in the Precambrian and Cambrian Carbonates of the Lesser Himalaya and arrived at the conclusion that only Lower Riphean to Lower Cambrian taxa are found in the Lesser Himalaya. The latest Precambrian (Vendian) stromatolite taxa are found in the Upper Krol Carbonates. The Lower Cambrian (Tommotian) taxa are restricted to only Lower Tal Formation.

Recently, Azmi (1987 and 1988) has critically assessed the small shelly fauna of the Chert-Phosphorite Member of Lower Tal and has emphasised that this fauna has great potential for correlation and, therefore, is directly of international relevance for the definition of Precambrian-Cambrian boundary.

Further, a positive isotopic excursion of $\delta^{13}C$ has been identified in the Krol D algal laminite (Aharon et al., 1987). This isotopic excursion may be related to evolutionary changes at the Precambrian/Cambrian boundary.

STOP 1

Middle Siwalik Section, Southern Limb of Mohand anticline, Khajnawar Rao

Location

This section of Middle Siwalik sandstones and mudstones is located at the intersection of the Khajnawar Rao (a seasonal stream) with the forest road leading from Mohand to Badshahibag. This intersection is 1·5 km from the Delhi–Dehra Dun highway (Fig. 2). North of the intersection, the Middle Siwalik rocks are exposed in a series of anticlinal and synclinal folds on both banks of this rivulet. Looking north, on the western bank, the Middle Siwalik grey sandstone-brown mudstone sequence rises abruptly from the alluvial plains lying to the south. Prominent terrace gravel deposits overlie the Middle Siwalik rocks. The terrace deposits are offset by faults.

Objectives

At Stop 1, can be examined the mudstone-sandstone sequence (lithofacies and sedimentary structures), pre-lithification folding and cleavage development, mud-injections, dewatering (?) structures and the tectonic contact between the southern alluvial plain and the overlying Siwalik sandstone. This contact has been named as the Mohand Thrust and is equivalent to the HFF (Himalayan Frontal Fault) or HFTL (Himalayan Front Tectonic Line, Nakata, 1972).

Description

At stop 1, the sandstone facies and mudstone facies occur. There are several variations in the sandstone facies (Fig. 11). The lithofacies are given in Table 3.

Table 3. Characteristics Of The Lithofacies At Stop 1.

Lithofacies	*Lithofacies description*	*Structure*
'Sc'	Light grey, medium sandstone	Trough cross bedding
'Sm'	Light grey, medium to coarse grained sandstone with mudy interclasts.	—
Sr	Fine grained, light grey colour sandstone.	ripple drift lamination
Fm	Siltstone, massive light grey colour.	—
Fm_1	Dark brown mottled mudstone.	—
Fm_2	Deep red, massive mudstone.	—

The sandstone lithofacies have accumulated largely in channels (channel floor and bar deposits). Erosional and scouring events are common.

Good exposures of the small-scale cross-bedded sandstones are present. These units are composed of muddy sandstone and show at least 2–3 prominent bedding surfaces of rib and furrow structures.

Another important facies is the horizontal stratified and ripple drift-laminated fine-grained sandstone facies. This lithofacies represents levee deposits.

The mudstones are predominantly grey to dark-brown in colour. They show a mottled character, at places, signifying pedological modification of floodplains which were largely under oxidising conditions.

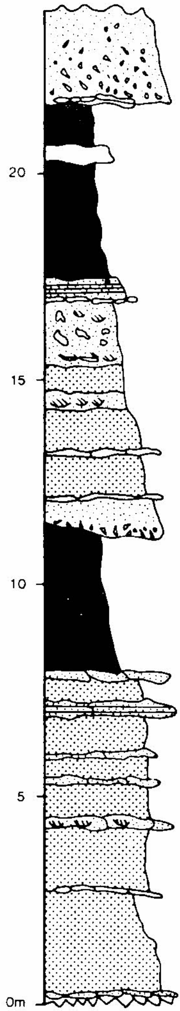

Fig. 11. Simplified log for the Middle Siwalik Subgroup at Stop 1, showing the vertical characters of the sandstone/mudstone sequence. Also notice the erosional surfaces with basal scour into the mudstone (For legend see Fig. 6).

The sequence is deformed into a series of anticlines and synclines. Outcrop-scale folds are present at several locations in the mudstone sequence (Fig. 12). The interesting point about these structures is the development of cleavage trending N-S. Early fractures in the sandstone and mudstone are filled by mud. These mud injections are related to the axial surfaces of folds. This would argue for a pre-lithification origin for the folds.

At the southernmost extremity of the exposures on the western bank of Khajnawar Rao, the Middle Siwalik rocks have tectonically crept over the Late Pleistocene-Holocene alluvial deposits of the piedmont zone. This contact has been referred to as the Mohand Thrust (Rao *et al.*, 1974) (Fig. *5).*

Fig. 12. Photograph showing the folding pattern within the mudstone (overbank) sequence near the Himalayan Frontal Thrust Line at Khajnawar Rao (Stop 1).

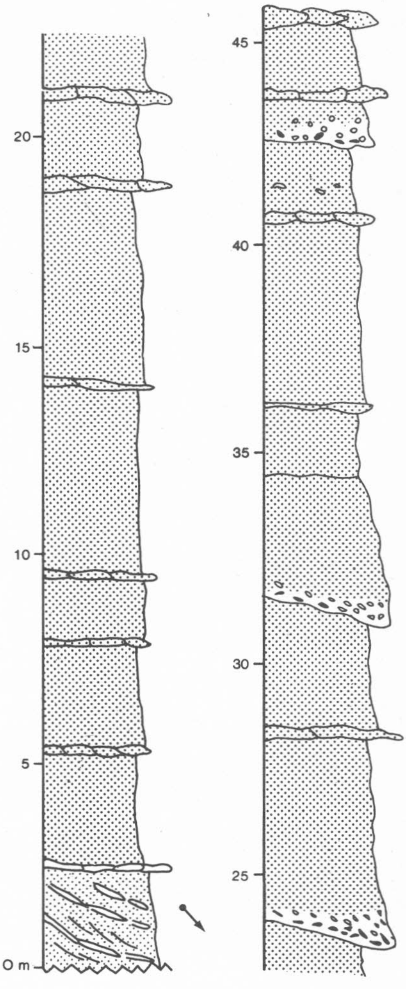

Fig. 13. Vertical litholog through a part of the multistoried sandstone complex showing the occurrence of prominent cemented layers. Also notice towards the base cemented layer along the large-scale trough cross-bedding (For legend see Fig. 6).

STOP 2A

Multistoried Sand Bodies of Middle Siwalik Sub-Group, Mohand-Dehra Dun Road

Location

Stop 2A is located on culvert No. 164/3 at ~21.8 kilometer from Dehra Dun on the Mohand-Dehra Dun road (Fig. 2). A spectacular scarp face of northeast dipping sandstones occurs in a minor tributary of the Mohand Rao. The 45 m section was measured in the eastern bank of Mohand Rao (Fig. 13).

Objectives

At Stop 2A can be examined the multistoried sandstone units of the Middle Siwalik Subgroup, the erosional surfaces separating various sedimentation units, and large-scale cross-beds.

Description

The sandstones are grey and medium-grained. They contain isolated clasts of rounded quartzite. Megascopically, quartz and micaceous minerals are identifiable.

The scarp face consists of multistoried sand bodies (Fig. 13). Several discontinuous erosional surfaces can be recognized in the sandstone scarp. Erosional surfaces are recognized by the channeled bases of the individual sandstone storeys. The channeled bases contain abundant intraformational debris in the form of intraclasts of grey mudstone. The average thickness of individual storeys is 3–5 meters. These storeys can be traced eastwards towards the valley. This indicates that the sandstone bodies are multistoried sheet bodies with channeled bases.

Towards the base of this exposure, a large scale trough cross-bed occurs. It stands out prominently because of the cementation ($CaCO_3$ cement) of the foreset surfaces (Fig. 14).

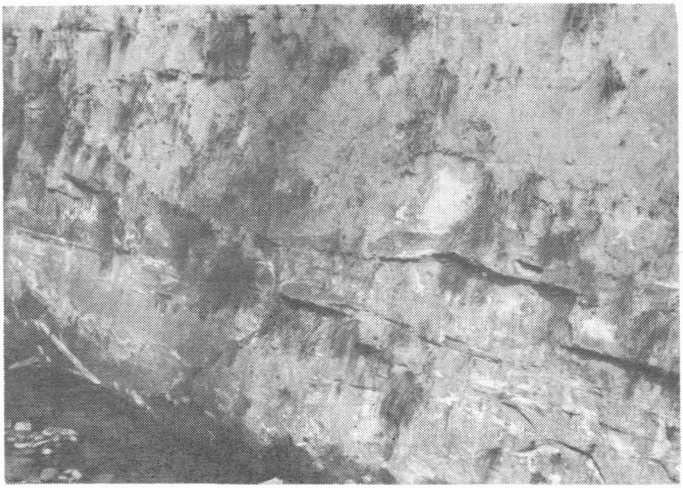

Fig. 14. Photograph showing lower part of the vertical scarp of the multistoried sandstone complex. Note the several erosional surfaces within the complex.

