JOURNAL OF THE PALAEONTOLOGICAL SOCIETY OF INDIA
VOL. 25, 1981, pp. 148—169(*For* 1980)

A CRITICAL REVIEW OF THE FOSSIL RECORDS IN THE KROL BELT SUCCESSION AND ITS IMPLICATIONS ON THE BIOSTRATIGRAPHY AND PALAEOGEOGRAPHY OF THE LESSER HIMALAYA

INDRA BIR SINGH

GEOLOGY DEPARTMENT, LUCKNOW UNIVERSITY, LUCKNOW-226 007

ABSTRACT

The Krol belt sedimentaries are made up of several thousand meters thick monotonous successions, which are devoid of any well-defined fossil-assemblages. Interspersed within these unfossiliferous successions are thin, fossil-bearing detached outcrops of Permian, Cretaceous, and Eocene ages. Environmentally, the unfossiliferous Krol belt succession basically represents deposits of a shallow tidal sea, under oxygenated conditoins well-suited for the luxuriant growth of organisms. The carbonate successions of the Krol belt are essentially deposits of tidal flats where algal mats and stromatolites are abundant; but without essentially any metazoans or their lebensspuren. Such palaeoecological situation existed during the pre-Phanerazoic history of the Earth, where abundant algae occurred without any significant evidence of metazoans.

Failure to recognize the importance of palaeoecology, and the wishful thinking to consider the Krol belt succession as Palaeozoic-Mesozoic deposits, has led to an indiscriminate grouping of the detached fossil-bearing outcrops (especially those of the Permian and Cretaceous ages) with the thick unfossiliferous sequences. At the same time, every feature, having slightest resemblance with a fossil, reported from the unfossiliferous Krol belt sediments has been accepted uncritically. This has led to an unwarranted confusion in the Lesser Himalayan biostratigraphy. If the so-called fossil records from the unfossiliferous sequences is critically evaluated and examined in the light of palaeoecology and palaeoenvironment of the host rock, almost all these reports appear questionable and, therefore they loose their biostratigraphic significance.

A biostratigraphic-palaeogeographic model for the Krol belt in particular and Lesser Himalaya in general is proposed which visualizes the Lesser Himalaya (and Central Himalaya)as northerly extended integral part of the Indian shield, and made up of essentially shallow tidal sea deposits of Precambrian age. During Late Carboniferous-Lower Permian a East-West running weak zone (rif-valley like) developed within the southern part of what today is Lesser Himalaya and witnessed deposition of fresh-water Gondwana sediments and a Lower Permian marine transgression. This zone (Subathu-Dogadda zone) was later reactivated and witnessed Late Cretaceous, and finally a Late Palaeocene-Early Eocene marine transgression. During Tertiary orogenic uplift of the Himalaya, these fossil-bearing outcrops have been further chopped and diplaced causing difficulty in biostratigraphic and palaeogeographic reconstruction of the Lesser Himalaya. Evidences of these three transgressions are present in the form of isolated, localised outcrops of fossil-bearing sediments of Early Permian, Late Cretaceous, and Late Palaeocene-Eocene ages, which are distributed within different litho-and tectono-stratigraphic units of Lesser Himalaya.

INTRODUCTION

The Lesser Himalaya comprise a zone south of the Central Crystalline and north of the Main Boundary Thrust, and are made up of thick sedimentaries, with few isolated patches of crystalline rocks. These sedimentaries of Lesser Himalaya exhibit little or no metamorphism and can be delineated into a number of belts, e.g. Larji-Deoban, Shali, Krol, Buxa, etc. The sedimentary belts of Lesser Himalaya are characterized by the dominance of quartzites, slates, and carbonates which are generally devoid of any fossil assemblages, though they represent deposits of a shallow tidal sea. The carbonate sequences of these belts are essentially tidal flat carbonates showing abundant algal mats and stromatolites (see Singh, 1979 a).

The Lesser Himalayan sedimentaries are traditionally considered to represent the Palaeozoic-Mesozoic deposits (Auden, 1934, 1937 ; Gansser, 1964 ; Krishnan, 1968). Later, some workers considered that some parts of Lesser Himalayan belts are Precambrian, for example, Valdiya (1964, 1969) assigned a Precambrian age to Calc Zone of Tejam and Pithoragarh ; Shali belt etc, but argued for a Palaeozoic age of Krol belt (Valdiya, 1975). More recently the Phanerozoic age of even the Krol belt has been questioned, and a Precambrian age for the entire Lesser Himalayan sedimentaries has been suggested (Singh, 1976, 1979a). It is proposed that the Lesser Himalayan sedimentaries and the Central Crystalline zone represent a northerly extension of Indian Precambrian shield and there was almost no sedimentation during Phanerozoic in this area, excepting during short-lived transgressions of Carboniferous-Permian, Jurassic-Cretaceous and Eocene along a narrow zone (Singh, 1979a). (In the light of new palaeontological data now the ages of these three transgressions can be more precisely dated as Early Permian, Late Cretaceous, and Late Paleaocene-Eocene. However, in the text these three transgressions are referred as Permian, Cretaceous and Eocene transgressions).

Palaeoenvironmental analysis of the Krol belt sequence

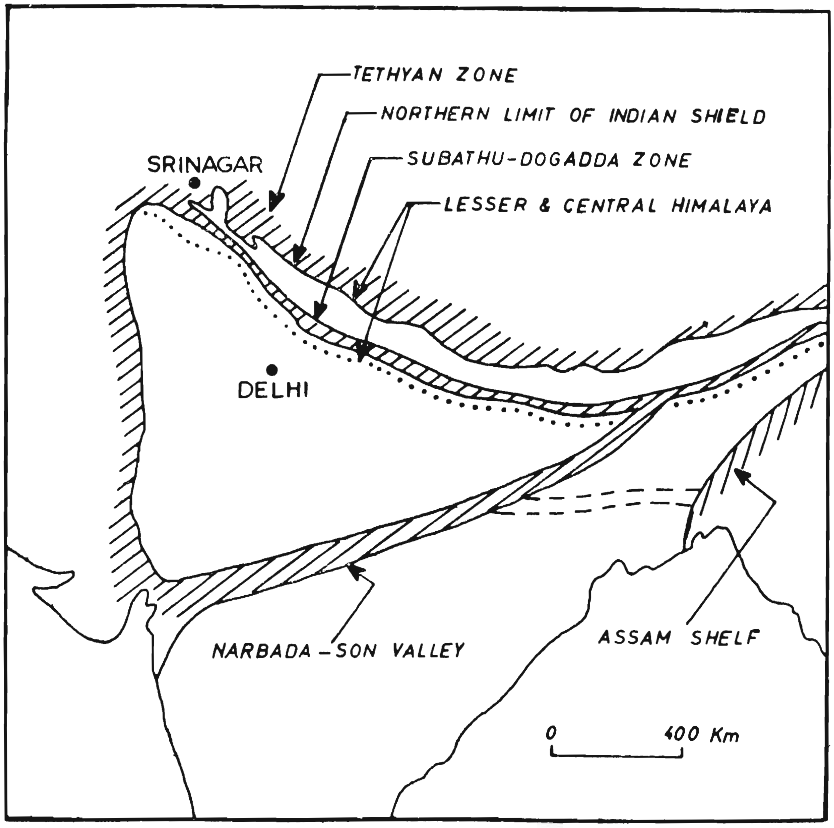

Fig. 1. Map showing Sabathu-Dogadda zone in Lesser Himalaya and Narbada-Son valley and their relationship with Tethys sea. These two zones witnessed transgressions only during Lower Permian, Late Cretaceous, and Late Palaeocene-Eocene.

demonstrates that they are essentially deposits of a shallow tidal sea under oxygenated conditions (Singh, 1980 a). The modern tidal flat environment is mainly characterized by dense benthonic communities, abundant trace fossils and bioturbated horizons (Reineck, 1970 ; Reineck and Singh, 1980). And if the Krol belt sequence is considered to be of Palaeozoic-Mesozoic age, it should be rich in benthonic communities and traces of life of benthonic organisms. On the contrary, well-defined metazoan fossil records and signs of their activity are lacking in these rocks, and consequently calls for a reassessment of age of Krol succession. In addition several detached outcrops of fossil-bearing sediments of Permian, Cretaceous and Eocene ages occur at various stratigraphic levels vis-a-vis type Krol succession, and are indiscriminately grouped with the main framework of Krol belt succession. A few body fossils and fossil-like features have also been reported from some of the lithostratigraphic units of the Krol belt. Bhargava (1979) has reviewed the reports of fossil records from the Krol belt sediments. He has unfortunately accepted most of these reports uncritically and proposed a Palaeozoic-Mesozoic age for the Blaini-Infrakrol-Krol-Tal sediments of the Krol belt. As the later expositions would show that most of these fossil reports are doubtful, and mutually contradictory and connote more than two ages for the same rock unit.

A critical analysis of the various fossil reports from the Krol belt succession has been attempted here, which amply demonstrates that most of the fossils recorded from the main unfossiliferous Krol succession are questionable and are in conflict with the reconstructed palaeoenvironment of these rock units.

STRATIGRAPHIC FRAMEWORK OF THE KROL BELT

The generally accepted view is that the succession of Krol belt, especially the Blaini-Infra Krol-Krol-Tal sequence represents a continuous succession in a single sedimentation basin without any significant breaks in sedimentation (see Bhargava, 1972 a, 1979 ; Singh, 1980 a).

The traditional chrono-stratigraphy of the Krol belt succession considers it to represent a continuous Palaeozoic-Mesozoic (up to Cretaceous) deposit, and is based mainly on two considerations (see also Singh, 1979 a) :

(1) that the Blaini conglomerate is of glacial origin, equivalent to Talchir boulder bed of the Peninsular Gondwana succession, and consequently Carboniferous-Permian in age, and

(2) that the Shell Limestone, capping the Tal succession is an integral part of the latter and is Cretaceous in age.

Thus the sequence below Balini conglomerate was presumed to represent the Palaeozoic time, while the succession above Blaini conglomerate and up to the (Tal) Shell Limestone was thought to represent the Mesozoic time. Consequently, a wishful thinking developed among the biostratigraphers working in the Lesser Himalaya to this effect and they accepted uncritically any report of fossil which fitted into this model of chronostratigraphy.

Lately, however, Valdiya (1975) proposed a modified biostratigraphy of the Krol belt succession, assigning a Palaeozoic age to the entire Krol belt. The Blaini Formation pushed down in age by him to Lower Palaeozoic, possibly Devonian (although no fossil-assemblage of Lower Palaeozoic is recorded from Blaini Formation). Valdiya (1975) further claimed that Mesozoic is totally absent from Lesser Himalaya ; completely ignoring the Cretaceous fauna reported from Shell Limestone, associated with Tal Formation (Middlemiss, 1885 ; Tewari and Kumar, 1967). Valdiya's (1975) proposal of biostratigraphy was mainly based upon the report of *Fusulina* from the Shell Limestone of Dogadda area, hence a Permian age (Kalia, 1974), and indiscriminate grouping of the fossiliferous Boulder Slate Sequence (Permian) with the Tal. However, later workers clearly demonstrated that the *Fusulina* reported by Kalia (1974) are nothing but various types of deformed oolites (see Tewari and Gupta, 1978 ; Kumar and Dhaundiyal, 1980 ; Bhatia, 1980 ; P. Singh, 1980), and the Shell Limestone of Dogadda area or Bansi member of Valdiya (1975) is not Permian, but definitely Cretaceous in age (P. Singh, 1980). Further, as discussed by Bhargava (1979), if the Boulder Slate Sequence (Permian) be part of basal Tal, it should be present in most, if not all the areas where Tal is exposed. As this is not the case, Boulder Slate Sequence cannot be the part of Tal succession. Further, the contact between Krol and Tal sediments is gradational, a fact also endorsed by Valdiya (1975). On the contrary Valdiya (1975) reports that the clasts in the Boulder Slate Sequence (his Jogira member) are mainy derived from Krol and Nagthat sediments. This could happen only when there is an unconformity between Krol Formation and Boulder Slate Sequence. Thus, the grouping of Permian fossil-bearing Boulder Slate Sequence with the Lower Tal which always shows a gradational contact with the underlying Krol and is devoid of any fossils is unnatural and not in accordance with the observed facts. Consequently, the biostratigraphy proposed by Valdiya (1975) can be dropped.

Recently, Singh (1976, 1979 a) questioned the validity of the traditional chronostratigraphic model of the Krol belt, mainly because the Blaini Formation is not of glacial origin and also not of Carboniferous-Permian age (Singh and Tangri, 1976 ; Singh, 1980 a), further the Shell Limestone is not an integral part of the Tal succession (Singh, 1979 b, c). Singh (1980 a) later proposed a modified chronostratigraphy of the Krol belt succession, claiming that the thick Krol belt succession, comprising Nagthat-Blaini-Infra Krol-Krol-Tal, is Precambrian in age and that, there are thin, detached fossil-bearing sediments, which represent deposits of three transgressions, namely Permian, Cretaceous, and Eocene ages on a Precambrian sedimentary basement of the Krol belt (see also Singh, 1976).

Consequently, it has been felt here pertinent that the fossil reports from Krol belt succession be closely scrutinized which, in turn, has revealed that except for the Permian, Cretaceous, and Eocene fossil-assemblages from thin detached outcrops, almost all the fossil records from unfossiliferous Krol belt sedimentaries are questionable and do not correspond to the palaeoenvironment of these sediments.

FOSSIL RECORDS IN THE KROL BELT SEDIMENTARIES

The fossil reports from the Krol belt sedimentaries can be placed into two broad categories :

(1) Sporadic fossils, reported from the thick unfossiliferous successions.

(2) Fossils from the thin, detached outcrops of fossil-bearing sediments, which belong to one of the three definite ages, namely Permian, Cretaceous and Eocene.

In the following review of the fossils, this distinction has been made as it seems to be of fundamental importance in understanding the chronostratigraphy of the Krol belt succession.

It is revealing to note that the fossil reports from the Krol belt sedimentaries have the following handicaps in common :

(1) None of the workers give a litholog along with the location of samples in the profile, and pointing out the yielding and non-yielding samples. The situation is so bad that many workers perhaps even feel that it is not at all necessary to give the litholog and precise location of the samples in it (see Valdiya, 1980 b), although this basic information is essential for any biostratigraphic study.

(2) Many of the reports are abstracts or short reports never followed by detailed papers.

(3) None of the authors discuss the causes of contradictory fossil reports from the same litho-unit.

(4) None of the reports discusses the palaeoecology of the fossil assemblages and rock units in which they are recorded.

FOSSILS FROM THE THICK UNFOSSILIFEROUS SUCCESSION OF THE KROL BELT

PRE-BLAINI SUCCESSION (SIMLA GROUP AND JAUNSAR GROUP)

The Blaini sediments overlie either the Simla Slates or the Nagthat Quartzites often with a localized time break of short duration. The relationship between Simla Slates (Simla Group) and Nagthat Quartzites (Jaunsar Group) is still unresolved. Bhargava (1972 a) considers them to be time equivalents ; although a number of workers think that the Simla Group makes the basement for the Krol belt sediments and must therefore be somewhat older than the Nagthat Quartzites.

Traditionally, the Simla Group sediments are considered to represent Palaeozoic succession because of its pre-Blaini position though no fossils have been recorded in them. Sinha (1977) records well-developed Riphean stromatolites from the algal mat carbonates of the lower part of Simla Group sediments suggesting a Late Precambrian age. The Simla Group sediments represent deposits of a shallow tidal sea in lagoons, embayments and tidal flats (Singh and Merajuddin, 1980, Singh, 1980 b). Nautiyal (1978, 1979) has described organic remains from the argillaceous succession near Satpuli (Garhwal), which are considered to be Simla Slates. The rocks yielded phytoplanktons, Chitinozoans, and a few algal and fungal (?) remains and organic plates; Nautiyal (1979) has further assigned a shallow marine environment and Late Precambrian age to these rocks.

The Nagthat Quartzite makes the topmost unit of the Jaunsar Group and represents deposits of shoals and tidal flats (Singh, 1980 c). The Jaunsar Group in general represents deposits of a shallow tidal sea ; no fossils have been recorded from these sediments, although they are presumed to represent Palaeozoic succession.

The completely unfossiliferous nature (with respect to metazoans) of the Simla and Jaunsar Group sediment despite their being deposits of shallow tidal sea environment and, presence of Proterozoic stromatolites favours a Precambrian age.

BLAINI FORMATION

The Blaini Formation is a marker horizon of the unfossiliferous Krol belt sedimentaries, as it is readily recognizable because of one or more pebbly mudstone units and a pink coloured carbonate unit. The age of Blaini Formation is critical for establishing the chronostratigraphy of the Krol belt sedimentaries. In the traditional model, the Blaini Formation is assigned a presumed Permo-Carboniferous age and is considered to be of glacial origin, correlatable to the Talchir boulder bed of the Indian peninsular shield.

Lately, however, some workers doubted its glacial origin and suggested submarine slumping and turbidity as mechanism for their formation (e.g. Rupke 1968 ; Valdiya, 1970, 1973), Singh and Tangri (1976) and Singh (1980a) argued that the glacial as well as turbidity current origin of Blaini Formation are not tenable on the grounds that the significance of pebbly mudstones of the Blaini Formation which account for only 10-15% of the total Blaini Formation have been overemphasized. The interbedded orthoquartzite, succession of rhythmite, and the pink carbonate, show features indicating deposition mainly in a shallow tidal sea and therefore the Blaini Formation represents deposits of mainly sand bar/shoal, tidal flat and algal mat regions. The process of mud flow or debris flow and fluvial processes played significrant role in the genesis of conglomerates of Blaini Formation. Even on the lithological grounds Blaini Formation is not correlatable with the Talchir Formation, because the Blaini conglomerates do not show any evidence of glacial environment.

Following is the critical analyses of the various fossil records from the Blaini Formation.

Prasad and Bhatia (1975) record some organic remains in the thin-sections of calc-arenites from the Lower Boulder bed of Blaini Formation, Deoria, Simla hills. However, no mention is made of the number of samples studied and frequency of organic remains observed. The authors claim to record "a few scalariform tracheids — — — —, one ostracode, some foraminifers, doubtful dinoflagellates, radiolarians, algae, shell fragments, and some unidentified tubular forms." No description of the forms including size, no magnification of the photographs, no repository is given—informations which are vital for any fossil record. Also, no attempt has been made to prove the organic nature of the record by staining with dyes (especially the tracheids, dinoflagellates, and algae). A closer scrutiny of the photographs reveals that this report of organic remains is rather vague. The photographs of dinoflagellate cyst, radiolaria are not at all convincing (pers. communication Dr. K. P. Jain, BSIP, Lucknow) and same is the case with the photographs of foraminifers, and shell fragments. Only the photographs of algal filament and tracheid look like some organic remains ; though their identification is very uncertain. Further, no mention is made by the authors, as to how these diverse groups of fossils occur together, especially in a supposedly glacial deposit? and what is the palaeoecology of these rocks. Based on the meagre, probable organic remains reported by Prasad and Bhatia (1975), it is not possible to suggest any age to the Blaini Formation ; though the authors proposed a Pennsylvanian to Permian age.

Shrivastava and Venkataraman (1975) describe a number of palynomorphs, recovered from the shales of Blaini Formation. There is confusion in the locality of the samples (see p. 196, Shrivastava and Venkataraman

1975). No mention is made of the number of samples analysed and how many proved to be yielding ; and no description of the forms and repository is given, which weakens the palaeontological validity of this report. The photographs are of very poor quality, and it is not possible to recognize any of the forms reported by the authors in the photographs and the identification cannot be relied upon (pers. Communication Dr. H. K. Maheshwari, B.S.I.P., Lucknow). Further, the Blaini Formation is traditionally supposed to be of glacial origin, equivalent to the Talchir sediments. It is astonishing that the assemblage reported by Shrivastava and Venkataraman (1975) shows not a single element of Talchir assemblage. The Talchir assemblage is dominated by radial monosaccate pollens, and not a single monosaccate pollen is reported in this assemblage. All the forms reported by the authors are Euro-American forms. Shrivastava and Venkataraman (1975) suggest a Carboniferous age to the Blaini Formation(especially Member B of Bhargava, 1972 a) opposed to the Pennsylvanian to Permian age suggested by Prasad and Bhatia (1975) for the unit (Member A of Bhargava, 1972 a) which is lithostratigraphically slightly older. Thus, the fossil report by Prasad and Bhatia (1975), as well as Shrivastava and Venkataraman (1975) are questionable and therefore geological ages assigned by these authors cannot be taken as valid.

Tewari (1979) recently records a band of Permian fossils near Nainital-Gethia-Bhowali region in Nainital area which he claims to be a part of Blaini Formation. The report does not give adequate lithostratigraphic details, and fossil assemblage is yet to be described.

The sediments (dominantly quartzites) in the Naini-Tal-Gethia-Bhowali region are traditionally considered to represent Nagthat Quartzite (Heim and Gansser, 1939 ; Tewari and Mehdi, 1964) ; while Raina and Dungrakoti (1975) name them Bhimtal Formation and consider that this sequence is not part of the Krol belt, but constitute the part of Deoban Group which is a para-autochthon underlying the Krol belt sediments. Shah and Merh (1978) call these quartzites as Bhimtal-Ramgarh Formation and equate them with Blaini Formation, while the quartzitic sandstone and variegated slates overlying them are correlated with the Infra Krol Formation. From these diversified descriptions it is quite apparent that this sequence cannot be considered as belonging to Blaini Formation, and also because the characteristic litho-units of Blaini Formation are missing. This outcrop therefore can only tentatively be considered as another outcrop of Permian fossil-bearing sediments in the Lesser Himalaya.

Singh and Tangri (1976) believe that the sediments of Blaini Formation are devoid of any recognizable fossils. This is rather unusual since the major part of the Blaini Formation is a shallow tidal sea deposit which normally should have prolific fauna. It will be interesting to record here that the carbonate horizon of Blaini Formation is essentially an algal mat deposit, locally showing development of columnar stromatolites of *Colonella*, and *Conophyton*(?) affinity, the presence of which in the Blaini carbonates and absence of recognizable fauna in this formation, are the pointers for a Precambrian age for these rocks.

INFRA KROL FORMATION

Infra Krol succession is a shale-dominant sequence showing gradational contacts with the underlying Blaini Formation and the overlying Krol Formation. The lower part of Infra Krol succession, immediately overlying the pink carbonate of Balini Formation, invariably shows intercalations of thin bands of carbonates; though the main part of the Infra Krol succession is mostly made up of dark-coloured shales.

Following are the few fossil records from the Infra Krol sediments :

Ghosh and Srivastava (1962) report trilete spores with affinities to *Selaginella* (family Selaginellaceae) and suggest a Permian age. However, the photographs of spores published by them are no different from those of modern spores, and surely this record has to be considered as contamination (Pers. Communication Dr. H. K. Maheshwari, BSIP, Lucknow). Sitholey *et al.* (1954) recorded well-preserved tracheids, and a few spores and pollens from a black compact shale bed exposed on the Kathgodam-Almora motor road (between second and third furlong after 11th mile before the old brewery). They believed this sample to have been recovered from the Krol Formation. A restudy of the same sample in detail yielded eleven genera and eighteen species (Lakhanpal *et al.*, 1958). These authors considered that this sample belongs to the Lower part of the Krol succession and the pollen/spore assemblage was found to be similar to the Permian assemblage of the various coal-fields in Peninsular India, and consequently Permian age was suggested for the assemblage as well as the Krol sediments. Later Sah *et al.* (1968) reassessed this palynomorph assemblage and pleaded for a lowermost Triassic age. This study is being discussed under Infra Krol because many workers, for example, Bhargava (1979) has opined that this sample locality of Sitholey *et al.* (1954) is from the Infra Krol. Both Lakhanpal *et al.* (1958) and Sah *et al.* (1968) discuss that out of numerous samples of Krol sediments studied for the microflora, collected from Simla, Sirmur, Chakrata, Mussoorie, and Nainital areas only one sample described above yielded the palynomorphs. Samples of Blaini and Infra Krol however proved to be completely barren (Sah *et al.* 1968).

The photographs of pollen and spores of Sitholey *et al.* (1954), Lakhanpal *et al.* (1958), and Shah *et al.*, (1968) from a lone specimen of Krol succession (which may be Infra Krol) are quite convincing and look similar to the palynomorphs of Raniganj Stage (Maheshwari, 1981). However, there are a few points worth considering before we accept this report as valid. It may be re-counted that these authors have admitted that they analysed a large number of samples from Krol sediments of different areas but failed to recover any identifiable plant material. The Infra Krol-Krol sediments of Nainital area are typically deposits of a shallow tidal sea (see Singh and Rai, 1980). In such an environment it seems ridiculous to find only algae and palynomorphs without marine fauna especially when these shallow marine deposits are being assigned Permian-Triassic age, which is essentially a period of prolific life activity. Thus, we cannot rule out the possibility that the palynomorph assemblage of Sitholey *et al.* (1954) and Lakhanpal *et al.* (1958) are a case of contamination in the laboratory. Sah himself (in Mathur and Sah 1980) has cast doubts on this report due to lack of its reproducibility. Another possibility is that the sample is part of a Permian fossiliferous outcrop, and not a part of the Krol succession sensu-stricto. In the light of the finds of Tewari and Singh (1979) of a plant-fossil rich Permian outcrop from the same area, the latter possibility seems to be quite probable. However, in no case this palynomorph assemblage can be associated with Infra Krol or Krol sediments.

Fuchs and Sinha (1974) report that Dr. I. Draxler studied several samples collected from the Infra Krol near Sitholey *et al.*'s (1954) locality, but could obtain only primitive globular forms and some unidentifiable plant fragments without any age significance.

Tewari and Singh (1979) have reported an outcrop in Jeolikot-Bhowali section yielding plant fossils namely, *Lepidodendron, Calamites, Annularia, Sphenophyllum, Schizoneura, Phyllotheca, Gangamopteris,* and *Glossopteris.* The authors consider this outcrop to be part of Infra Krol succession, and assign a Permian age to the Infra Krol sediments. However, no litholog, thickness, lateral extent, and details about the nature of lower and upper contact of the fossil-bearing unit, and no description and photographs of the fossils are given. Thus, pending publication of further details, the report can be considered only tentative. Further, the sediments of the Jeolikot-Bhowali section are traditionally considered to represent Nagthat Quartzite ; while Raina and Dungrakoti (1975) consider this sequence to be Deoban Group and not part of the Krol belt. Shah and Merh (1978) correlate part of this unit to Infra Krol. In the light of such contrasted viewpoints about the lithostratigraphy of this area plant-fossil yielding outcrops of Tewari and Singh (1979) cannot be considered as definite Infra Krol.

Little sedimentological or palaeoenvironmental information is available for the Infra Krol sediments. Preliminary palaeoenvironmental analysis of the Infra Krol sediments by Bhargava and Singh (1980) indicate that these sediments are mainly made up of successions of tidal bedding, lenticular bedding, wavy bedding, small ripple bedding suggesting a low-energy muddy to mixed tidal flat environment. The black shale facies may be related to extremely protected muddy tidal flats to shallow lagoons. The rocks of Infra Krol age exposed on the Kilbury-Nainital section has already been interpreted as deposits of coastal shallow lagoon with tidal effects (Bhargava and Singh, 1980).

In the light of coastal lagoon-tidal flat palaeoenvironmental setting for the deposition of Infra Krol in Nainital area, the fossil find of land plants supposedly with Infra Krol (Tewari and Singh, 1979) becomes highly questionable. The reported plants are characteristically land plants which are known to be found some distance from the coast. Placement of this Permian plant fossil-bearing outcrop under the Infra Krol is more doubtful because the sediments of Infra Krol in Nainital area (lagoonal-tidal flat facies) are devoid of any marine Permian fauna and are essentially unfossiliferous. Consequently, the Permian plant-yielding outcrop of Tewari and Singh (1979) must be considered as an independent unit, and may represent product of fresh water deposition within the Subathu-Dogadda weak zone during Permian period of crustal instability (for details see later).

Inspite of the tidal flat-lagoonal facies of deposition, the total absence of benthos, bioturbation horizons, as well as any definite fossils remains strongly suggest a Precambrian age for the Infra Krol sediments.