The foreset surfaces are directed towards NE with inclinations varying between 25°–35° (The palaeoflow direction can be obtained by rotating the cross-bedding along the bedding strike by an angle of 30°). The resulting palaeoflow direction after tilt correction is 125°.

Calcareous cementation is a prominent feature of the sandstone unit. Cementation is largely bedding concordant.

From evidence presented in the preceding paragraphs, it is inferred that these deposits formed in various growth stages of channel bars in big braided rivers. The rivers were shallow relative to their width, floored by bars and channels of low sinuosity, and with a bedload of sand and pebbly sand.

STOP 2B

Large Scale Trough Cross-Stratification with Intraformational Mudclasts

Location

Stop 2B is located at the Iron Bridge (21.6 km from Dehra Dun) and Mohand Rao intersection (Fig. 2). There are cliff-forming sandstones on the southern bank of the river. Low-lying river-bed outcrops trending 110°–390° are, however, the subject of interest at this outcrop. The extent of these low-lying exposures is 40 m.

Objectives

At Stop 2B, can be seen the large-scale trough cross-beds, intraformational mud clasts, and cementation in sandstone.

Description

The sequence represents a 12 m interval (Fig. 15) through a multistoried sandstone complex. There are two major erosional surfaces. From the accompanying photographs (Fig. 16), it is seen that the depth of scouring is of the order of 1 meter. Intraformational clasts occur in these

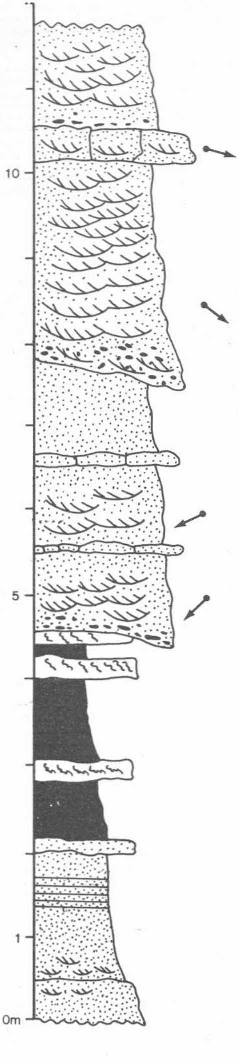

Fig. 15. A simplified sedimentary log of a part of multistoried sandstone complex at Stop 2B showing the mudstone interval (lens shaped) and large scale trough cross-stratified sandstone units. Also notice a fining up sequence at the base with change in structure from small scale trough cross bedding to parallel lamination (For legend see Fig. 6).

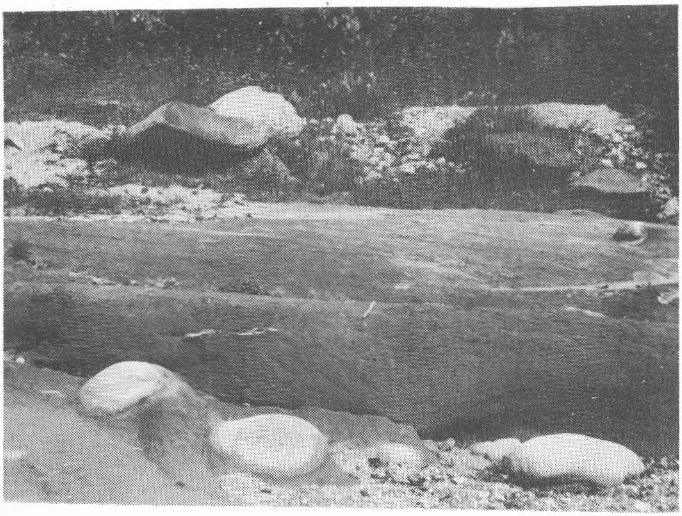

Fig. 16. Photograph shows channelised sandstone body within the multistoried sandstone complex at Stop 2B. Notice the various erosional surfaces with intraformational clasts. Scour fill type large scale trough cross stratification (Photograph near Iron Bridge on Mohand-Dehra Dun Road).

scour-fill units. Extrabasinal clasts, predominantly of quartzite also occur in the sandstone.

The mud clasts are of variable size and shape—the largest clasts measure up to 30 cm. Variability of directions in the various flow events is common. Clasts are oriented along the foreset stratification. Carbonaceous and coalified plant material are present. It can be interpreted that these materials were derived from a vegetated floodplain which was largely under reducing conditions. Cementation in the sandstones is pronounced. The cemented sandstone stands out prominently (Figs. 17A and B). These layers, though

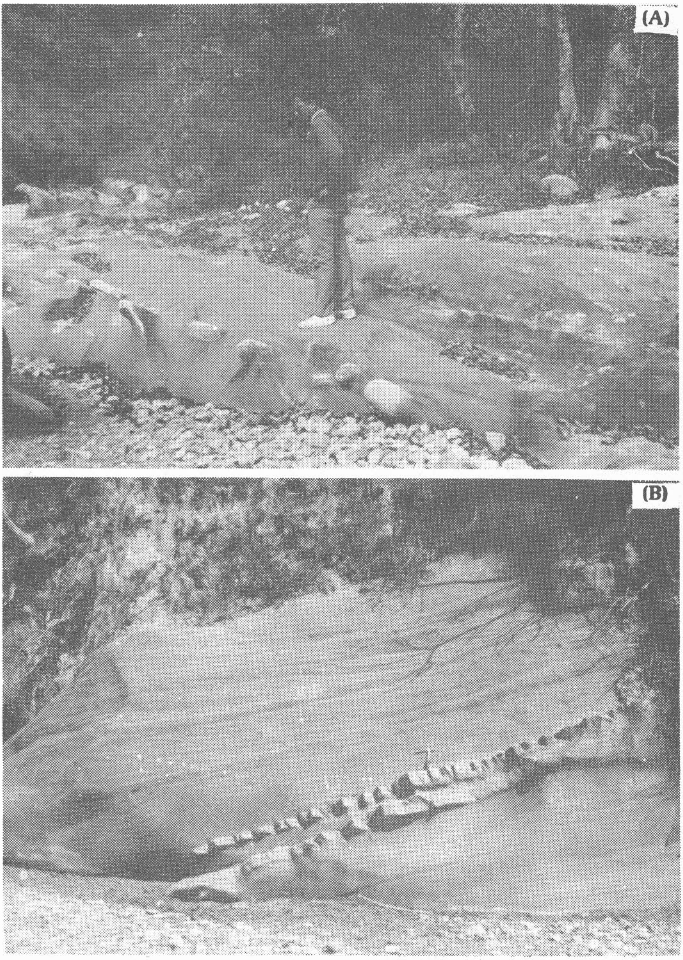

Fig. 17. (A) Photograph showing laterally discontinuous cemented layer in the friable sandstone body at stop 2B near Iron Bridge. **(B)** For comparison, a laterally continuous cemented layer is shown from a different locality.

Fig. 18. Photograph showing the medium grained grey colour sandstone with a scour surface at the base. Underlying variegated mudstone with marl layer which is showing trace fossils at Stop 2B.

discontinuous laterally, can be traced for several meters and follow primary stratification surfaces. Two other points which deserve notice at this section are the presence of very thin (1–2 mm), clay units in the sandstone. The depth of later scouring events is also controlled by the occurrence of the cemented layers.

Associated with this sandstone facies is the variegated mudstone facies 4 m thick (Figs. 15 and 18). The various units that are recognized are:

a) Laminated mudstone
b) Massive mudstone
c) Calcareous mudstone with abundant trace fossils

d) Grey marl

e) Purple mudstone

These deposits are not laterally continuous, and hence represent sediment accumulation in a low-energy pool in the channel belt.

STOP 3

Fining Upward Sequence of the Middle Siwalik Sub-Group, Mohand-Dehra Dun Road

Location

Stop 3 is located on culvert No. 165/2 at 20.8 km from Dehra Dun on the Mohand-Dehra Dun Road, in the Mohand Rao (fig. 2). A 25 m section was measured on the western bank of Mohand Rao (Fig. 19).

Objectives

At Stop 3, can be examined a 8 m thick fining-upward cycle (Figs. 19 and 20). The diminution of grain-size with change in sedimentary structures from large-scale trough cross-bedding to small scale ripple drift lamination and finally into mudstone with gradational contact is seen.

Description

The sandstones are grey, and medium- to fine-grained. Isolated pebbles of quartzite are present. Sandstone is multistoried in nature and each body is separated by major erosional surfaces along with intraformational clasts (mud balls of grey colour) with some extraformational clasts of quartzite. Individual sand bodies are 2 m to more than 5 m thick. Internally, they are trough cross-stratified. Ripple-drift cross-lamination is present (Fig. 19). Several layers of calcareous sandstone exist; thickness of these layers varies from 5 cm to 15 cm.

The fining upward cycle starts from a major erosional surface which is showing scouring and comprises mud

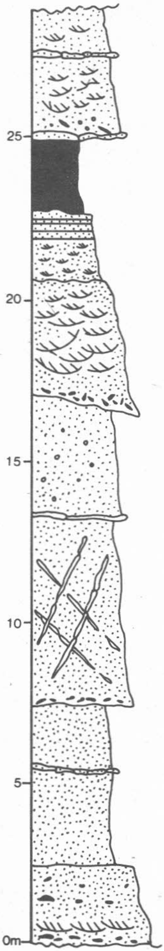

Fig. 19. A simplified sedimentary log of a part of multistoried sandstone complex at Stop 3, showing the large trough cross stratified channel body and a fining upward sequence. Note the variation in structures. Also notice the sub-vertical fractures which are cutting across and filled by calcareous cement (For legend see fig. 6).

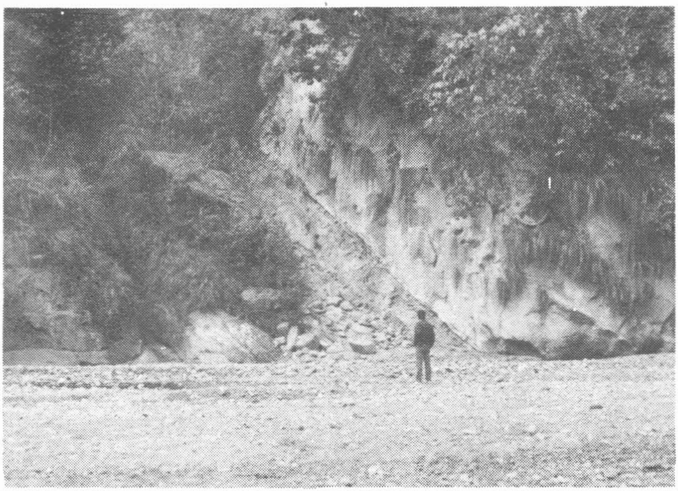

Fig. 20. Photograph of a fining upward sequence within thickly bedded multistoried sandstone complex at Stop 3. Note the change in sedimentary structures from large scale trough cross bedding to ripple drift lamination and massive siltstone.

clasts (grey coloured) with their size up to 15 cm. Sandstone is grey in colour and coarse- to fine-grained. Lower 3 m–5 m thick body shows trough cross-stratification, fining up and passes upward occasionally into ripple drift lamination and finally into parallel lamination. This sandstone passes gradationally into siltstone. Greenish-grey siltstone indicates reducing conditions. It is capped by 10 cm thick calcareous mudstone (Fig. 19).

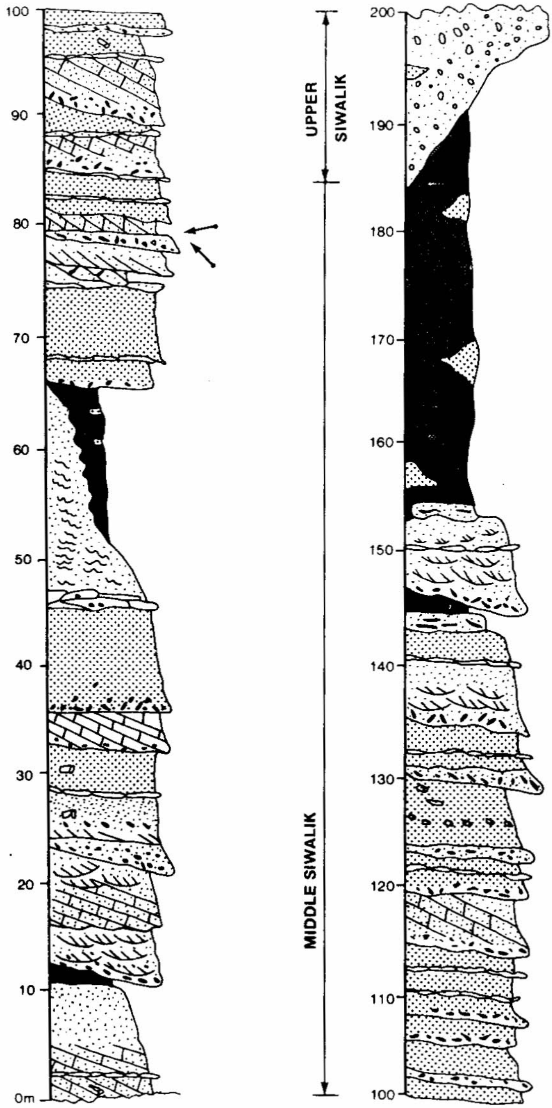

Fig. 21. A simplified log of the upper part of Mohand Rao section showing the contact relationship of the Middle and Upper Siwalik Subgroup. Note the various sedimentary structures and synsedimentary structures and synsedimentary deformational structures at stop 4 (For legend see fig. 6).

STOP 4

Transitional Sandy Lithofacies of Middle Siwalik Subgroup and Conglomerate Lithofacies of Upper Siwalik Subgroup

Location

Stop 4 is located in the Mohand Rao (Fig. 2) and extends over a distance of 0.5 km in the river bed. It can be approached by a track to the rivulet from 18.8 km stone on the Mohand-Dehra Dun Highway. The culvert number from which this track originates is 167/5.

Objectives

At Stop 4, can be examined the evidence for synsedimentary deformation in multistoried sandstone bodies, red mudstones, bioturbated marl, and rapid lateral facies variations from sandstone to mudstone. Also, can be seen the nature of the contact between the sand-mud dominated lithofacies (Middle Siwalik Sub-group) and the conglomerate lithofacies (Upper Siwalik Sub-group).

Description

The sequence consists of an alternation of sandstone and red mudstone (Fig. 21). Sandstone is grey in colour, coarse to medium-grained and, at places, pebbly. Both trough and planar cross-stratified units are observed. Mudballs are common in the sandstone and vary from 5 to 15 cm. The percentage of extrabasinal clasts has increased here (compare this with what has been observed at Stop 2B).

Interesting observations can be made from a cemented sandstone layer in which there is evidence for synsedi-

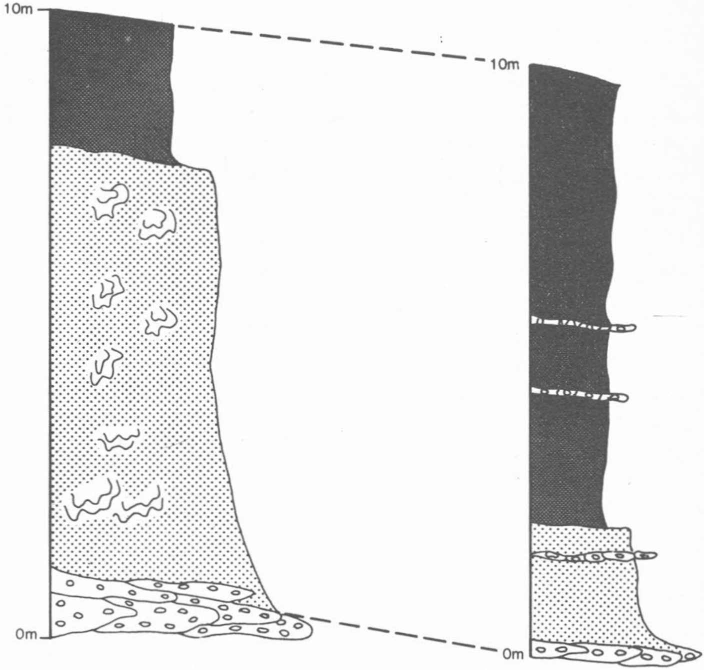

Fig. 23. Log showing the rapid lateral variations in the lithofacies from sandstone to siltstone at Stop 4. Note the thickly bedded intra and extraformational conglomerate at the base (For legend see fig. 6).

mentary deformation (Fig. 22). The cross-beds are deformed; convolute bedding is present. This layer is calcareous. The following deductions can be made:

a) deposition of trough cross-bedded sandstone.
b) local failure leading to convolute bedding.
c) early cementation of the convolute layers.

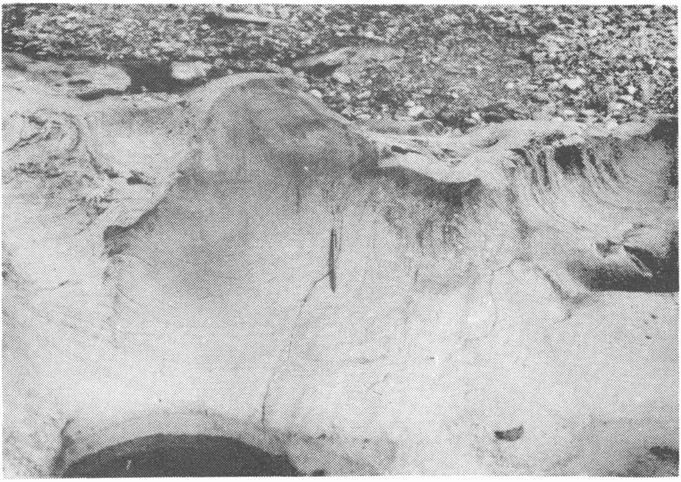

Fig. 22. Photograph of calcareous sandstone with prominent early digenetic cementation in the upper part of the Middle Siwalik sequence in the Mohand Rao section. Notice the development of convolute bedding in the sandstone. Cementation post-dated the synsedimentary deformation of the bed.

Rapid facies variations from the sandstone facies to the mudstone facies are observed (Fig. 23). The mud intervals consist of reddish brown micaceous siltstone, grey, ripple bedded sandstone, parallel laminated siltstone, nodular and mottled siltstone, and bioturbated calcareous siltstone.