KROL FORMATION

The Krol Formation is the major lithostratigraphic unit of the Krol belt and is essentially a sequence of dolomite and limestone together with minor amounts of shale and sandstone. In most of the sections, the underlying Infra-Krol shales become gradually calcareous and ultimately grade into shaly carbonates of the Lower Krol, though in Solan area a sandy unit (Krol Sandstone) is developed between the Infra Krol and Krol sediments.

Ghosh and Srivastava (1962) made palynological studies in sixty nine samples collected from Rajpur-Mussoorie muletrack, and a few samples proved yielding. These authors have not given the position of samples in the litholog, although described a number of spores from Krol A and D units belonging to the families Polypodiaceae, Selaginellaceae, Podocarpaceae and Pinaceae and assign a Triassic age to these rocks. All these families are still living today and the photographs of the palynomorphs look more akin to present day pollen and spores. Thus, these records are all contaminations and have no biostratigraphic validity (see Maheshwari, 1981).

There are two papers recording Mesozoic nannofossils from the Krol Formation, i.e. Tewari (1969) and Sinha (1975). Tewari (1969) reports coccolithophorids from the limestone and shale at the contact of Krol B and C stages in Krol Hill, and suggests a probable Jurassic age, as coccolithophorids are not known from rocks older than Jurassic. Tewari (1969) has neither given any litholog of the section, number of samples studied, nor the method of separating the nannofossils. Tewari has not described the forms, and the photographs are of very poor quality. Most probably the reported features are recrystallized carbonate aggregates.

Similarly, Sinha (1975) described coccoliths from the Krol B of Pachmunda syncline. According to Sinha (1975) the coccoliths were separated from a single sample, and only a few forms of coccoliths were recovered. Dr. S. A. Jafar, University of Hyderabad an authority on nannoplanktons, in a personal communication states "the paper by Sinha (1975) lacks several ingredients to command serious attention and unless the original material is carefully tested under strict control of contamination in the laboratory itself, it would be premature to draw any conclusion. Nevertheless, I must declare that a few forms of nannofossils documented in this paper are genuine, but scarcity of these is a puzzle, especially when they show fairly moderate state of preservation—this makes me suspect that contamination in the lab. is not totally ruled out".

Further, that "Plate I of Sinha (1975), fig. 1 is a coccolith slightly overgrown with calcite and covered with foreign particles ; but identification is wrong. This is *Chiastozygus litterarius* (Gorka) Manivit, and not the *Zygolithus concinnus*. Figs. 2, 3 and 4 are not nannofossils. Plate II (figs. 1, 2, 3) shows a true coccolith at different magnifications, but again the identification is wrong. The form is *Cyclagelosphaera rotaclypeata* Bukry, 1969, and not the *Tergestiella margereli*. Plate III, fig. 1 is out of focus and even generic identification is not possible. In plate III, fig. 2 only half of the coccolith is visible, specific identification is difficult, but affinity with genus *Zygodiscus* can be established".

In the light of above comments by Dr. S. A. Jafar, biostratigraphic significance of the coccoliths reported by Sinha (1975) becomes highly questionable.

It is also interesting to note that in the table presented by Sinha (1975) showing the distribution and range of various genera identified by him, there are forms which are restricted only in the Upper Cretaceous. Therefore the Krol B Unit should have been assigned an Upper Cretaceous age. Contrary to normal logic Sinha (1975) prefers a vague Upper Jurassic to Upper Cretaceous age than the precise Upper Cretaceous age. Sinha (1975) further claims that the mixing of Jurassic and Cretaceous forms was due to turbidity currents. In spite of the cases of reworking of fossils, the age of Krol B, according to Sinha's (1975) data should be Upper Cretaceous. It seems that for convenience Sinha has not opted for the specific Upper Cretaceous age as it would have created difficulty in fixing the position of the overlying Tal Formation, which is supposed (although erroneously) to be Jurassic to Cretaceous in age.

The mineralogical study of Krol Formation in Simla hills by Kharkwal and Bagati (1974) and Bagati and Kharkwal (1979) indicate that the Krol succession is extensively dolomitized and recrystallized and is product of deposition in tidal flats. The red shales of Krol B are closely associated with dolostones (Bagati and Kharkwal, 1979), though they also contain microcrystalline calcite (Kharkwal and Bagati, 1975). The Krol B of Mussoorie and Nainital areas is also product of deposition in tidal flats-shallow lagoons (Singh *et al.* 1980 ; Singh and Rai, 1980), and show recrystallization and dolomitization.

Sinha (1975) completely ignored the palaeoenvironment of the Krol sediments. In the light of the well documented tidal flat environment for the Krol sedimentation it is not possible to visualize the absence of benthonic communities and presence of only coccoliths, and further imagine turbidity currents operating in a tidal flat setting. Moreover, it is not possible to extract nannofossils from a recrystallized, dolomitized sediments, even if present. Thus, the reports of nannofossils from Krol sediments can be dismissed as of no consequence.

Mithal and Chaturvedi (1972) recorded certain algal features from Upper Krol of Mussoorie hill, which they assign to algae of Solenoporaceae family hence a Palaeozoic-Mesozoic age. A closer look of the photographs reveals that these features are similar to the vugs of bird's eye dolomite described by Singh *et al.* (1980).

The foraminifera from the Upper Krol Formation (Krol D), described by Kumar (1978a) are undoubtedly various types of oolites and coated grains. Kumar (1978 b) further described many genera of algae from the Krol D sediments of Simla hills and assigned a Permo-Triassic age to the Upper Krol sediments. The illustrations are very neatly comparable to the coated grains with sparry carbonate nucleus, indeterminate intraclasts showing patchy recrystallization into sparitic carbonate, ill-developed oolites, multiple oolites, broken algal mats and micro-stromatolites, hence without any age significance. No definite calcareous algae are recognizable. Kumar (1978 a, b) made no comments how he visualizes a Permo-Triassic age for Upper Krol sediments, while Sinha (1975) assigned a Upper Jurassic-Upper Cretaceous age to the Middle Krol sediments of the same area. Neither a litholog nor position of the samples is given. No palaeoecological comments have been made on the absence of molluscan fauna in a facies, which is normally dominated by them.

Recently, Valdiya (1980 a) described a single specimen of *Linoproductus ?* sp. from Upper Krol sediments of Nainital area. He gives a geological cross section of the Nainital area but does not give any information about the details of litholog, thickness, and lateral extent of the unit which has yielded the specimen, and the palaeoecology of the deposits. The sequence from where this specimen is reported to have been collected is essentially an algal mat sequence of upper intertidal-supratidal zone showing extensive algal mats. *Linoproductus* lives in colonies in the subtidal zone. Valdiya (1980 a) does not make any comments on this palaeoecological discrepancy. Further, without making any critical comments on the Upper Jurassic-Upper Cretaceous nanno fossils reported by Sinha (1975) he asserts a Permian age for Krol sediments. It is interesting to note that the lone specimen of *Linoproductus?* was collected by two students, and the later search by different workers in the supposed area of its occurrence failed to yield any other specimen of brachiopod or any other metazoans.

The report of the lone specimen of *Linoproductus ?* sp. by Valdiya (1980 a) can be a geological oddity, but until more specimens are found and the horizon is located in the field, it cannot be given any biostratigraphic significance. And if a Permian horizon is proved to be present in association with the Krol dolomites of Nainital, it must be treated as another detached outcrop of Permian age, because of the palaeoecological discrepancy between the Krol succession proper and the Permian fossil-bearing outcrop (as discussed below).

Environmentally, the Krol sediments represent deposits of a shallow tidal sea where various facies belong to a complex of subtidal, intertidal, and supratidal subenvironments, and the intertidal-supratidal zone deposits are more abundant (see Awasthi, 1970 ; Kharkwal and Bagati, 1976 ; Singh and Rai, 1980 ; Singh *et al.*, 1980).

The tidal flat facies of Phanerozoic times are characterized by dense benthonic communities, which leave their record in the form of shell beds or bioturbated horizons. Locally, interspersed within such sequences of carbonate tidal flat, layers of algal mats and ill-developed stromatolites may be present, though always associated with the metazoans, especially the molluscs. In Phanerozoic times extensive and thick sequences of algal mats could not develop in the intertidal zones, because the molluscs and many other metazoans which abundantly inhabit the intertidal zone, feed on them. Therefore, thick exclusive intertidal algal mat sequences during Phanerozoic times are an impossibility.

On the contrary, carbonate tidal flat facies of Precambrian times are characterized by thick sequences of algal mats where under suitable environmental conditions columnar stromatolites may be abundant. Extensive algal growth during Precambrian was possible because of the absence or rarity of competing metazoans.

Significantly, the Krol sediments in Nainital area, along with a variety of algal mat and stromatolitic sequences, have also yielded a well-developed stromatolite assemblage, i.e. *Conophyton garganicus*, *Baicalia baicalica*, *Colonella* sp. (Singh and Rai, 1977, 1980). This stromatolite assemblage is considered to be a characteristic Proterozoic (middle Riphean) assemblage in India, U.S.S.R. and Australia (see Walter and Preiss, 1972). Gundu Rao (1970) reports algal oncolites from Krol sediments showing Precambrian affinity.

Valdiya (1980c) considers that because the stromatolites of Krol Formation are small in size (stunted), they are probably Palaeozoic in age. Identification of any biological forms is done on the basis of ratios of shape dimensions and not the absolute size. The stromatolites are identified on the basis of shape dimensions, branching pattern of columns, nature of micro-laminations etc. and not the absolute size. The absolute size is mainly controlled by the physical environmental factors e.g., wave and current activity. In Vindhyan basin the same forms of stromatolite, e.g. *Baicalia* occurs in dcm long columns in few units, while in other units it is present as 2-3 cm high columns (smaller in size than in the Krol Formation). The columns may grow upright or inclined, sometimes making an angle of only 5°—10° from horizontal.

Probably under the influence of this thinking of Valdiya (1980c), another worker from Nainital A. Kumar (1980) describes the stromatolites of Krol Formation as new forms, namely *Crossia*, *Krolia*, *Nainitalia*, *Plumia*. Significantly, A. Kumar (1980) does not give adequate descriptions of these forms. No thin-sections were studied to understand the micro-laminations which is a must in the study of stromatolites, and he does not compare them with the existing form genera of stromatolites. To avoid comparison with existing form genera of stromatolites he even ignores the paper of Fuchs and Sinha (1975) reporting stromatolites in Krol Sediments of Nainital, and the paper of Singh and Rai (1977) where stromatolites from Krol Formations are described. Pl. I—fig. 1 (*Crossia*) of A. Kumar (1980) is the same as Fig. 3 (*Baicalia*) of Singh and Rai (1977) ; while Pl. I—fig. 3 (*Krolia*) is the same as fig. 5 of Fuchs and Sinha (1975). However, A. Kumar (1980) is very emphatic that these are new stromatolite forms and Permian in age.

A. Kumar (1980) also reports a few algae, namely *Garwoodia*, *Epiphyton*, *Renalsis*, and *Mizzia* from the dolomites of Krol Formation. There is no description of forms and photographs are of very poor quality. Thus, the stromatolite forms and algae reported by A. Kumar apparently do not have any palaeontological and biostratigraphical validity.

In the light of the palaeoecological conditions of the Krol sediments discussed above, and the questionable fossil records (almost all of them can be discarded more so for the biostratigraphic inferences), it is highly improbable that the age of Krol sediments be Palaeozoic or Mesozoic. The existing data strongly favours a Late Proterozoic age for the Krol Formation.

TAL FORMATION

The Tal Formation makes the topmost unit of the Krol succession in most areas, and is mainly an argillo-arenaceous succession with a characteristic phosphate-bearing carbonate, chert and black shale unit at the base and algal mat carbonates and quartzites in the upper Tal. The contact between the Tal and underlying Krol is more or less gradational, where algal mat carbonates of upper Krol gradually merge to black phosphatic shales etc. with bands of algal mat and stromatolitic carbonate. This change in facies denotes only a change from oxygenated, well-aerated tidal flat of upper Krol into a restricted, poorly circulated tidal flat-shallow lagoon of Lower Tal. Even in areas where phosphate-bearing unit is absent, the Krol carbonates show a gradual change into the overlying shales and sandstones of Tal Formation.

The Tal Formation as discussed here excludes the topmost Shell Limestone Member as suggested by Singh (1976, 1979 c). Ghosh and Srivastava (1962) recorded a single spore of family Schizaeaceae, which is a living family. The photograph of the spore looks akin to a present-day spore and hence the report can be dismissed as contamination (pers. Comm. Dr. H. K. Maheshwari B.S.I.P., Lucknow).

Singh (1979 d) rejected the fossil records from the Tal Formation (excluding those from the Shell Limestone) and asserts that the fossil records from the Tal Formation can best be considered as the evidence of indeterminate organic remains which can be of Late Precambrian age. The reports of fossils from Lower Tal sediments by Shrivastava and Mehrotra (1974) and Srivastava (1974) can be rejected as they do not give any descriptions of the forms recorded (see Singh, 1979 d ; Bhatia, 1980). Recently Bhatia (1980) made a good review of the fossil occurrences from the Tal Formation.

Shrivastava (1972) reports *Posidonia* cf. *ornati* from the phosphate-bearing Lower Tal sediments. Singh (1979 d) rejected this identification because these disc-like bodies with concentric ornamentation do not show the more significant features of a lamellibranch, i.e. muscle impression, hinge, umbo etc. and the specimens are present as supposed mould and cast and are 1/5 or less in size than the *Posidonia*. Shrivastava (1972) does not give any repository which further cuts down the palaeontological validity of this report. As also pointed out by Singh (1979 d) these small disc-like bodies may be phosphatic or chitinous shells of primitive brachiopods of Late Precambrian. It is rather surprising that despite these shortcomings, Bhatia (1980) accepted this report of genus *Posidonia*, except that he doubted its specific level identification. Possibly Bhatia (1980) has been overwhelmed by the traditional view of considering Tal as Jurassic-Cretaceous.

Interestingly the phosphorite-bearing Lower Tal sediments contain algal mat and stromatolitic sequences with evidences of deposition partly in intertidal zone of a shallow restricted lagoon-tidal flat area (unpublished data). Stromatolites and oncolites are reported from this unit by Raha and Gururaj (1970) and Raha (1972). Srivastava (1973) records 'estherids' from the Middle Tal sediments. From the illustration these 'estherids' looks similar to the *Posidonia* reported by Shrivastava (1972) and can be best regarded as small disc-like bodies of indeterminate character. In this report too the shell or carapace is present only as cast. The illustrations and descriptions are highly vague, and no repository has been given. The lithological description of the sediments which yielded 'estherids' corresponds to the unit E, F of Singh (1979 c) which show features of tidal flat deposits. The 'estherids' are known to occur only in continental fluvial-lake sediments. Thus, the record of 'estherids' also looks doubtful. It is worth mentioning that Pratap Singh (1980) greatly emphasizes the record of 'estherids', and considers it to be an evidence to indicate that the upper part of Lower Tal and some parts of Upper Krol represent continental deposits. He totally ignores the facies characteristics of these sediments which clearly point to a shallow marine environment ranging from tidal flats to shoals as suggested by Singh (1979 c).

Bhargava (1972 b) records some structures resembling moulds of tadpole nests from quartzite of Upper Tal, and considers it to be Upper Jurassic age indicator (Bhargava, 1976). The photographs of these features are more akin to inorganic sedimentary structures like load structure or concretions and cannot have any age significance. The term tadpole nests is often used in sedimentological literature for describing the interference ripple marks.

Patwardhan (1978) describes some organic remains from the phosphorites of Lower Tal and assigns them to belong to the family Moravamminidae which is known from Permian rocks. Interestingly, the family Moravamminidae is a new family created by Termier *et al.* (1975, 1977) to accommodate certain peculiar sponges occurring with a rich assemblage of typical Permian fauna. It is really surprising that in Lower Tal Formation fossils belonging to the family Moravamminidae be present ; while more common Permian fauna is completely absent. As discussed by Bhatia (1980) the forms reported as Moravamminids by Patwardhan (1978) do not show their characteristic features. Ahluwalia (1980) quotes that the identification of Moravamminids in Tal sediments has also been doubted by Prof. Pokorny of Czechoslovakia. Consequently, the report of Moravamminid can be safely forgotten since they can have no palaeontological or biostratigraphic significance. Ahluwalia (1978) further recorded some foraminifera and porifera from the same horizon from which the Moravamminids were recorded. Identification and validity of these records are not only questionable, but amusing in that the same form has been considered as Moravamminid by Patwardhan (1978) and as *Palaeobigenerina*(?) by Ahluwalia (1978) (see Bhatia, 1980). Bhatia (1980) therefore rejected the identification of both Patwardhan (1978) and Ahluwalia (1978). Bhatia (1980), however, considers these vague forms as dasycladacean alga—*Cylindroporella*, without providing its adequate description or adhering to the usual palaeontological norms.

Interestingly, Ahluwalia (1980) points out that the forms considered to be *Cylindroporella* by Bhatia (1980) cannot be *Cylindroporella*, because it lacks the spiral nature which is supposed to be its most characteristic feature, and the identification of *Cylindroporella* for these vague organic forms has been doubted by Dr. Elliott and Dr. Bassoullet, authorites in this field.

Bhatia (1980) is very emphatic with respect to the Lower Cretaceous age of Lower Tal sediments. However, his interpretation of age is based only upon the record of *Posidonia* by Shrivastava (1972), and his own creation of alga *Cylindroporella* from the indeterminate organic remain. However, as discussed above, identification of both the forms is questionable. Further, the age of genus *Posidonia* as given in Treatise is Lr. Carb. to Upper Jurassic (Moore, 1969, p. 343).

How and why Bhatia (1980) extended the age of genus *Posidonia* into Lower Cretaceous is an enigma, especially when there is no other faunal support. Further, Bhatia (1980) does not make any comments on the palaeoecology of the Lower Tal and explain, as to why no well-defined benthonic assemblage is present in the sediments, if they were to be of Cretaceous age.

Simple burrows (Banerjee and Narain, 1976) and some bioturbation (Singh, 1979 c) are present in the Tal sediments indicating that some metazoans were certainly present leaving behind traces of their life activity.

To sum up the fossil record of the Tal Formation one can safely state that there are some indeterminate organic features present which can be of latest Precambrian age. And there is evidence that a few metazoans had already appeared, leaving their record in the form of burrows. The traditional presumed Jurassic-Cretaceous age of the Tal Formation can be rejected as there are no definite fossils to support it, although the environment of deposition of Tal sediments is a shallow tidal sea, partly on the tidal flats, areas which in Phanerozoic times are characterized by extensive benthonic communities. A point worth mentioning is that the carbonate horizons of Tal Formation show extensive algal mats and stromatolite development (Bhargava, 1979, fig. 2 ; Sharma, 1976), but no well-defined metazoans, a situation which existed only during Precambrian times.

SUMMARY

Summing up the critical analysis of the reported 'fossils' from the unfossiliferous succession of the Krol belt, one can safely say that most of these fossil reports do not have any resemblance with the organisms and a few are case of laboratory contamination ; while others are organic remains of indeterminate characters. One can only wonder how uncritically such fossil records have been published and utilized in building up the chronostratigraphy of the Krol belt sediments.

Palaeo-environmental studies clearly show that the conditions were well-suited for the growth and development of life during deposition of Krol belt sedimentaries. Another significant point emerges that all the carbonate horizons of Krol belt succession, i.e. Simla Slate-Blaini-Krol-Tal are essentially algal mat carbonates where under suitable environmental and palaeoecological conditions columnar stromatolites of Proterozoic affinity are present.

FOSSIL-BEARING HORIZONS OF THE KROL BELT

Within the Krol belt sediments there are a number of thin, detached outcrops of definite fossil-bearing sediments. On the basis of their fossil-assemblages, these outcrops can be classified into three ages, viz. Permian, Cretaceous, and Eocene. In the traditional model of Krol belt chronostratigraphy, most of these outcrops are considered to represent the integral part of the Krol belt sedimentaries. However, Singh (1976, 1979 a) proposed that these outcrops of fossil-bearing sediments are product of three transgressions, namely Permian, Cretaceous, and Eocene, along a weak zone within the Precambrian Krol belt sedimentaries.

FOSSIL-BEARING HORIZONS OF PERMIAN AGE

Middlemiss (1887) mapped a horizon which he referred to as 'Volcanic breccia' occurring discordantly over the Krol belt sequence in the Garhwal area. It is from this horizon, redesignated as Boulder Slate Sequence, that Ganesan (1971, 1972) reported an assemblage of bryozoa, namely *Fenestella affisichwaldi*, *Fenestella garhwalensis*, *Fenestella oculata*, *Polypora middlemissi*, *Polypora dieneri*, and *Dogaddanella audeni* from a single locality near Jogira in Garhwal district and assigned a Middle to Upper

Carboniferous age. Shanker and Ganesan (1973) reported that the Boulder Slate Member (Sequence) is a well-developed horizon which is richly fossiliferous containing bryozoa, lamellibranchs, and brachiopods, and suggested the age of Boulder Slate Sequence to be Carboniferous to Permian. Shanker *et al.* (1973) list the fossils obtained from the Boulder Slate Sequence and give a Westphalian age. Chaturvedi and Talent (1971) propose a Permian age for the bryozoa and brachiopods of the Boulder Slate Sequence.

These reports established the presence of a Permian fossiliferous horizon in the Krol belt.

Waterhouse and Gupta (1978) studied a few samples of the Boulder Slate Sequence and systematically described nine brachiopod and five bivalve genera and point out that the fauna is of Sakmarian age. However, as the study of Waterhouse and Gupta (1978) is based on the grab samples of only one locality, their generalizations regarding the precise Sakamarian age of the fauna of Boulder Slate Sequence is to be taken cautiously.

More recently, M. P. Singh *et al.* (1979) record a Permian fossil-bearing outcrop from the Tal Nadi valley. This Permian horizon is associated with Subathu sediments. The fossils include lamellibranchs, namely *Eurydesma* cf. *mytiloides*, *E. aff. allatum*, *Megadesmus* (*M.*) *nobilissimus*, *M.* (*M.*) sp., *Schizodus* spp., *Astartila intrepeda*, *Astartila blatchfordi* and a Lower Permian age is suggested. The authors do not give any litholog, thickness and lateral extent of the fossil-bearing outcrop. No description of fossils is given, and no information is given whether only lamellibranchs are present or they are associated with bryozoans and brachiopods.

However, the interpretation of M. P. Singh *et al.* (1979) about the existence of overturned succession in the area has little validity because the supposed Carboniferous of Ganesan (1971, 1972) is actually the Lower Permian and homotaxial with this record. Moreover as discussed elsewhere the Permian of Kalia (1974) and Mehrotra *et al.* (1976) is actually Upper Cretaceous in age, and the Devonian of Tewari *et al.* (1976) is questionable.

Bhatt and Singh (1980) describe Brachiopod and bryozoan fauna occurring together in the Boulder Slate Sequence. They describe the brachiopod species *Cleiothyridina semiconcava* in the assemblage which points to an Artinskian age. Summing up the existing data of fauna from Boulder Slate Sequence they suggest that the age of Boulder Slate Sequence is Lower Permian (Asselian, Sakmarian and Artinskian).

As already discussed, if the horizon yielding the lone specimen of *Linoproductus ?* sp. from the upper Krol sediments of Nainital area (see Valdiya, 1980 a) becomes established then it could be another outcrop of Permian transgression associated with Krol sediments.

This postulation gets strengthened by the record of two more outcrops of Permian fossil-bearing sediments in Nainital area (see Tewari, 1979 ; Tewari and Singh, 1979). Tewari (1979) reports *Protoretepora*—a cryptostome bryozoa, impressions of Productids and a large fusulinid foraminifera from an outcrop in Nainital-Gethia-Bhowali region and assigns a Lower Permian age. Details of litholog, thickness and lateral extent of fossil-yielding outcrop, and photographs or description of the fossils are not given. Thus, we have to consider this report as tentative. Tewari (1979) considers this fossil-bearing outcrop to be part of Blaini Formation. However, as discussed earlier the tectono-stratigraphic position of the sediments with which this fossil outcrop is associated is highly disputable, and this fossil occurrence cannot be considered a part of the Blaini Formation.

Tewari and Singh (1979) record an outcrop of Permian plant fossils from nala cuttings in the Jeolikot-Bhowali section. However, no litholog, no thickness and lateral extent of the fossil-bearing horizon, and no description and photographs of the forms are given, so the report has to be taken as tentative. The grouping of this fossil bearing outcrop with Infra Krol, as done by Tewari and Singh (1979) is questionable as the sediments in question are not considered Infra Kol by many workers, as discussed earlier.

Mathur and Sah (1980) record a fossil outcrop near Gainthia in Nainital-Bhowali area yielding an Upper Carboniferous-Lower Permian fauna. The authors propose that this outcrop belongs to Blaini-Infra Krol sediments. However, the outcrop is located in an area of rather uncertain tectono-stratigraphy. The sediments near this fossil-bearing outcrop are considered Infra Krol (Pal and Merh, 1974), Nagthat (Fuchs and Sinha, 1974) and Deoban Group (Raina and Dungrakoti, 1975).

Raina and Dungrakoti (1975) reported a few poorly preserved fossils from two outcrops in the Deoban Group farther east to the locality of Tewari (1979). The fossils show poorly preserved bryozoans of Palaeozoic affinity. It is most probably another outcrop of Permian transgression in Lesser Himalaya.

As discussed by Shanker and Ganesan (1973) the Boulder Slate Sequence, containing Permian fossils is rather extensive in Garhwal region ; however, there is almost no information about the thickness of this unit in various sections, and no data is available on its palaeoecology and palaeoenvironment. Tectono-stratigraphic position of this unit is highly disputable. Shanker and Ganesan (1973) consider it to be a thrust sheet (their Lower Bijni Unit) within the Garhwal nappe that is contended to have been brought on the Krol belt sediments from North, originally located near south of Central Crystallines. Valdiya (1975) believed this unit to be integral part of Lower Tal succession (Jogira Member), thus considering it to be integral part of the Krol belt. Singh (1976, 1979 a) considers this unit to represent a product of Permian transgression on the Precambrian Krol belt sedimentaries. Kumar and Dhaundiyal (1980) consider the Boulder Slate Sequence to be part of Blaini Formation, thus part of the Krol belt sequence.

Shanker and Ganesan (1973) describe that the Boulder Slate Member contains pebbles which are subrounded to subangular varying in size from a few millimetres to 12 cm., and occasionally up to 30 cm. The pebbles are of brown weathering limestone, ash-grey limestone, bluish grey limestone, grey and white quartzite, dark slate and occasional granite, though Shanker and Ganesan (1973) do not comment upon their provenance. Nevertheless, dominance of large clasts of carbonates (which are rather unstable) implies a close vicinity of the source rock. Valdiya (1975) also gives the similar nature of clasts in the Boulder Slate Sequence, and asserts that these clasts are derived undoubtedly from the underlying Infra Krol-Krol, and Nagthat formations.

If the observations of Valdiya (1975) are true, then it is a clear indication that Boulder Slate Sequence is post-Krol and has been deposited on an eroded Krol belt sequence, at the site of its present position in the Krol belt and does not represent a thrust sheet as visualized by Shanker and Ganesan (1973). To the present author the above observations are a clear indication that the Boulder Slate Sequence represents a product of deposition of a Permian transgression on the top of eroded Krol belt sequence, which also supplied the larger clasts.

We urgently need a careful study of Boulder Slate Sequence in several sections, where detailed observations should be made on the nature of its lower and upper contact, nature of clasts and its probable provenance, palaeo-environmental analysis on the basis of sedimentary structures, systematic collection of palaeontological samples in vertical measured profiles and a detailed study of the fauna to enable us to reconstruct the nature of Boulder Slate Sequence and to fix the lower and upper age limits of this fossiliferous horizon.

At the present state of our knowledge the Boulder Slate Sequence and other Permian outcrops of the Krol belt seem to represent product of deposition of a transgression of Lower Permian sea on a Precambrian basement as visualized by Singh (1976, 1979 a). The fauna of Boulder Slate Sequence is rather similar to the fauna of UmariaMarine Beds and its equivalents in the Narbada-Son valley and is also comparable in age (see Waterhouse and Gupta 1978 ; and Bhatt and Singh, 1980).