Close to the contact with the conglomerate predominated intervals of the Upper Siwalik Subgroup, large mudstone clasts measuring upto 50 cm are present in the sandstone units.

The conglomerates occur on the western bank of Mohand Rao. Stratification in this sequence is prominent because of the interlayered lenticular pebbly sandstones.

STOP 5

Conglomerate and Sand Lenses of Distal Alluvial Fan of the Upper Siwalik Subgroup Mohand-Dehra Dun Road

Location

Stop 5 is located at 169/4 culvert and between 16·4 to 16·6 km from Dehra Dun on the Mohand-Dehra Dun road (Fig. 2). A 34 m section is measured on the NW bank of Mohand Rao (Fig. 24). Beds are dipping towards North.

Objectives

After examination of the transition zone of sandy braided stream (the Middle Siwalik) to gravelly braided stream (the Upper Siwalik) at Stop 4, can be examined the gravel bedload braided stream (the Upper Siwalik) of distal alluvial fan with well stratified and imbricated clasts (Fig. 25). Cross stratified sandstone lenses are interbedded with the conglomerate (Fig. 26).

Description

The sequence consists of conglomerate and sandstone lenses (Figs. 24 and 25). The maximum size of the clasts is upto 35 cm. They are poorly-sorted and are generally floating in sandy matrix. These conglomerates are well-stratified and show imbricate structure. Thickness of the conglomerate beds varies from 4 m to more than 10 m.

Clasts are subrounded to rounded. Few broken clasts

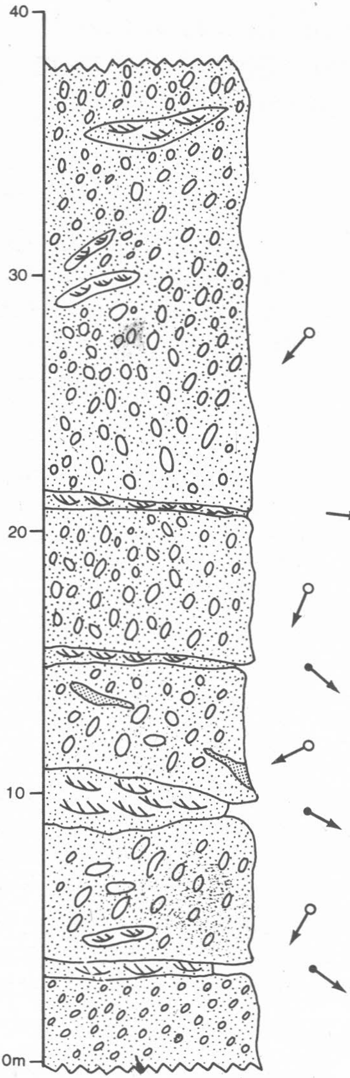

Fig. 24. A simplified log of the Upper Siwalik conglomerate in the Mohand Rao at Stop 5. Notice the large scale trough cross stratified sandstone lenses. (For legend see fig. 6).

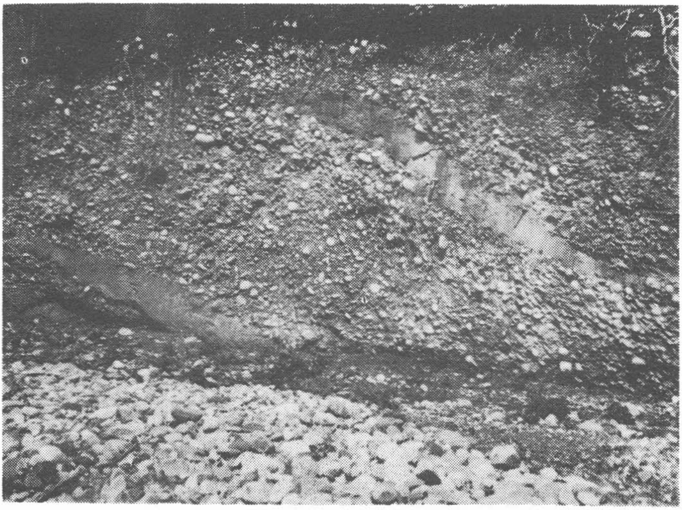

Fig. 25. Photograph showing stratified sands tone lens of the Upper Siwalik Subgroup. The characteristic features of this conglomerate facies are a clast support texture, poorly sorted character and a well developed clast imbrication at Stop 5.

are present indicating transport under high-energy conditions.

Pink and grey quartzites are the dominant component of the conglomerate. Other clasts are of granite, phyllite and limestone.

Lenses of sandstone are up to 2 m in thickness (Fig. 26). Trough cross-stratification is the dominant sedimentary structure in these lenses (Fig. 24). The thickness of individual cross beds is up to 30 cm. Sandstone is coarse-grained and grey in colour. Lower contact of sand lenses

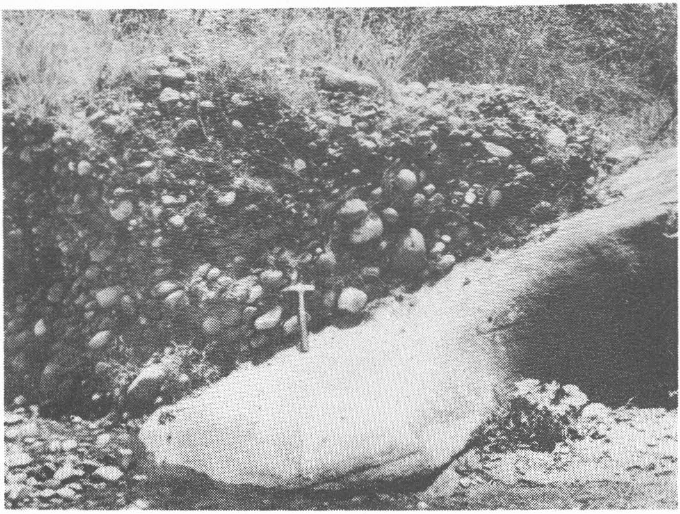

Fig. 26. Photograph showing trough cross stratified sandstone lens and an upward reduction in size of clasts in the conglomerate.

generally follow the configuration of conglomerate beds whereas upper contact is erosional and irregular.

STOP 6

Interbedded Argillite (Mudstone)—Siltstone and Sandstone Sequence of Chandpur Formation, Shahanshai Ashram, Jharipani Mule Track

Location

Stop 6 is located on the mule track from Shahanshai Ashram to Jharipani (Fig. 2). The Chandpur Formation is exposed along this mule track from the Toll barrier to Pathanghat for about 1·5 km (Fig. 27).

Objectives

At this stop, can be examined the variations in the litho-facies of the predominantly argillaceous facies of the Chandpur Formation.

Description

The sequence consists of black to grey argillites with interbedded sandstone and siltstone. Sandstone and silt-stone within the argillites are 2 to 15 cm thick and show laminations. The sandstone gets relatively thicker in the upper part and can be traced for few hundred meters. These sandstones show laminations and pass upward into Nagthat Formation. The scale of lamination, continuity of thinly bedded units and straight planar contacts between layers indicate their deposition under low energy conditions, most probably in lagoons in the nearshore shelf.

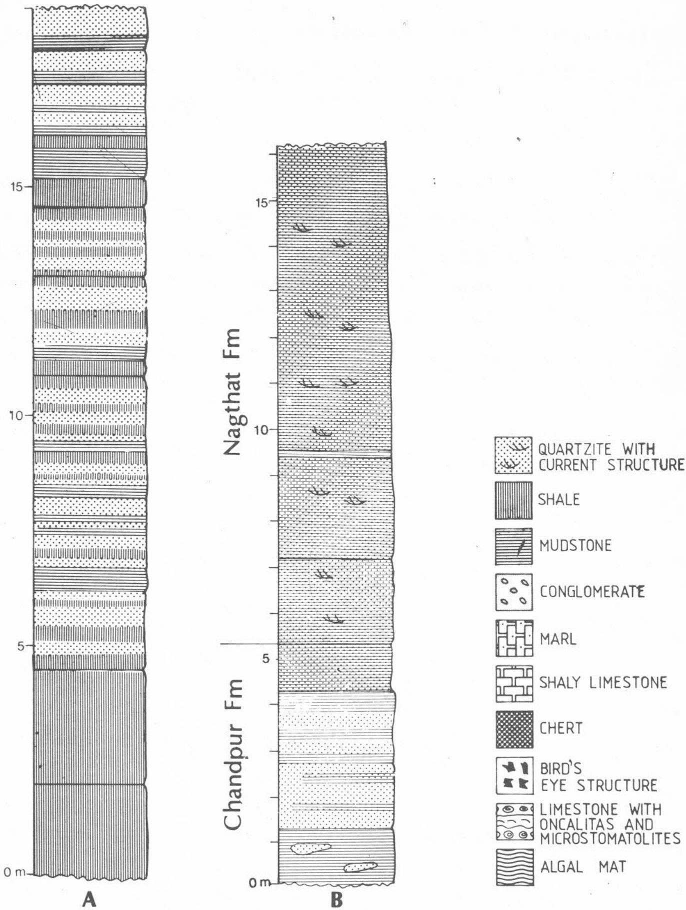

Fig. 27. **(A)** Litholog showing the lithological variation in the lower part of Chandpur Formation at Stop 6.
(B) Litholog showing the contact relationship of the Chandpur and Nagthat Formations at Stop 6. Also note the variation in the thickness of the quartzite unit.