This palaeontological information supports the contention of Singh (1976, 1979 a) that the Permian transgression in the Subathu-Dogadda zone and Narbada Valley are related. The previously given Carboniferous age to the Boulder Slate Sequence can be modified to Lower Permian in view of the findings of new, better preserved fauna (see also Bhatt and Singh, 1980).

FOSSIL-BEARING HORIZONS OF CRETACEOUS AGE

A fossil-bearing outcrop was discovered by Medlicott (1864) in the Tal Valley which yielded fragmentary fossils and were assigned a probable Jurassic age by Middlemiss (1885). It was believed to represent the topmost horizon of Tal succession, representing a dominantly argillaceous-arenaceous succession above the carbonates of Krol sediments. This occurrence of Shell Limestone led to the belief that the Krol belt succession extends in age up to Jurassic-Cretaceous and the Krol belt sequence below the Shell limestone must represent the entire Palaeozoic-Mesozoic (see Auden, 1934, 1937). This Shell Limestone is developed only in the Mussoorie-Garhwal area and caps an about 2000 m thick unfossiliferous Tal succession which in turn makes the topmost unit of almost 6000 m thick unfossiliferous Krol belt sedimentaries. For almost 100 years no systematic study of the fossil content of this Shell Limestone horizon was undertaken.

Tewari and Kumar (1967) recorded bryozoa, calcareous algae, and foraminifers and suggested a Lower Cretaceous age of the Shell Limestone on the basis of presence of *Laterocavea* sp., and *Neomeris*. However, the study was based only on grab samples, and it is not specified as to which part of the 30 m thick Shell Limestone has yielded this assemblage.

Kalia (1974) recorded a fauna, namely fusulinids from this horizon, and suggested a Permian age for the Shell Limestone in Dogadda area, and later described algal assemblage and asserted a Permian age (Kalia, 1976). Simultaneously, Mehrotra *et al.* (1976) also described Permian fossil algae from the Shell Limestone near Singtali and named it as Singtali Formation.

Valdiya (1975), fascinated with the Permian age proposed by Kalia (1974) for the Shell Limestone (Bansi member of Valdiya), proposed a revised chrono-stratigraphy of the Krol belt sedimentaries and a Permian age for the Tal sediments. Recently, VALDIYA (1980d) again modifies his earlier proposal and separates the Shell Limestone (Bansi Member of VALDIYA, 1975) from the Tal Formation, probably because of the doubts raised by many workers about its Permian age. However, VALDIYA (1980d) without giving any additional faunal evidence and ignoring the Cretaceous fossils recorded from the Shell Limestone suggests a Palaeocene age for the Shell Limestone. He further proposes that Shell Limestone and Subathu sediments make a single unit, an observation which is in contradiction with the existing field as well as palaeontological data. However, the age assignments given by VALDIYA to the Shell Limestone are rather confusing. VALDIYA (1980c, p. 35) correlates Shell Limestone (Bansi Member) with Kakra Formation of Srikantia and Bhargava, 1967 (which makes the lowest part of Subathu succession and upper Palaeocene in age). VALDIYA (1980c, p. 42) refers Kakra Formation to be Upper Cretaceous-Palaeocene in age, and on p. 44 (VALDIYA, 1980c), writes Singtali or Bansi (Shell Limestone) to be Upper Cretaceous-Palaeocene—a confusing state of affair.

However, the Permian age proposed by Kalia was doubted by most of the workers, especially as her fusulinids proved to be deformed oolites (Bhatia, 1975 ; Nakazawa in a communication to Raina and Krishnaswamy, 1976 ; Tewari and Gupta, 1978 ; Bhargava, 1979).

P. Singh (1980), and Bhatia (1980) made a somewhat detailed study of the fossil contents of the Shell Limestone and convincingly demonstrate that the *Fusulina* reported by Kalia (1974) are various types of deformed oolites. Further Bhatia (1980) describes that some of the Permian algae reported by Kalia (1976) and Mehrota *et al.* (1976) are actually bryozoa of Cretaceous affinity, while others are Cretaceous algae, and there are no forms of Permian affinity. Mathur (1977) refutes the Permian age of Singtali Formation of Mehrota *et al.* (1976). and gives a Cretaceous-Palaeocene age.

Tewari and Singh (1976), Tewari and Gupta (1978) assign an Upper Cretaceous to Palaeocene age to the Shell Limestone and added *Lithothamnium* and globorotalids to the list of fossils earlier reported by Tewari and Kumar (1967) giving a Lower Cretaceous age. They argue that due to presence of globorotalids Shell Limestone cannot be older than Maestrichtian. Saklani *et al.* (1977) describe a Shell Limestone from Satengal Klippe and assign a Cretaceous-Danian age.

The report by Maithani (1972) of fossils of Late Triassic to early Jurassic/Cretaceous age from supposedly Tal Formation (Shell Limestone) has been rejected by Bhatia (1980), and Kumar and Dhaundiyal (1980), as his collection seems to be mainly from the Subathu sediments (Eocene) and suffers with erroneous identification. The present author also supports this view, and no consideration is given to this report while reviewing the age of Shell Limestone.

Bhatia (1980), based mainly on the identification of cyclostomatous bryozoa (Cerioporidae), Milleporina, and calcareous algae assigns a Upper Cretaceous (Maestrichtian-Danian) age to Shell Limestone, and shows that Singtali Formation is also Late Cretaceous in age and homotaxial to Shell Limestone.

P. Singh (1980) based upon the identification of foraminifers—*Globotruncana*, *Heterohelix* and *Hadbergella*, bryozoa *Ceriocava*, and coral *Elephantaria* gives a Late Cretaceous (Coniacian) age to the Shell Limestone, including the so called Bansi member of Valdiya (1975) in Dogadda area.

Dhaundiyal and Kumar (1976) record a shell limestone horizon occurring together with rocks of Pre-Blaini age (Probably Nagthat sediments), naming it as Shankarpur Formation ; but later changed the name to Binj Formation (Kumar and Dhaundiyal, 1980). They presume that this shell limestone is of Lower Palaeozoic age.

Tewari and Gupta (1978) comment that the shell limestone of Shankarpur Formation is of Upper Cretaceous-Palaeocene age. Bhatia (1980) comments that the fossil contents of shell limestone of Binj Formation are identical to those of Shell Limestone capping the Tal Formation and that the two are correlatable and homotaxial. Bhatia (1980) further asserts that the fossil contents of the Shell Limestones from localities at Bansi, Nilkanth, Singtali, Shankarpur and Satengal are homotaxial and of Maestrichtian-Danian age (see also Tewari and Gupta, 1978).

If the age of Shell Limestone of Binj Formation of Kumar and Dhaundiyal (1980) is Maestrichian-Danian then the Shell Limestone in Mussoorie-Garhwal area does not possess any fixed stratigraphic position, but represents a transgressive horizon, which can be associated with different litho-units in different areas. The explanation of Bhatia (1980) to explain the Late Cretaceous age of Shankarpur (Binj) Formation by a regional strike fault is not tenable as there are no field reports of such a fault, and moreover, except for Shell Limestone, other rock units do not show any repetition.

A fossiliferous outcrop of probable Eocene age was recorded by J. N. Dhaundiyal near Nainital (Anonym. 1978), and a shell limestone band associated with this outcrop has yielded Mesozoic microfauna (according to Acharyya and Ray in Anonym., 1979). This outcrop may only tentatively be considered as a probable Late Cretaceous fossil-bearing horizon, because no systematic and reliable palaeontological data is yet available.

THE LOWER CONTACT OF SHELL LIMESTONE

As the first record of Shell Limestone (Middlemiss, 1885) was made in an area where it caps the topmost Quartzite Member of the Tal Formation it was considered to represent the topmost unit of the Krol belt sequence. The Shell Limestone is not present on the top of Tal succession of Nigali and Korgai synclines of Himachal Pradesh, though the Tal succession is rather thick and well-developed (see Bhargava, 1972 a).

The lower contact of Shell Limestone with the underlying unfossiliferous Tal succession is mostly accepted as conformable ; although, Auden (1937) suggested an unconformity between the Quartzite Member and the overlying Shell Limestone. Recently, Singh (1979 b) argues in favour of a sedimentation break between the two. In the field, the passage from the thick unfossiliferous succession of Tal sediments to the fossiliferous Shell Limestone is so abrupt and prominent that one keeps on wondering how the unfossiliferous Quartzite and Shell Limestone can be interrelated and grouped together. Singh (1979 b) demonstrates that the Quartzite Member is an orthoquartzite where most of the quartz grains show secondary overgrowth. Further, the quartz grain occurring in the Shell Limestone often show abraded overgrowth, implying that the quartz grains of the Shell Limestones are derived from a sedimentary source in the vicinity. The quartz grains of the Quartzite Member and Shell Limestone show close similarity in the size, extinction characteristics and inclusions, suggesting that Quartzite Member may have supplied the quartz grains during deposition of Shell Limestone. This interpretation requires that before the commencement of sedimentation of Shell Limestone, the Quartzite Member was already lithified with silica diagenesis (producing secondary overgrowth) implying that there is a sedimentation break between Shell Limestone (Nilkanth Formation of Singh, 1979c) and the underlying Quartzite Member.

Surprisingly, Bhatia (1980) completely ignores the implications of the above-mentioned observations and comments that there is no sedimentation break between the Quartzite Member and the Shell Limestone, and interprets the above observations only to indicate "a partial reworking of the unconsolidated Quartzite Member under high energy conditions". However, how secondary overgrowth around quartz grains can take place in an unconsolidated sediment without lithification and diagenesis, Bhatia does not explain. At least, the present author is not aware of such a miraculous process. Palaeoenvironment of deposition of Quartzite Member and the overlying Shell Limestone is rather similar, as both represent deposits of a shaol-sand bar/beach complex of a shallow tidal sea (Singh, 1979 c). Bhatia (1980), P. Singh (1980) also propose a shallow-water, high energy environment of deposition for Shell Limestone.

Though, accepting the palaeoenvironment of the Quartzite Member and Shell limestone as suggested by Singh (1979 c), Bhatia (1980) argues that he cannot accept Quartzite Member as Precambrian in age, while Shell Limestone is Cretaceous, as (according to Bhatia) it would be a strange coincidence that the two units of same depositional environment but widely different ages (one of Precambrian, and the other of Late Cretaceous age) overlie one above the other. However, to the present author it is more strange to accept two units of same environment and also the age (Cretaceous age) juxtaposed one above the other, while one is rich in fossils and the other is devoid of any fossils. Bhatia (1980) does not explain why the Quartzite Member (which according to him is also Late Cretaceous in age) does not contain any fossils ; while the overlying Shell Limestone is rich in fossils, when both are the product of deposition of similar environment.

Kumar and Dhaundiyal (1980) carried out detailed mapping in the Garhwal syncline and recognize an unconformity (local unconformity) between Quartzite Member (Phulchatti Quartzite and Shell Limestone (Manikot Shell Limestone). They observe that Krol sediments get "......attenuated in the south-western part of the Synform probably due to erosion and subsequent deposition of the upper Tal Manikot Shell Limestone in area between the Tal Nadi and west of Khoh river", which clearly suggests that Shell Limestone is a transgressive unit resting partly on the eroded Krol succession.

Kumar and Dhaundiyal (1980) describe that Shell Limestone occurs unconformably over different litho-stratigraphic units of the area, e.g......."the shell limestone rests unconformably over the Blaini in the Binj Nadi section due to pinching/erosion of the Krol....".

"An outcrop of shell limestone is seen along the left bank of the Binj Nadi unconformably overlying the Binj Formation...". "The Manikot Shell Limestone, however reappears south of Dhura and gain prominence eastwards, first overlying the Blaini, then Lower Krol in the Khoh river section west of Dogadda, Middle Krol south of Dogadda and overlies the Upper Krol south of Gajwar".

"Manikot Shell Limestone has been mapped on the south-western and eastern slopes of Shankarpur Hill in the Chandrabhaga Valley, west of Narendranagar, resting unconformably over the Blaini and/or Binj Formation, south of Duwadhar over the quartzite of the Saknidhar Formation......".

These field observations clearly indicate that the Shell Limestone is an independent transgressive unit occurring on the top of different rock units of Krol belt and Garhwal nappe ; hence cannot be considered as topmost unit of the Tal Formation. Hence, the contention of Bhargava (1979), Bhatia (1980) that the Shell Limestone occurs regularly over the Quartzite Member is not correct. These observations, along with the petrological studies of Singh (1979 b) in the Nilkanth area demand an independent status for the Shell Limestone unit (Nilkanth Formation) as suggested by Singh (1979 c).

To summarize, one can conclude that the Shell Limestone is a significant litho-stratigraphic unit mostly developed in Mussoorie-Garhwal area. This unit must be considered as an independent litho-stratigraphic unit (Nilkanth Formation), and not a part of the Tal succession. The present status of palaeontological data indicate that the age of Shell Limestone is most probably Late Cretaceous. Unfortunately, all the palaeontological studies available are based on grab samples. The succession of Shell Limestone is about 30 m thick and a study of closelyspaced samples in vertical section may help in determining the lower and upper age limits of the Shell Limestone. The extension of age of Shell Limestone into Palaeocene is being assigned mainly on the basis of presence of globorotalids, as determined in thin-sections. However, the differentiation and identification of globorotalids and *Globotruncana* in thin-sections is rather disputed, and the question whether the shell limestone is exclusively Late Cretaceous or partly extends into Lower Palaeocene is still an open question.

FOSSIL-BEARING HORIZONS OF EOCENE AGE

Late Palaeocene-Eocene fossil-bearing outcrops in the Krol belt are mostly referred to as Subathu sediments. These Subathu sediments occur as scattered outcrops of small and large dimensions in the southern part of the Krol belt, near the Main Boundary Fault. The Subathu sediments are best developed in Simla hills. Eastwards, there are extensive outcrops of these sediments in Mussoorie-Garhwal area. Outcrop of Subathu sediments are also known near Tanakpur.