STOP 7

White And Purple Coloured Quartzite Interbedded With Siltstone And Argillites Of The Nagthat Formation of The Shahanshai Ashram Jharipani Mule Track

Location

It is located at a distance of about 2 km from the toll barrier (Fig. 2). The Nagthat Quartzite occurs for a distance of about 750 meters at Pathanghat.

Objectives

At this stop, the contact relationship between the Nagthat Quartzite and Blaini diamictite can be examined (Fig. 28).

Description

The thinly bedded Chandpur Formation passes transitionally into thinly to thickly bedded sequence of siltstone with interbedded argillites (mudstones) in the lower part. It shows laminations and is grey to purple coloured. Higher up, thinly bedded quartzite sandstone with interbedded shale pass into thickly-bedded grey to white quartzite. Locally gritty quartzite is present. Near the contact of Blaini Formation (Fig. 28A) glauconitic and pyrite-bearing quartzite is present. Trough cross stratification, ripple bedding and parallel lamination are commonly observed. Interbedded siltstone and mudstone show sharp contact relationship.

The mixed type of facies (interbedded quartzite, siltstone and rarely shale) have been deposited in mixed to sandy tidal flat environment (Singh, 1978).

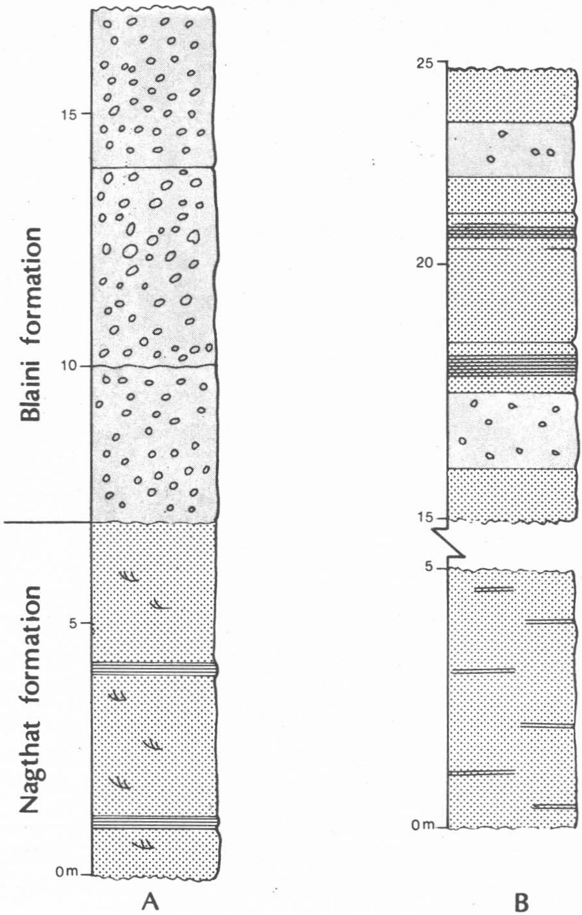

Fig. 28. **(A)** Litholog showing the contact relationship of Nagthat and Blaini Formations at Stop 7 (For legend, see fig. 27). **(B)** Litholog showing the variation in the lithology of the Blaini Formation at Stop 8 (For legend, see fig. 27).

STOP 8

Conglomerate-Quartzite-Siltstone of The Blaini Formation at Pathanghat

Location

It is located near the major bend at Pathanghat about 2·7 km from the Toll barrier (Fig. 2) and occurs for a distance of about 400 meters.

Objectives

At this stop can be examined the different kinds of conglomerate associated with quartzite, siltstone and shale

Fig. 29. Photograph showing angular clasts of quartzite floating in arenaceous matrix of Blaini diamictite at Stop 8.

(argillites). An idea of clast supported and matrix supported conglomerate can be obtained (Figs. 28 A and B).

Description

At stop 8, the clast-supported conglomerate and matrix-supported conglomerate with quartzite having interbedded shale are present (Figs. 28 A and B). The clast supported conglomerate contains fragments of limestone, quartzite, siltstone, sandstone and jasper. The Blaini conglomerate contains arenaceous matrix and angular clasts of quartzite ranging in size up to 5 cm (Fig. 29). The well-bedded quartzite/sandstone with interbedded shale contain ripple marks and parallel lamination. They have been deposited by subaqueous channelised flows in shallow marine environment.

Interestingly, most of the clasts are similar in lithogical character to the underlying Nagthat and Chandpur Formation. If these are indeed proven to have been derived from similar units, this contact would be an unconformity.

STOP 9

Infra-Krol-Lower Krol (Krol A Member) Transitional Contact

Location

Stop 9 is located 2·5 km away from Stop 8 on the mule track leading towards Jharipani (Fig. 2). There is a continuous steep ascent of approximately 100 m through Infra Krol sequence after leaving the unmetalled motorable road. After this ascent, the southwestward view (left side) is of Dun valley where Dehra Dun-Mussoorie Highway can be clearly seen.

Objectives

At this stop, can be examined the transitional passage from **Infra-Krol** to Lower Krol (Krol A) rocks (Fig. 30).

Description

At about 400 m from stop 8, there is a good development of **Infra-Krol** sequence represented by dark grey to black-coloured, thinly bedded/laminated argillites with inter-bedded siltstones and sandstones. Higher up, carbonaceous shale becomes predominant and is generally cleaved. These argillites show a prominent bleached and iron-stained character. The Infra-Krol is trnsitionally succeeded by a sequence of interbedded calcareous shale, marl and grey, fine-grained limestone (Figs. 30 and 31). The scale of limestone bedding varies from 5–50 cm. The Infra-Krol rocks

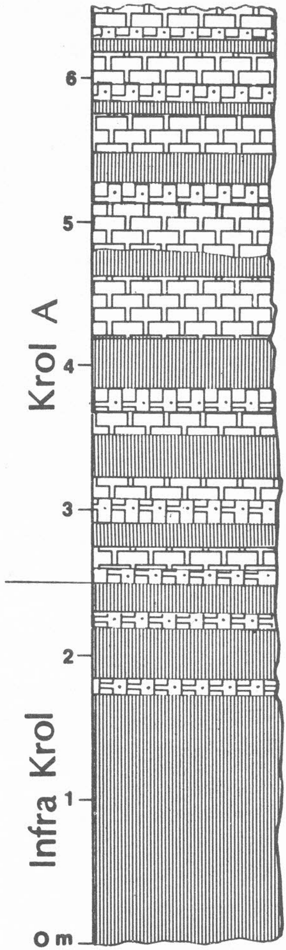

Fig. 30. Litholog showing the contact relationship of Infra Krol and Lower Krol (Krol A) member at stop 9 (For legend, see fig. 27).

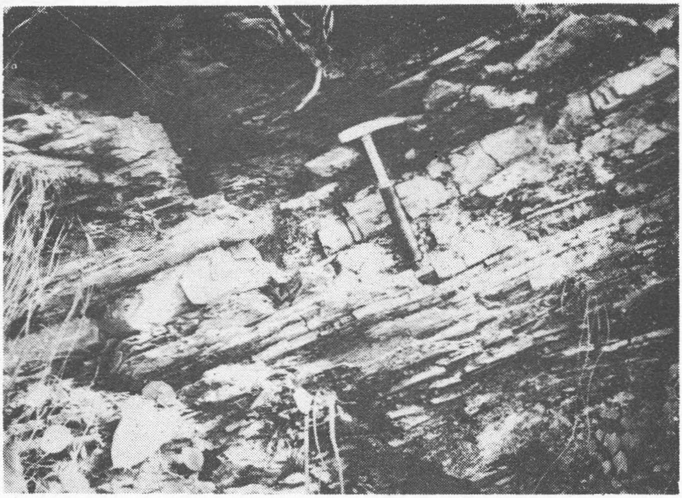

Fig. 31. Photograph of the Infra-Krol and Krol A sequence showing interbedded calcareous shale, marl and fine-grained sandstone at Stop 9.

are exposed for about 2 km distance and the Lower Krol (Krol A) for about 1·2 km along the mule track.

The Infra-Krol Formation indicates near-shore shelf (lagoonal or embayment) conditions followed by carbonate deposition of the subtidal-intertidal zone (Singh et al., 1980).

STOP 9R

A transitional passage from Infra Krol-Lower Krol can also be seen on Dehra Dun-Mussoorie highway stop 9R near Kolukhet Toll Barrier between 13 and 14 kilometer stones. A detailed road log of lower part of Krol A is shown in Fig. 32.