Subathu sediments are well-developed in the Simla hills, where they occur as extensive units of supposedly autochthon resting unconformably over the Simla Slates or locally over Precambrian carbonate outcrops. There are also a number of outcrops of Subathu sediments in the so called tectonic 'windows', and also a number of outcrops lying over the Infra Krol or Blaini sediments of Krol belt supposedly as thrust sheets.

The Subathu sediments are made up of a number of lithologies complexly intermixed, and on the basis of foraminiferal fauna an Upper Palaeocene to Middle Eocene age has been given (Pant and Iqbaluddin, 1962 ; Mathur, 1969). Srikantia and Bhargava (1967) proposed the name Kakara Series for the lowermost part of the Subathu sediments belonging to the Late Palaeocene age.

Deposition of Subathu sediments in the Simla hills took place in a shallow sea, in the areas of shelf mud zone, tidal flats, and sand bars (Singh, 1978). The Subathu sediments in Simla hills grade upwards into Dagsai sediments, which has not yet yielded any definitive fauna. But, on the basis of primary sedimentary structures and trace fossils, Singh (1978) proposes that they represent deposits of an estuarine complex, mostly under marine influence. Dagsai sediments are overlain by the fluvial Kasauli sediments.

In Mussoorie-Garhwal region, Subathu sediments occur in patches, mostly overlying the Shell Limestone (Late Cretaceous in age) with an unconformable contact, making the youngest unit in the Krol belt ; and also in the windows, i.e. Bidhalna and Pharat windows, where they overlie the Simla Slates with an unconformable contact. Tewari and Singh (1976) discuss on the basis of foraminiferal assemblage that the Subathu sediments in Dogadda area range in age from Upper Palaeocene to Lower Eocene. Mathur (1977) studied the Subathu sediments overlying the Tal Formation in Garhwal area and also proposes a Upper Palaeocene to Lower Eocene age. The Subathu sediments in Garhwal area are not overlain by younger sediments, as is the case in Simla hills.

In Garhwal area, invariably the Subathu sediments overlie the Shell Limestone mostly with an unconformable contact ; though at places the contact seems to be gradational. However, there are many outcrops of Shell Limestone which are not overlain by Subathu sediments. Following explanation is proposed for the outcrops where Shell Limestone of Upper Cretaceous age exhibit apparently gradational contact with the overlying Subathu sediments :

During Late Cretaceous times Garhwal area represented an important depositional centre where extensive but thin cover of Shell Limestone was deposited in response to Late Cretaceous transgression. At the end of Cretaceous times the transgressive sea regressed leading to break in deposition of Shell Limestone. However, it seems that in a few localized pockets of Garhwal area water-bodies continued to exist causing sedimentation in Palaeocene. When in Late Palaeocene a renewed transgression took palse, a new phase of marine sedimentation started, continuing into Lower Eocene. It is in such areas that the sedimentation from Late Cretaceous into Eocene seems to be continuous, and the contact between Shell Limestone and Subathu sediments looks gradational.

Recently a fossiliferous outcrop has been recorded near Nainital by J. N. Dhaundiyal which seems to be Eocene in age (Anonym 1978). Bhandari and Agarwal (1967) report a Subathu outcrop near Tanakpur yielding foraminifers of Lower Eocene age.

In the Krol belt the Subathu sediments occur in two tectono-stratigraphic positions, namely in the autochthonous zone upon which Krol belt is supposed to have thrusted, and on the Krol belt sediments, which are supposed to have been deposited further north before being thrusted southwards. However, it is interesting to note that the Subathu sediments of the so called autochthon and thrusted sheet are aligned within a narrow zone, and are rather similar in facies and age.

The traditional model of Krol belt evolution visualizes that the Eocene transgression was rather extensive and deposited Subathu sediments over various lithounits of Lesser Himalaya, and it is in the Middle Eocene that Krol belt was thrusted southwards, riding over the Simla Slates with a Subathu sediment cover. If this model is true then there should have been facies differences between the Subathu sediments occurring on the autochthon and in the Krol belt. Further, the Subathu sediments must have been more extensive in the autochthon zone with records also in northerly part of Lesser Himalaya. On the contrary, almost all the Subathu outcrops are restricted within the southern part of the Lesser Himalaya and there are no facies or faunal differences in the Subathu sediments of autochthon and those of the Krol belt. This supports the postulation of existence of a weak zone-Subathu-Dogadda zone along which transgression took place (Singh, 1976, 1979 a), and demands that the Krol belt was not thrusted during Eocene times.

Ranga Rao (1968, 1970) argued in favour of an autochthonous Krol belt, contrary to the postulation of Auden (1934, 1937) that Krol belt is allochthon. The present author is of the opinion that the Krol belt has remained in its present position at least since Permian time, and hence qualifies to be an autochthon.

FOSSIL RECORD FROM OTHER TECTONO-STRATIGRAPHIC UNITS ASSOCIATED WITH KROL BELT

The Krol belt is considered to be a large thrust sheet which rests over autochthonous units of Lesser Himalaya. The more important tectono-stratigraphic units which lie in juxtaposition with Krol belt are Shali belt, Deoban belt, Garhwal Group, Chamoli-Tejam belt which are often grouped together and referred as Deoban-Garhwal Group sediments or Shali-Deoban belt and are considered to represent autochthon of Lesser Himalaya.

Carbonate units of Shali-Deoban belt often exhibit well-developed stromatolites of Late Precambrian age (see Valdiya, 1969). Because of the autochthonous position and the record of Late Precambrian stromatolites in the Shali-Deoban belt, many workers agree upon its late Precambrian age. However, others correlate the Krol belt with the Shali-Deoban belt and assign a Palaeozoic-Mesozoic age to the entire Lesser Himalaya (see Auden, 1934 ; Fuchs, 1967, Sharma, 1976). However, fossil reports from the Shali-Deoban belt are far more rare and vague than in the Krol belt. Kumar and Singh (1979) report Precambrian microbiota from the Deoban carbonates of Chakrata area ; while Raha (1980) describes Proterozoic microbiota from the Jammu Limestone which also exhibits Proterozoic stromatolites. Nautiyal (1980) describes algal remains (filamentous, spheroidal) of cyanophycean affinity from the Gangolihat dolomite.

Tewari (1975) and Tewari *et al.* (1976) reported a few scolecodonts of Devonian affinity from the sandy limestone of Bijni unit of Shanker and Ganeasn (1973) belonging to Garhwal nappe. Except for sketches, no litholog, photographs, or description of the forms are given. No other Devonian faunal elements are recorded, thereby further diluting the significance of this find.

Agarwal (1974) described a few bryozoans from the phyllitic slates of Garhwal Group and suggested a Ordovician-Silurian age. However, the photographs do not show any resemblance with the bryozoans and are most probably iron-oxide encrustations on slicken slides within the phyllitic layers. Banerjee and Rawat (1978) have recorded stromatolite *Kussiella* from the carbonate rocks immediately overlying the phyllite slates near Rudraprayag (Garhwal Group) and assigned a Late Precambrian age to these rocks.

Jutogh Formation makes the part of a thrust sheet on the Krol belt, and Sah *et al.* (1977) recorded Precambrian-Cambrian palynomorphs from it and assigned a Cambrian age. Sah *et al.* (1977) state that this assemblage is comparable to the acritarchs recorded from the Calc Zone of Chamoli by Prakash (1974). However, the illustrations of Sah *et al.* (1977) are of long-ranging forms, and they are invariably found in most of the macerates of younger sediments and are considered as contamination (pers. commun. Dr. K. P. Jain and Dr. Maheshwari, B.S.I.P., Lucknow).

Thus, there is no reliable fossil record from the Shali-Deoban belt ; though the carbonate sequences are essentially algal mat succession which under suitable conditions show development of stromatolites of Late Precambrian affinity.

Rastogi (1973) reports a solitary specimen of bryozoa *Polypora* cf. *ornata* from the Shali belt. No litholog, or extent of fossil-bearing horizon is given. If this report gets supplemented by more specimens from the locality, it would represent the westernmost occurrence of Permian fossiliferous outcrop within the Lesser Himalaya. At present, this report can only be considered as a tentative record without any biostratigraphic significance.

Raina and Dhungrakoti (1975) report a Palaeozoic fossil-bearing outcrop in the Deoban Group sediments, east of Nainital. This outcrop is considered here as a manifestation of Permian transgression in the Subathu-Dogadda zone of Lesser Himalaya.

There are a number of outcrops of Subathu sediments on the Shali-Deoban succession in Himachal Pradesh related to the Eocene transgression.

MARINE TRANSGRESSIONS IN THE LESSER HIMALAYA

Singh (1976, 1979 a) proposed that the Central and Lesser Himalaya represent northern continuation of Indian shield and represent sequences of essentially Precambrian age, where a weak zone ; namely Subathu-Dogadda zone existed in the Precambrian basement of Lesser Himalaya. The detached fossil-bearing outcrops of Carboniferous-Permian, Jurassic Cretaceous and Eocene sediments are located along this zone and represent marine transgressions of these three ages. In the light of new palaeontological data, ages of these three transgressions are modified as Early Permian, Late Cretaceous and Late Palaeocene-Eocene.

PERMIAN TRANSGRESSION

Permian fossil-bearing horizons are well-known from the Lesser Himalayan zone of Eastern Himalaya, where both marine fauna-bearing and land flora-bearing Permian outcrops are present within a narrow belt often referred to as Gondwana belt in Eastern Himalaya. Jain and Thakur (1975) provide a review of the Gondwana belt of Eastern Himalaya ; while Acharyya and Shah (1975) provides a collected information on the Permian fossil-bearing horizons in the Lesser Himalaya. This Gondwana belt is the eastern extension of the Subathu-Dogadda zone of Singh (1976, 1979 a).

The record of Permian deposition in the Lesser Himalaya is either in the form of marine fossil-bearing outcrops of Lower Permian, or in the form of fresh-water coal-bearing Gondwana-type sediments yielding flora of Lower Permian affinity ; though sometimes both these types are closely associated. The lowestmost unit of such successions is often of a boulder slate character, the most well-known being the Rangit Boulder Slate of Sikkim. Contrary to the traditional view of thrusted contact of Gondwana sediments, Banerji *et al.* (1980) have recently proposed that the Rangit valley Gondwana represent deposits in down-faulted basins within an older metamorphosed basement. It is here proposed that the Gondwana belt sequences of Lesser Himalaya represent down-faulted basins within the Subathu-Dogadda zone, probably a rift-valley like zone.

Further westward, Pushkar Singh (1973) records occurrences of Palaeozoic fossil-bearing outcrops in the Lesser Himalaya of Nepal and Bhutan containing ill-preserved brachiopods and bryozoans. Most probably these outcrops represent westward continuity of Permian outcrops.

Recently, Tewari (1979) records a Permian fauna-bearing outcrop ; while Tewari and Singh (1979) record Permian land flora-bearing outcrop in the Nainital area. This land flora-bearing Permian outcrop is the westernmost record of Gondwana belt in Lesser Himalaya. The Palaeozoic fossil-bearing outcrop of Raina and Dhungrakoti (1975) in the vicinity of Nainital is probably also a record of Permian outcrop.

Boulder Slate Sequence of Garhwal area is the western extension of this Permian fossil-bearing belt.

The record of a single specimen of bryozoa from the Shali belt (Rastogi, 1973) may be regarded westernmost Permian fossil outcrop in the Subathu Dogadda-zone. However, as this report is based upon only one specimen, this occurrence has to be treated only tentative.

All these Permian fossil records clearly suggest that they are related to a single marine transgression in the Subathu Dogadda-zone.

The marine Permian fauna from different outcrops of Gondwana belt and from the Boulder Slate Sequence compares well and seems to be of Early Permian age (see also Acharyya and Shah, 1975).

Permian fauna-bearing outcrops occur at four localities in the Peninsular shield, namely Badhaura, Umaria, Manendragarh, and Rajhara occurring along the Narbada-Son lineament, a weak zone along which Permian transgression took place (see also Shah and Sastry, 1975). Although, Shah and Sastry (1975) are of the opinion that the sea, depositing sediments in Rajhara and Manendragarh area entered along the Son lineament, while the sea depositing Umaria and Badhaura sediments entered along the Narbada valley and the area between Umaria and Manendragarh were separated by a high land ; to the present author it seems more probable that the transgressive sea in the Son valley and Narbada valley were continuous.

Waterhouse and Gupta (1979) discuss that the fauna of Umaria marine bed, Boulder Slate Sequence of Garhwal is similar in age and composition to the Lower Permian fauna recorded from the northern slopes of Mt. Everest (belonging to Tethys=Tibetan zone), demonstrating a close geographic relationship between three regions, and similar climatic regime. According to these authors this implies a relatively narrow latitudinal spread, within 5° to 10°. This suggests that the original latitudinal spread have not been reduced by more than 1° to 3°, if at all.

These palaeontological observations demand that there cannot have been any significant crustal shortening between Narbada valley and Tethys zone since Permian times. And many of the large-scale nappe structures, etc., in the Lesser and Central Himalaya which require a significant crustal shortening in these areas are either pre-Permian in age (probably Precambrian), or no nappes at all. This supports the contention of the author (Singh, 1976 ; 1979) that the Lesser and Central Himalaya represent northern continuation of Indian Precambrian shield and that there is a close relationship between the transgressions in the Narbada valley and Subathu-Dogadda zone. This also rules out the possibility of underthrusting of the Indian shield into the Lesser Himalaya, as visualized by some workers.

CRETACEOUS TRANSGRESSION

The Late Cretaceous transgression in the Lesser Himalaya is well-documented by the presence of a Shell Limestone, showing Late Cretaceous fossils, in the Mussoorie-Garhwal region. Recent finding of probable Cretaceous fossil-bearing outcrop near Nainital (Anonym. 1979) supports its eastward extension. The record of fossiliferous band in the Lesser Himalaya of Nepal containing lumachelle, and Mesozoic molluscs (Fuchs and Frank, 1970) is probably the easternmost record of the Late Cretaceous transgression. Late Cretaceous fossil-bearing outcrops are not yet recorded west of Mussoorie.

It is interesting to note that P. Singh (1980) points out that the Shell Limestone of Mussoorie-Garhwal and the Coralline Limestone (Bagh beds) in Narbada valley are coeval and characterized by the same bryozoa genus, i.e. *Ceriocava nilkanthi*. This observation supports the postulation of Singh (1976, 1979 a) that the Cretaceous transgression in the Narbada valley and the Subathu-Dogadda zone of Lesser Himalaya are closely related.

PALAEOCENE-EOCENE TRANSGRESSION

Late Palaeocene-Eocene marine fossil-bearing outcrops (mostly known as Subathu sediments) occur in well-developed successions in the western part of the Lesser Himalaya, especially the Jammu and Simla hills, where they occur mainly along a narrow belt near the Main Boundary Fault. Subathu sediments of Jammu area are discussed by P. Singh (1973), who gives Lower Eocene to early Middle Eocene age to these sediments. However, the lowermost part of the succession, represented by lateritic beds and lignite intercalations can be of Late Palaeocene age. Going eastward another important occurrence of Subathu sediments is in the Garhwal area. Further eastward, probable Subathu sediments seem to be present near Nainital, and an outcrop of Subathu sediments near Tanakpur. There are outcrops of Palaeogene sediments in the Lesser Himalaya of Nepal and Bhutan containing *Nummulites* fauna, which can be assigned an Upper Palaeocene to Lower Eocene age (Pushkar Singh, 1973). Subathu outcrops in Lesser Himalaya of Nepal are also reported by Auden (1970) and RangaRao (1970).

All these Subathu outcrops are rather similar faunistically and also in age (mostly Late Palaeocene-Lower Eocene) and occur within the narrow Subathu-Dogadda zone and represent product of deposition of a single transgression within this zone. Until recently no Subathu outcrops were known east of Bhutan. However, recently Jain and Dutta (1978) record marine dinoflagellate assemblage of Eocene age from a sample of limestone from the limestone patches, occurring near the contact between Siwalik and Gondwana rocks in Siang district of Arunachal Pradesh. The setting of occurrence of this Eocene outcrop is similar to those of Subathu sediments in the western part of Lesser Himalaya. Tripathi et al. (1979) record a fossiliferous Eocene sequence from Dihang valley, Siang district, Arunachal Pradesh within the Gondwana belt of Lesser Himalaya. The sediments have yielded a characteristic foraminiferal assemblage of Laki (Lower Eocene) age. These reports of marine Eocene from the Arunachal Pradesh opens up the possibility that the marine Eocene outcrops are present throughout the Subathu-Dogadda zone from the westernmost to the easternmost part of the Lesser Himalaya.

PALAEOGEOGRAPHIC RECONSTRUCTION

The Subathu-Dogadda zone containing fossiliferous outcrops represents a narrow belt running near the southern margin of Lesser Himalaya following roughly the Himalayan strike and within a few kilometers of Main Boundary Fault. It is proposed here, that the Main Boundary Fault is a manifestation of the earlier Subathu-Dogadda weak zone, a rift-valley like zone.

It seems that during the initial stages of break up of the Pangea or Super-Gondwana continent, the Indian shield was subjected to many tectonic stresses, causing cracking and developmant of rift-valley like structures in the continental crust of the Indian shield during Late Carboniferous-Early Permian times which resulted into several well-defined zones of fluvial sedimentation of Gondwana age, e. g. Domodar valley zone, Mahanadi valley zone, Godavari valley zone etc. Simultaneously, two weak zones, namely, Narbada-Son valley in Peninsular part of the Indian shield, and Subathu-Dogadda zone in the Himalayan part of the Indian shield were activated where in down faulted basins fluvial sedimentation took place and they also witnessed Early Permian marine transgression. Another manifestation of stresses in the crust of northern part of Indian shield is in the form of volcanic activity of Lower Permian age in Kashmir (Agglomeratic Slates) and in Arunachal Pradesh (Abor Volcanics). It is already discussed that the Permian fauna of Narbada-Son valley, Subathu-Dogadda zone of Lesser Himalaya, and Tethys Himalaya are very similar. Thus, all the three areas seem to have had been interconnected (Fig. 1).

It seems probable, that the Subathu-Dogadda zone was continuous all along the Lesser Himalaya, connected in the west with the Salt Range-Kashmir sea and Tethys, and with the open sea beyond India in the east. At the same time the Permian sea of Narbada-Son valley was connected to the Subathu-Dogadda zone somewhere near Sikkim or may be further east ; while in the west the Narbada-Son valley was connected to the Salt Range through Rajasthan. It is in the small down-faulted blocks within the Subathu-Dogadda zone (prominently in the Eastern Himalaya) that the freshwater Lower Gondwana sediments were deposited (see Banerji et. al. 1980).

After the regression of sea during Middle Permian from both the Narbada-Son valley, and Subathu-Dogadda zone, another transgression affected these two areas during Late Cretaceous. The Cretaceous outcrops until today are known only in the Narbada valley, and not in the Son valley, and only in the western sector of Subathu-Dogadda zone and not in the eastern extension. The connection of Narbada valley with the Subathu-Dogadda zone through west is likely ; although, whether Cretaceous transgression extended into Son valley and had connection with Subathu-Dogadda zone near Sikkim and whether Subathu-Dogadda zone in Late Cretaceous had connection with the Assam shelf in the east are still open questions.

The third trangression of the sea in these two areas was during Late Palaeocene and continued most probably until early Middle Eocene. This Palaeogene transgression was meagre in the Narbada-Son valley and seems to have affected only the westernmost part of the Narbada valley ; while in the Subathu-Dogadda zone this transgression was more extensive. However, the Palaeocene-Eocene sediments of the Subathu-Dogadda zone become thin and less extensive going eastwards. Definite Palaeocene-Eocene outcrops are present from Jammu until in Nepal. However, the record of marine Eocene fossils in the Arunachal Pradesh by Jain and Dutta (1978) and Tripathi et al. (1979) opens the possibility that the Eocene sea of the Subathu-Dogadda zone had connection with the Assam shelf in the east.

The question of width of transgressive sea in the Lesser Himalaya can be debated. The presence of fossil-bearing outcrops within a narrow zone points to a narrow sea-way ; although it is possible that the sea was rather broad, but the sequences are preserved only within a narrow zone.

ACKNOWLEDGEMENT

This paper is outcome of extensive discussions with numerous fellow workers, engaged in the Himalaya or other areas ; many of them even not sharing the present author's views.

Special mention be made of Dr. S. Kumar, Dr. S. K. Singh, Dr. R. P. Sharma, and Dr. M. P. Singh of the Geology Department, Lucknow University, and Dr. D. K. Bhatt, G. S. I., Lucknow for extended discussions and patient listening of author's point of view and comments. Discussions with Dr. H. K. Maheshwari and Dr. K. P. Jain, B. S. I. P., Lucknow on the palaeobotanical records from Lesser Himalaya were very useful. Thanks are expressed to Dr. S. A. Jafar, University of Hyderabad for his comments on nannofossil reports from Krol sediments. Dr. D. M. Banerjee, Delhi University offered valuable suggestions and made a critical reading of the manuscript. However, it may be emphasized that the views expressed in this paper are entirely the author's responsibility.

REFERENCES

ACHARYYA, S. K. and SHAH, S. C. 1975. Biostratigraphy of the marine fauna associated with the diamictites of the Himalayas. *Bull. Ind. Geol. Assoc.* **8** : 9-23.

AGARWAL, N. C. 1974. Discovery of bryozoan fossils in the calcareous horizon of Garhwal Group, Pauri-Garhwal district. *Him. Geol.* **4** : 600-618.

AHLUWALIA, A. D. 1978. Discovery of Upper Palaeozoic fossils (Foraminifera of Porifera?) from Mussoorie Phosphorite, Lower Tal Formation, Kumaun Lower Himalaya, India. *Contr. Him. Geol.* **1** : 20-24. Hindustan Publishing Corporation, Delhi.

AHLUWALIA, A. D. 1980. Age of Lower Tal Phosphorite, the present status of its fossils and their stratigraphic relevance (ms.)

ANONYMOUS, 1978. Fossiliferous horizon in Nainital. *News, Geol. Surv. Ind.* **9** (4) : 5.

ANONYMOUS, 1979. Structural and stratigraphic setting of the 'Shankarpur Formation' and the 'Tal Shell-Limestone', U. P., Himalaya. *News, Geol. Surv. Ind.* **10** (6) : 2.

AUDEN, J. B. 1934. The geology of the Krol belt. *Rec. Geol. Surv. India.* **57** : 357-454.

AUDEN, J. B. 1937. The structure of the Himalayas in Garhwal. *Rec. Geol. Surv. India.* **71** : 407-433.

AUDEN, J. B. 1970. Discussion "On the Krol Nappe hypothesis" *J. Geol. Soc. India.* **11** : 288-294.

AWASTHI, N. 1970. Some aspects of the Krol Formation of the Himalaya, India. *Contr. Mineral. and Petrol.* **28** : 192-220.

BAGATI, T. N. and KHARKWAL, A. D. 1979. Microfacies analysis, environment of deposition and diagenesis of the carbonate rocks of the Krol Formation, Simla Himalaya. *Bull. Ind. Geol. Assoc.* **12** : 43-62.

BANERJEE, D. M. and NARAIN, H. J. 1976. Trace fossils in the Lower Tal Formation of Mussoorie and their environmental significance. *Jour. Sed. Petrol.* **46** : 234-239.

BANERJEE, D. M. and RAWAT 1778. Stromatolitic structures in Lameri, a member of Garhwal Group near Rudraprayag, Garhwal Himalaya, U.P. *Workshop on stromatolites, Udaipur (Preprint)*.

BANERJEE, P. K., GUHA, P. K. and DHIMAN, L. C. 1980. Inverted metamorphism in the Sikkim-Darjeeling Himalaya, India. *Jour. Geol. Soc. India.* **21** : 330-342.

BHANDARI, L. L. and AGARWAL, G. C. 1967. Eocene (Subathu series) of the Himalayan foothills of North India. *Pub. Centre Adv. Study Geol. Punjab Univ.* **3** : 57-77.

BHARGAVA, A. K. and SINGH, I. B. 1980. Some palaeo-environmental observations on the Infra Krol Formation, Lesser Himalaya. *Jour. Palaeont. Soc. India.* **25** : 26-32.

BHARGAVA, O. N. 1972a. A reinterpretation of the Krol Belt. *Him. Geol.* **2** : 47-81.

BHARGAVA, O. N. 1972b. A note on structures resembling molds of tadpole nests in Upper Jurassic Tal Formation, Simla Himalaya, India. *Jour. Sed. Petrol.* **42** : 236-238.

BHARGAVA, O. N. 1976. Geology of the Krol belt and associated formations : a reappraisal. *Mem. Geol. Surv. India.* **106** (I): 168-234.

BHARGAVA, O. N. 1979. Lithostratigraphic classification of the Blaini, Infra Krol, Krol and Tal Formations—a review. *Jour. Geol. Soc. India.* **20** : 7-16.

BHATIA, S. B. 1975. The anatomy of the Blainis. *Bull. Ind. Geol. Assoc.* **8** : 243-258.

BHATIA, S. B. 1980. The Tal Tangle. In : *Stratigraphy and Correlations of Lesser Himalayan Formations.* 79-96. Hindustan Publishing Corporation (India) Delhi.

BHATT, D. K. and SINGH, M. P. 1980. A note on the fauna of Artinskian (Lower Permian) affinity from Garhwal synform, Lesser Himalaya. *Jour. Pal. Soc. India* (in press).

CHATURVEDI, R. S. and TALENT, J. A. 1971. A preliminary note on the discovery of richly fossiliferous Permian rocks in Garhwal Himalayas in Lansdowne area. *Second seminar on Him. Geol. W. I. H. G.* (Special report).

DHAUNDIYAL, J. N. and KUMAR, G. 1976. On the geology of part of the Garhwal Syncline, Tehri Garhwal and Garhwal districts, Uttar Pradesh. *Proc.* 125th *Ann. Celebr., G. S. I. Symposium, Lucknow.*

FUCHS, G. 1967. Zum Bau des Himalayas. *Denkschr. Akad. Wiss.*

Wien. Math. Nat. Kl. **113** : 1-211.

FUCHS, G. and FRANK, W. 1970. The geology of West Nepal between the Rivers Kali Gandak and Thulo Bheri. *Jahrbuch der Geol. Bundesanstalt, Sonderband.* **18** : 1-103.

FUCHS, G. and SINHA, A. K. 1974. On the geology of the Nainital (Kumaon Himalaya). *Him. Geol.* **4** : 563-580.

GANESAN, T. M. 1971. Note on the first record of fenestellid bryozoa in the 'Volcanic Breccia' of Garhwal. *Ind. Min.* **25** : 257.

GANESAN, T. M. 1972. Fenestellid bryozoa from the Boulder Slate Sequence of Garhwal. *Him. Geol.* **2** : 431-451.

GANSSER, A. 1964. *Geology of the Himalayas.* Inter Science, London. 289 p.

GHOSH, A. K. and SRIVASTAVA, S. K. 1962. Microfloristic evidence on the age of Krol bed and associated formations. *Proc. Nat. Inst. Sci.* **28A** : 710-717.

GUNDU RAO, C. 1970. A note on the oolites in the Krol Series and their age significance. *Publ. Centr. Adv. Stud. Geol.* **7** : 127-129.

HEIM, A. and GANSSER, A. 1939. The Central Himalayas : Geological observations of the expedition of 1936. *Mem. Soc. Helv. Sci. Nat.* **73** (1) : 245 pp.

JAIN, A. K. and THAKUR. V. C. 1975. Stratigraphy and tectonic significance of the Eastern Himalayan Gondwana Belt with special reference to the Permo-carboniferous Rangit Pebble Slate. *Bull. Ind. Geol. Assoc.* **8** : 50-70.

JAIN, K. P. and DUTTA, S. K. 1978. Lower Tertiary dinoflagellates, spores, and pollen grains from Siang district, Arunachal Pradesh. *Jour. Pal Soc. India.* **21 & 22** : 106-111.

KALIA, P. 1974. Upper Permian fusulinids from Garhwal Himalaya. *Proc. 2nd Indian Colloq. Micropalaeont. and Stratigraphy, Lucknow University.* 107-110.