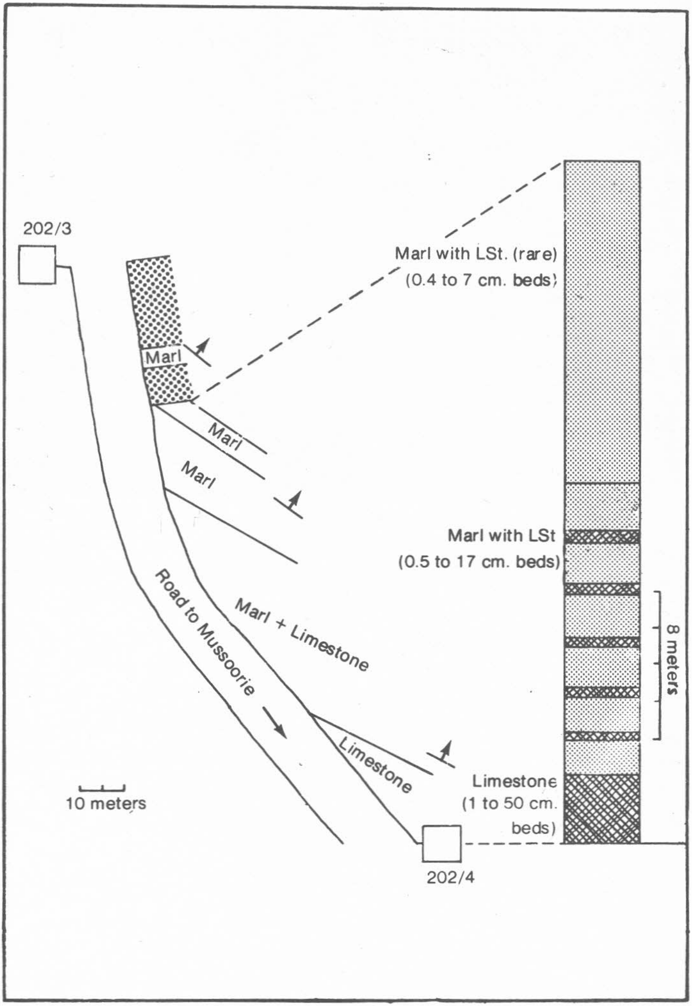

Fig. 32. A simplified road log of the lower part of Krol A Member at Stop 9R.

STOP 10

Middle Krol (Krol B Member) of Krol Formation

Location

This stop is located at a distance of about 1·4 km from stop 9 close to the mule track–footpath diversion (Fig. 2). Footpath leads down to the Kolukhet Toll Barrier on Dehra Dun-Mussoorie Highway (this footpath is not to be followed).

Objective

At this stop, can be examined the lithological character of Krol B Member of the Krol Formation (Fig. 33).

Description

Succeeding the Lower Krol shales and marls, the most conspicuous lithology of dominantly purple and green shales of Middle Krol (Fig. 33) (Krol B Member) is exposed for about 750 m distance all along the mule track. In the lower part, there are few cm thick carbonate layers. Thin silt layers are also present. Occasionally, graded bedding can be observed within thin sandy layers.

Purple and green colour succession of Krol B represents the deposit of a protected lagoon or embayment (Singh et al., 1980).

This unit is not well-developed in most parts of the Mussoorie syncline. Therefore, the Rajpur-Mussoorie mule track is important to study the Krol B Member of the Krol Formation.

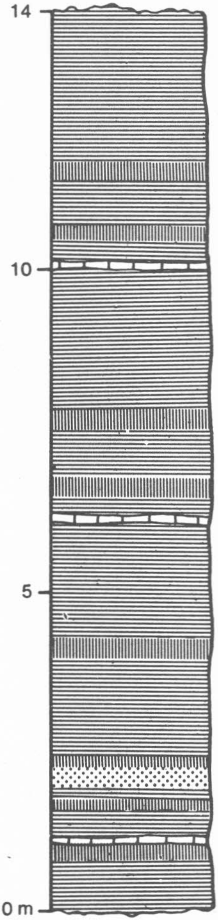

Fig. 33. Litholog showing the lithological variation of Krol B at Stop 10. Note the thin carbonate layer in the shale (For legend, see fig. 27).

STOP 11

Upper Krol (Krol-C) Carbonates, Abandoned Toll Barrier, Jharipani

Location

Approx. 150 metres from Stop 10 on mule track to Jharipani (Fig. 2).

Objective

At this stop, can be examined the carbonates of the Krol C Member (Fig. 34).

Description

The Krol-C carbonate rocks are well-developed between abandoned Jharipani Toll barrier and slightly before the Barlowganj suspension bridge on the Rajpur-Mussoorie mule track. The Krol-C massive limestone (Fig. 34) is dark grey in colour and about 100 m thick. Gypsum and calcite pockets and oolites are commonly found in these rocks. The Krol-C carbonates are characterised by the occurrence of marble and high cement grade limestone in the Mussoorie sycline. Extensive open-cast mining of these limestones was being carried out earlier but has since been banned because of environmental degradation in the Mussoorie hills. The Krol-C carbonate lithofacies is interpreted to be the result of tidal flat environment in which evaporitic conditions also prevailed. The oolitic carbonates associated with algal-mat carbonates indicate high energy conditions and are deposited in the intertidal zone.

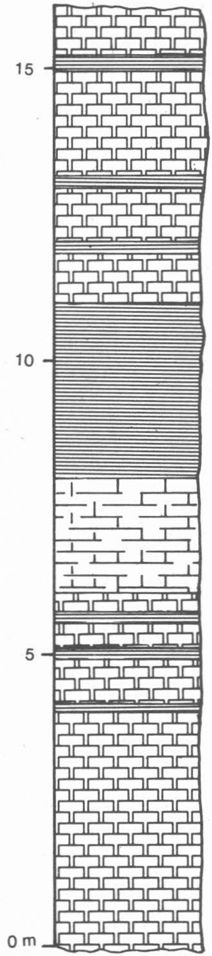

Fig. 34. Litholog showing the variation in lithology of Krol-C at Stop 11 (For legend, see fig. 27).

STOP 11R

The Krol-C massive limestone is exposed on the Dehra Dun-Mussoorie highway near Bhatta (Fig. 2). These rocks were earlier quarried for manufacture of lime. Krol-C limestones are also seen in Maldeota section on both the sides of the Kumalda bridge. Stratified stromatolites (*Stratifera* msp.) and oolites are clearly seen near this bridge on the right bank of river Bandal.

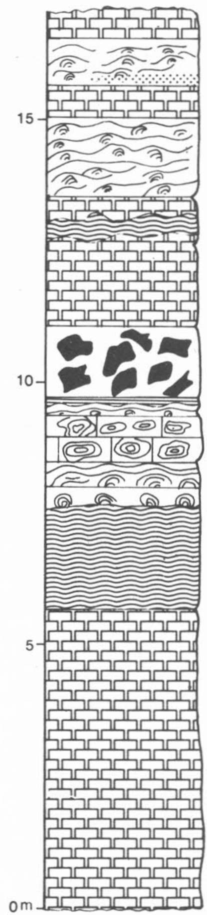

Fig. 35. Litholog showing the association and variation in algal mat facies at Stop 12. Note the bird's eye structure and fenestral fabric (For legend see fig. 27).

STOP 12

Upper Krol (Krol-D) Algal-Mat Carbonate Facies, Barlowganj

Location

Barlowganj suspension bridge (Fig. 2).

Objective

At this stop, can be examined the Upper Krol (Krol-D) algal mat facies (Fig. 35) and the depositional environment interpreted.

Description

A well-developed algal mat carbonate facies of the Upper Krol Formation (Krol D) is exposed below the suspension bridge at Barlowganj on the Jharipani-Mussoorie motor road. The algal-mat facies (Fig. 35) is characterised by the profuse development of bird's eye structure, irregular fenestral fabric in bird's eye dolomite algal oncolites (Fig. 10D), smooth and crenulated algal laminites, stratified stromatolites (*Stratifera* msp.), micro-stromatolites (Fig. 10E) and calcareous algae. Singh et al. (1980) and Tewari and Qureshy (1985) have interpreted that the algal mat facies of the Upper Krol Formation in Mussoorie and Garhwal syncline is essentially microbially deposited by precipitation and entrapment of carbonate particles by cyanobacteria/blue-green algae in tidal flat environment. The algal mat of intertidal flats is dominated by crenulated algal laminites and stromatolites. The bird's eye fenestral fabric is prominent in the supratidal zone which results from desiccation where carbonate sediments are subaerially exposed. Similar intertidal-supratidal depositional environment is suggested for the development of the algal mat carbonates being observed at the stop.

STOP 12R

The Upper Krol algal mat carbonate facies is extensively developed in the Mussoorie syncline and better exposures are available for detailed investigations at many localities in the Mussoorie hills. It is advised that a traverse from Mall road to Gun Hill will give a better understanding of this facies. The complex cyclicity of different algal mat facies have been observed in Krol-(D) dolomite exposed at Mall road, Camel's back, Kinkraig, Dhobighat-Chamasari area, near Maldeota and Surkhet PPCL mine and Kumalda-Khetu mule path. The stromatolite asemblage recorded from the Krol-(D) Formation of Mussoorie syncline include *Conophyton* Maslov (Fig. 10 F, G), small laterally linked *Conophyton*, *Stratifera irregularis*, *Paniscollenia*, Patomia, *Aldania*, *Irregularia*, Oncolites and microstromatolites (Tewari, 1984 a, b; 1987).

STOP 13

Carbonate Lithofacies of The Upper Krol (Krol E) Near Contact With Overlying Phosphatic Tal Formation on Mussoorie-Tehri By-Pass Road

Location

Stop 13 is located on the Mussoorie-Tehri by-pass road, approximately 3·5 km from Dehra Dun-Mussoorie road diversion (Fig. 2), (this road takes off to the east from the Dehra Dun-Mussoorie road 200 m before Kinkraig).

Objectives

At this stop can be examined two major lithostratigraphic units of the Mussoorie Syncline. The carbonate rocks of the Upper Krol (Krol E) (Fig. 36) and the chert-phosphate rocks of the Lower Tal are exposed. Also we will examine the complex folding patterns in these interbedded sequences (Fig. 37).

Description

The Upper Krol (Krol E) rocks consist of laminated grey, fine-grained limestone with very thin calcareous shale partings (Fig. 36). There are continuous beds and can be traced laterally over the outcrop. Few nodules of siderite are present in this part of the sequence. Calcite veins are common at some places. This lithofacies is succeeded by argillaceous dolomite which on weathered surfaces give a buff-coloured appearance. The feature that is commonly observed in the carbonates is fenestral fabric (Fig. 37).

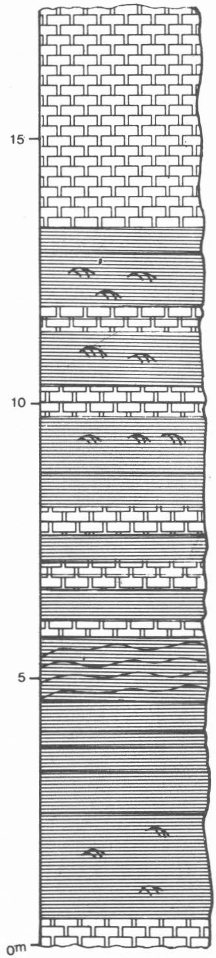

Fig. 36. Litholog showing the variation of lithology of Krol E at Stop 13 (For legend, see fig. 27).

The basal Tal rocks consist of an association of chert-phosphorite dark-grey limestone and carbonaceous shale. Occasionally phosphatic nodules are present. Phosphorite-chert beds are usually 5 to 10 cm thick. This particular outcrop shows complex fold patterns (disharmonic folding) (Fig. 37).

The lower part of the sequence consisting of laterally continuous laminated limestones indicate deposition in calm waters possibly in the subtidal zone. The upper argillaceous dolomites with prominent fenestral fabrics and scour features indicate inter-tidal supra-tidal zone.

STOP 13R

The stop is located at Mussoorie-Tehri road at about 125 m distance from the Mussoorie-Tehri road diversion. At this stop the uppermost Krol (Krol E) is represented by well-bedded argillaceous dolomite which grades into mainly thinly bedded, chert bed (4·5 m) of Lower Tal. The Krol/Tal contact is characterized by a few limonitic layers with rare occurrence of phosphatic bands. Other interesting notable features in this section (Fig. 38) are the occurrence of 1 m thick bioherm of stratified and domal stromatolites in highly shattered cherts, about 2·5 m above the Krol/Tal contact, and one meter thick friable yellow sandstone-siltstone bed occurring 9 m below the contact. This yellow sandy bed, in general appearance, looks to be of aeolian origin but there is no definite evidence to substantiate or otherwise.

The Krol/Tal contact is well developed in both limbs (northern and southern) of Mussoorie Syncline (Fig. 7). Best exposures can be seen in PPCL (Pyrites, Phosphates and Chemicals Limited) Mines at Maldeota and Durmala where

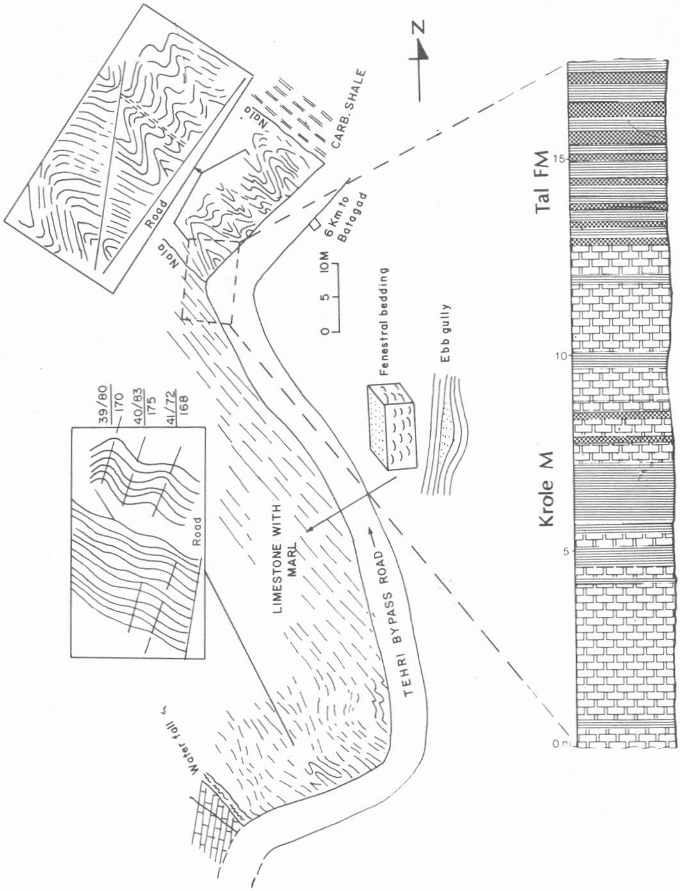

Fig. 37. Vertical and road log showing contact of carbonate unit of Upper Krol (Krol E) and the chert phosphate units of the Lower Tal rocks at Stop 13 (For legend, see fig. 27).

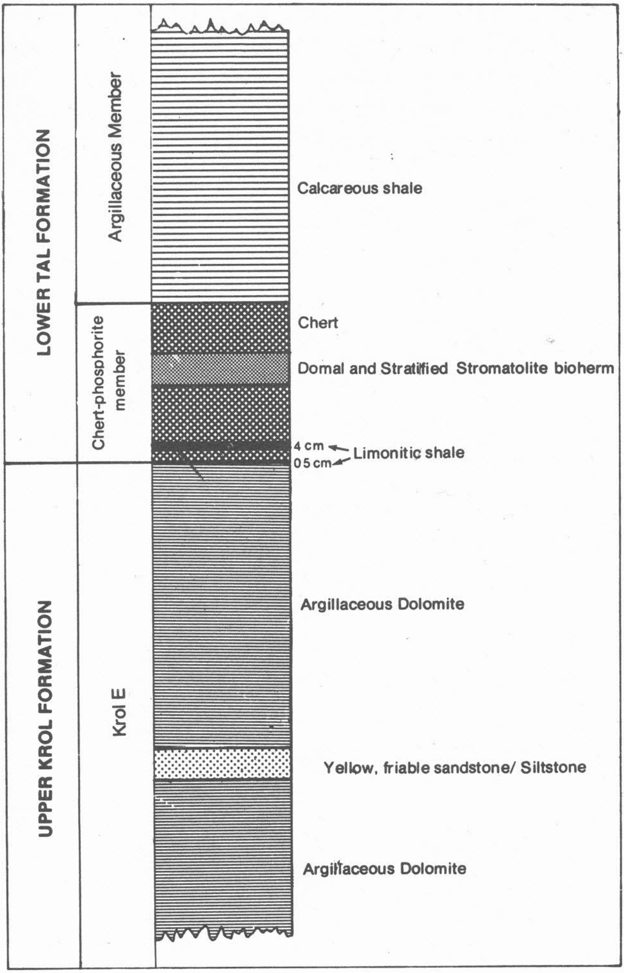

Fig. 38. Log showing the Krol-Tal contact lithologies at stop 13R near Mussoorie-Tehri road diversion.

main phosphorite body, averaging 3–3·5 m thickness, is extensively developed and is being commercially exploited for fertilizer under the trade name of "Mussoorie Phos". Field parties interested in Lower Cambrian stromatolites are advised to visit Durmala PPCL Phosphorite Mine.

STOP 14

Arenaceous and Argillaceous Facies at The Middle and Upper Tal Stratigraphic Contact

Location

This stop is located 2 km from Batagad and 8 km from Kinkraig on Mussoorie-Tehri by-pass road (Fig. 2). South-facing scarp consisting of rocks of the Tal Formation occurs on the road. The scarp face shows large detached rocks which have moved as rock-falls.

Objectives

At this stop, lithofacies belonging to the Middle and Upper Tal units can be examined. The relationships between the lithofacies and their properties including stratification and variations in colours are documented.

Description

The predominant lithofacies are a red to grey mudstone and a cross-bedded grey quartzite with prominent thin parting of shale (Fig. 39).

Red and grey mudstone Facies (lagoon-intertidal to supra-tidal zone): Towards the base, red and grey micaceous thinly laminated siltstone occurs. Scale of bedding is variable from a few mm to about 5 centimeters. The bedding is of the parallel even type and is laterally continuous. Iron-staining is a prominent feature of the outcrop. Red siltstones show some discoloration zone which cut across stratification. Interestingly, grey and dark siltstones are present as

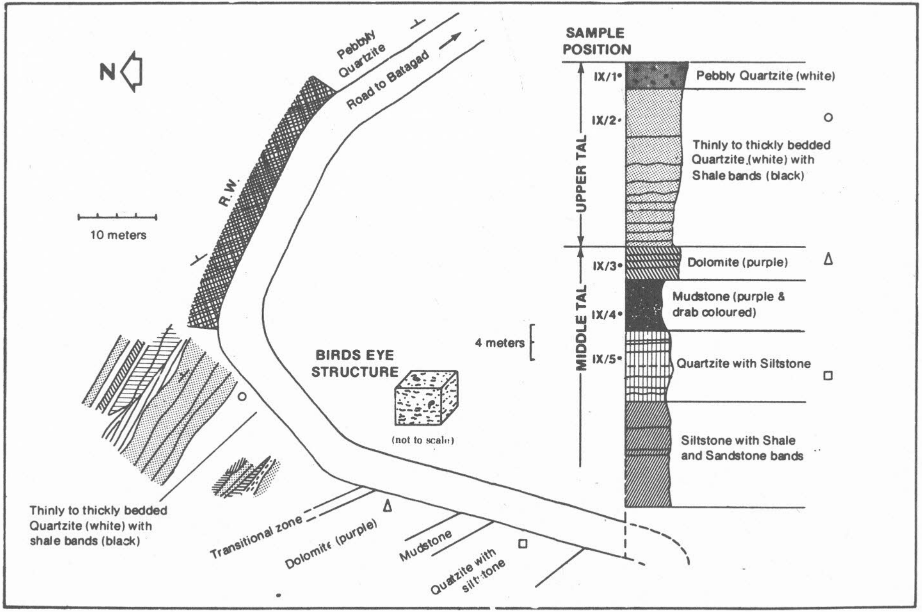

Fig. 39. Road log with simplified vartical log showing variation in the facies between Middle and Upper Tal units at Stop 14. Note the different types of sedimentary structures.

discontinuous patches within the red siltstone units (Fig. 40). Bioturbation features are prominent in some places on bedding surfaces (Fig. 41). Banerjee and Narain (1976) had originally described a few well-preserved trace fossils in this lithofacies occurring along the Mussoorie-Tehri road between Batagad and Masrana (Fig. 7). Singh and Rai (1983), however, documented abundant trace fossils from this section and Rai and Singh (1983) also found trilobite impressions near Kaplani village, about 7·8 km from Mussoorie town on Mussoorie-Tehri road.

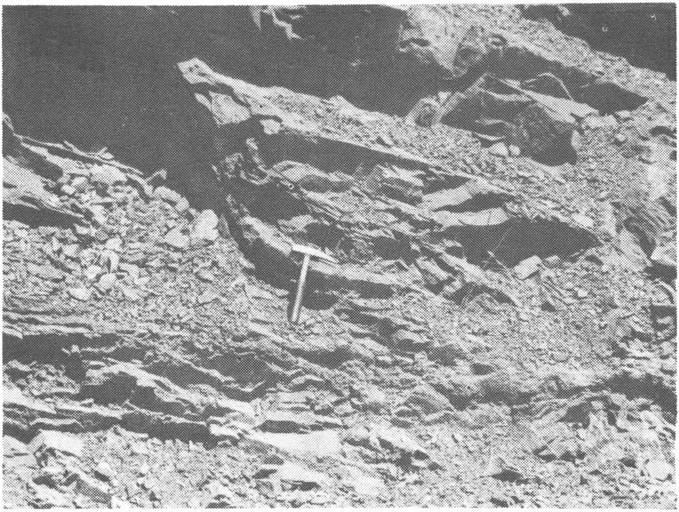

Fig. 40. Photograph showing discontinuous patches of dark grey to purple siltstone within the red siltstone unit.

The scale of bedding increases in the section with the incoming of sandstones. The sandstones are laminated and grey in colour. Sandstone units measure up to 10–15 cm

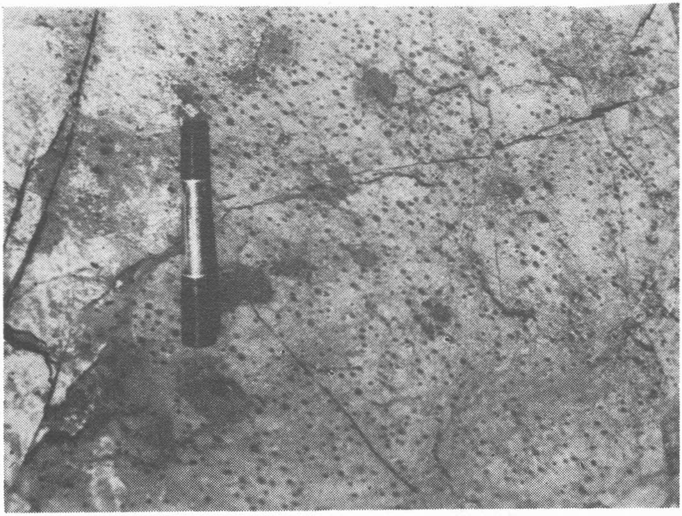

Fig. 41. Photograph showing bioturbation features and trace fossils (skolithos) in the siltstone unit at Stop 14.

in thickness and several of these show mm thin siltstone layers. Cross-lamination is present and indicates current structures. Rippled surfaces are common (Fig. 39).

Lenticular bodies of carbonates are also present in this facies. One 62 cm thick bed of dolomitic limestone with well developed fenestral fabric can be observed. Thinly laminated carbonates occur at the top of this facies.

White cross-bedded quartzite and thin shale facies (Beach-Barrier Bar Zone). This lithofacies consists of white and grey cross-bedded quartzite and thin shale layers usually measuring from few mm to 5 cm. The thin shales occur as partings and are black in colour. Megascopically, these shales are without any features. At places, these take the character of alternations in which the quartzite is the thicker element. The interface between shale and quartzite show an undulatory surface, possibly related to the stage of burial compaction at the interface. Fragments of shale are, at places, incorporated in the quartzites. The quartzites are pebbly and micaceous at some levels.

The chief sedimentary structure of the quartzite is a mega-cross bedding the scale of which is of the order of 1 meter (Fig. 42). Note the low angle character of the cross-bedding. At places, also note the rapid alternations between shale and the quartzite. As against this, in the large-scale cross-bed the partings are relatively few (try and explain this contrast).

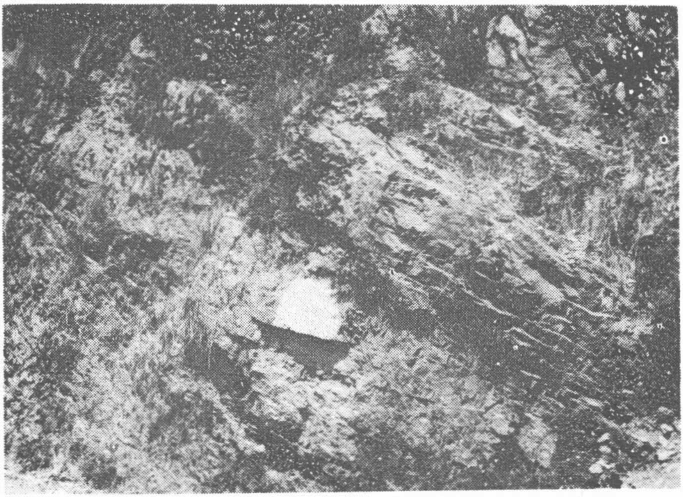

Fig. 42. Photograph showing mega cross bedding of the order of 1 m in the quartzite facies.

Higher up, the succession consists of cross-bedded pebbly and gritty quartzite with thin interbeds of micaceous green, fine-grained siltstone/sandstone. The quartzites are feldspathic, at places. At some levels, the interbeds consist of red shales. It is worthwhile to go around and make sketches and take measurements on the large-scale cross-beds in the quartzite.

Notice that the quartzites themselves are not reddened and that the clasts incorporated in them are not red coloured.

The contact between the two major lithofacies shows an angular discordance. This raises the question whether these two lithofacies types representing a lagoon-intertidal-supratidal zone and a bar complex, are time contemporaneous.

CONCLUDING REMARKS

In this field excursion, we have attempted to conduct you through a transect bringing out some of the salient features of the Sub- and Lesser-Himalaya. The emphasis, as stated at the outset, is on stratigraphy and sedimentological aspects.

There are, however, several other exposures and sections which student parties may visit. A visit to the PPCL Phosphate Mine at Maldeota would be a rewarding experience. This is the locality where the first definite Cambrian conodont micro-fossils were discovered.

This area also offers the possibility of gaining experience in the mapping of Quaternary deposits (Dun gravels). Furthermore, field instruction could also be imparted in the areas of Neotectonics, Geomorphology and Structural analysis.

Coming back to the stratigraphic-sedimentologic aspect, we would encourage students to go on from this assembly of information to the palaeotectonic and palaeogeographic reconstruction of this sector in the light of the positioning and evolution of the Proterozoic-early Palaeozoic basin, the positioning and evolution of the Neogene foreland basin, their present day tectonic juxtaposition and evolution of the Dun depression.

We are conscious that the information presented in this excursion guidebook is far from complete. This to a certain extent is by design. There is, however, sufficient information for the 'uninitiated' to feel 'initiated' and go on for the quest of knowledge of the geologic evolution of the Sub- and Lesser Himalaya.

ACKNOWLEDGEMENTS

Many of us have been concerned that suitable instructional materials for geological field trips are lacking. Geological Society of India felt that such materials should be prepared for the diverse geological terrains of India. This is the first of such an attempt.

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