KALIA, P. 1976. Fossil algae from the Upper Tal Shell Limestone and their age implication. *Jour. Pal. Soc. India.* **19** : 41-47.

KHARKWAL, A. D. and BAGATI, T. N. 1974. Diagenetic and epidiagenetic silicification in carbonate rocks of the Krol Formation. *Bull. Ind. Geol. Assoc.* **7** : 35-41.

KHARKWAL, A. D. and BAGATI, T. N. 1975. Mineralogy and origin of the red shales of the Krol Formation. *Him. Geol.* **5** : 469-478.

KHARKWAL, A. D. and BAGATI, T. N. 1976. Zoned carbonate crystals in the Krol Formation of the Simla Himalaya, India. *N. Jb. Miner. Mn. H.* **4** : 162-169.

KRISHNAN, M. S. 1968. *The Geology of India and Burma..* Higginbotham, Madras. 536 p.

KUMAR, G. and DHAUNDIYAL, J. N. 1980. On the stratigraphic position of the Tal Formation, Garhwal Synform, Garhwal and Tehri Garhwal districts, Uttar Pradesh. *Jour. Pal. Soc. India.* **23& 24** : 58-66.

KUMAR, A. 1980. A note on the new forms of stromatolites and trace fossils from Nainital area, Kumaun Himalaya, India. *Geophytology.* **10** : 265-266.

KUMAR, S. 1978a. Some foraminifera from the Krol Formation of Simla Himalaya. *Contr. Him. Geol.* **1** : 92-96.

KUMAR, S. 1978b. Calcareous algae from the Krol Formation of Himalaya. *Ind. Jour. Earth Sciences.* **6** : 19-23.

KUMAR, S. and SINGH, S. N. 1979. Discovery of micro-organisms from the bedded cherts of the Deoban Limestone (Late Precambrian), Lesser Himalaya, Uttar Pradesh. *Curr. Sci.* **48** : 209-211.

LAKHANPAL, R. N., SAH, S. C. D. and DUBE, S. N. 1958. Further observations on plant microfossils from a carboniferous shale (Krols) near Nainital with a discussion on the age of the bed. *Palaeobotanist.* **7** : 111-120.

MAHESHWARI, H. K. 1981. Mesozoic palaeobotany of the Himalayas ; a critique. *Palaeobotanist* (in Press).

MAITHANI, J. B. P., 1972. A study of the molluscan fauna from the Tal Formation (Garhwal) and its significance in correlation. *Him. Geol.* **2** : 239-251.

MATHUR, N. S. 1969. Biostratigraphy of the Subathu Beds (Eocene), Simla Hills. Unpublished Ph. D. Thesis, Panjab University, Chandigarh.

MATHUR, N. S. 1977. Age of the Tal and Subathu formations in the Garhwal region, Uttar Pradesh, India. *Bull. Ind. Geol. Assoc.* **10** : 21-27.

MATHUR, N. S. and SAH, S. C. D. 1980. Palaeontological evidence on the presence of Blaini-Infra Krol transition bed at Gainthia (Nainital) Kumaun Himalaya. *Him. Geol.* **8** (2) : 1034-1041.

MEDLICOTT, H. B. 1964. On the geological structure and relations of southern portion of the Himalayan ranges between the river Ganges and Ravee. *Mem. Geol. Surv. India.* **3** : 1-212.

MEHROTRA, P. C., PAL, A. K., BHATT, D. K., and ALI, K. N. 1976. Discovery of fossil algae from the Singtali Limestone and its bearing on the tectonic set up of the Garhwal nappe. *Geophytology.* **6** : 133-149.

MIDDLEMISS, C. S. 1885. A fossiliferous series in the Lower Himalaya in Garhwal. *Rec. Geol. Surv. India.* **18** : 73-77.

MIDDLEMISS, C. S. 1887. Physical geology of West British Garhwal with notes on the route traverses through Jaunsar-Bawar and Tehri-Garhwal. *Rec. Geol. Surv. India.* **20** : 26-40.

MITHAL, R. S. and CHATURVEDI, R. S. 1972. Possible algal structures in the Upper Krol Limestones of Mussoorie area, Uttar Pradesh. *Geol. Surv. India, Misc. Publ.* **15** : 265-268.

MOORE, R. C. 1969. Treatise on Invertebrate Palaeontology, Part N (Volume I (of 3). Mollusca 6. Bivalvia.

NAUTIYAL, A. C. 1978. Discovery of the Cyanophycean algal remains and microplanktons in the Late Precambrian schistose phyllites and its bearing on the age of the Amri Unit, Garhwal Himalaya, India. *Curr. Sci.* **47** : 295-299.

NAUTIYAL, A. C. 1979. The organic remains of the Garhwal Himalayan argillaceous sequence (Late Precambrian). *Ind. Jour. Earth Sciences.* **6** : 24-31.

NAUTIYAL, A. C. 1980. Cyanophycean remains and Paleoecology of the Precambrian Gangolihat dolomites Formation of Kumaon Himalaya. *Indian Jour. Earth Sci.* **7** : 1-11.

PAL, D. AND MERH, S. S. 1974. Stratigraphy and structure of the Nainital area in Kumaon Himalaya. *Him. Geol.* 4 : 547-562.

PANT, S. C. AND IQBALUDDIN, 1962. Note on the larger foraminifera from the Subathu beds. *Ind. Miner.* **16** : 423.

PATWARDHAN, A. M. 1978. First Moravamminids from the Himalaya. *Nat. Acad. Sci. Letters.* **1** : 7-8.

PRAKASH, G. 1974. Discovery of acritarchs and other organic remains in the carbonate rocks of the Lesser Himalaya, U. P. *Publ. Centr. Adv. Study Geol. Chandigarh.* **10** : 85-95.

PRASAD, A. K. AND BHATIA, M. R. 1975. Fossil tracheids and other microfossils from the Blaini tillite horizon, Simla hills, India. *Bull. Ind. Geol. Assoc.* **8** : 191-195.

RAHA, P. K. 1972. Algal stromatolites from the Krol Formation of the Mussoorie syncline, Uttar Pradesh. *Palaeobotanist* **21** : 227-230.

RAHA, P. K. 1980. Proterozoic microbiota from stromatolitic black chert of Jammu Limestone, Udhampur district, Jammu and Kashmir, India. *Jour. Geol. Soc. India.* **21** : 572-574.

RAHA, P. K. AND GURURAJ, M. N. 1970. A note on occurrence of algal (Stromatolitic) structures in the phosphatic limestones of the Tal Formation of Mussoorie syncline near Mussoorie, U. P. *Indian Minerals.* **24** : 396-399.

RAINA, B. N. AND DUNGRAKOTI, B. D. 1975. Geology of the area between Nainital and Champawat in Kumaon Himalaya, U. P. *Him. Geol.* **5** : 1-27.

RAINA, B. N. AND KRISHNASWAMY, V. S. 1976. A review of recent geological work in the western section of the Himalaya. *Him. Geol. Seminar, New Delhi.* 35 p.

RANGA RAO, A. 1968. On the Krol Nappe hypothesis. *Jour. Geol. Soc. India.* **9** : 153-156.

RANGA, RAO, A. 1970. Author's reply to discussion by J. B. Auden on the paper "On the Krol nappe hypothesis". *Jour. Geol. Soc. India.* **11** : 295-302.

RASTOGI, S. P. 1973. A note on the occurrence of a fenestellid bryozoa in the Lower Limestone Unit of the Shali Formation. *Ind. Min.* **27** : 88-91.

REINECK, H. E. (Ed.) 1970. Das Watt, Ablagerungs-and Lebensraum, Kramer, Frankfurt am Main. 142 p.

REINECK, H. E. AND SINGH, I. B., 1980. *Depositional Sedimentary Environments.* 2nd Edition, Springer verlag, Berlin. 549 pp.

RUPKE, J. 1968. Note on the Blaini Boulder Bed of Tehri Garhwal, Kumaon Himalayas. *Jour. Geol. Soc. India.* **9** : 131-133.

SAH, S. C. D., MAITHY, P. K. AND BHARGAVA, O. N. 1977. Some significant palynomorphs B Member of the Jutogh Formation of Simla hills. *Jour. Geol. Soc. India.* **18** : 139-145.

SAH, S. C. D., VENKATACHALA, B. S. AND LAKHANPAL, R. N. 1968 Palynological evidences on the age of the Krol. *Publ. Centr. Adv. Stud. Geol. Panjab Univ.* **5** : 115-120.

SAKLANI, P. S., KHANDURI, H. C. AND SINGH, S. 1977. A reappraisal of geology of a part of Mussoorie syncline around Satengal, Garhwal Himalaya. *Chayanica Geol.* **3** : 95-103.

SHAH, D. K. AND MERH, S. S. 1978. Structural geology and stratigraphy of Bhimtal-Bhowali area in Kumaun Himalaya—a reinterpretation. *Jour. Geol. Soc. India.* **19** : 91-105.

SHAH, S. C. AND SASTRY, M. V. A. 1975. Significance of Early Permian marine faunas of Peninsular India. 391-395.

SHANKER, R., DHAUNDIYAL, J. N. AND KAPOOR, H. M. 1973. The fossiliferous bed (Boulder Slate Member) of Garhwal syncline. *Jour. Pal. Soc. India.* **17** : 50-54.

SHANKER, R. AND GANESAN, T. M. 1973. A note on the Garhwal Nappe. *Him. Geol.* **3** : 72-82.

SHARMA, K. K. 1976. On the occurrence of stromatolitic limestones in Lower Tal Formation of Pari Tibba, Mussoorie (Uttar Pradesh) and their paleoecological significance. *Chayanica Geologica.* **2** : 91-99.

SHARMA, V. P. 1976. Geology of the Kulu-Rampur belt, Himachal Pradesh, *Mem. Geol. Surv. India.* **106** (2) : 235-407.

SINGH, I. B. 1976. Evolution of Himalayas in the light of marine transgressions in the Peninsular and Extra-peninsular India. *Proc. 125th Ann. Celebr. G. S. I. Symposium, Lucknow* (Preprint).

SINGH, I. B. 1978. On some sedimentological and palaeoecological aspects of Subathu-Dagsai-Kasauli succession of Simla hills. *Jour. Pal. Soc. India.* **21** & **22** : 19-28.

SINGH, I. B. 1979a. Some thoughts on the evolution of Himalaya and the northern limit of the Indian shield. *Geol. Rdsch.* **68** : 342-350.

SINGH, I. B. 1979b. Recognition of a sedimentological break between Quartzite and Limestone Members of the Tal Formation, Lesser Himalaya, India. *Curr. Sci.*. **48** : 206-208.

SINGH, I. B. 1979c. Environment and age of the Tal Formation of Mussoorie and Nilkanth areas of Garhwal Himalaya. *Jour. Geol. Soc. India.* **20** : 214-225.

SINGH, I. B. 1979d. Author's reply to Comments on—Environment and age of the Tal Formation of Mussoorie and Nilkanth areas of Garhwal Himalaya. *Jour. Geol. Soc. India.* **20** : 619-623.

SINGH, I. B. 1980a. Sedimentological evolution of the Krol belt sediments. *Him. Geol.* **8** (2) : 657-683.

SINGH, I. B. 1980b. Precambrian sedimentary sequences of India : their peculiarities and comparison with modern sediments. *Precambrian Research.* **12** : 411-436.

SINGH, I. B. 1980c. On the depositional environment of the Nagthat Quartzite,Lesser Himalaya. *Jour. Geol. Soc. India* (inpress).

SINGH, I. B. AND MERAJUDDIN, 1980. Some sedimentological observations on the Chhaosa Formation (Simla Slates) in the Simla hills. *Him. Geol.* **8** (2) : 684-702.

SINGH, I. B. AND RAI, V. 1977. On the occurrence of stromatolites in the Krol Formation of Nainital area and its implications on the age of Krol Formation. *Curr. Sci.* **46** : 736-738.

SINGH, I. B. AND RAI, V. 1980. Some observations on the depositonal environment of the Krol Formation in Nainital area. *Him. Geol.* **8**(2) : 633-656.

SINGH, I. B., RAI, V. AND BHARGAVA, A. K. 1980. Some observations on the sedimentology of the Krol succession of Mussoorie area, Uttar Pradesh. *Jour. Geol. Soc. India.* **21** : 232-238.

SINGH, I. B. AND TANGRI, A. K. 1976. Some observations on the sedimentology of the Blaini Formation, Himachal and U. P. Himalayas. *Proc. 125th Ann. Celebr. G. S. I. Symposium, Lucknow.* (Preprint)

SINGH, M. P., MEHROTRA, P. C. AND KACKER, A. K. 1979. Discovery of Permian fossils from Tal nadi section of the Garhwal Himalaya, U. P. *Curr. Sci.* **48** : 348-349.

SINGH, P. 1973. Geology of the Subathu Group of Jammu and Kashmir State. *Him. Geol.* **3** : 284-298.

SINGH, P. 1980. Microfauna, age, palaeoenvironment and palaeobiogeography of the Tal Formation, Lesser Himalaya, Garhwal, Uttar Pradesh, India. *Curr. Sci.* **49** : 255-261.

SINGH, PUSHKAR, 1973. A note on the fossiliferous formations in Lesser Himalaya of Nepal and Bhutan. *Him. Geol.* **3** : 372-380.

SINHA, A. K. 1975. Calcareous nannofossils from Simla Hills. *Jour. Geol, Soc. India.* **16** : 69-77.

SINHA, A. K. 1977. Riphean stromatolites from Western Lower Himalaya, Himachal Pradesh, India. In : *Fossil Algae* (ed. E. Flugel) Springer Verlag, Heidelberg. 86-100.

SITHOLEY, S. V., SAH, S.C.D., AND DUBEY, S. N. 1954. Plant microfossils from carbonaceous shale (Krols) near Nainital. *Jour. Sci. and Ind. Research.* **13 B**(6) : 450-451.

SRIKANTIA, S. V. AND BHARGAVA, O. N. 1967. Kakara Series : a new Palaeocene formation in Simla Hills. *Bull Geol. Soc. India.* **4** : 114-116.

SRIVASTAVA, J. P. 1974. Conodonts from Carboniferous and Permian rocks of Kashmir Valley and from the phosphorite zone of Mussoorie , U. P. *Pub.Centr. Adv. Stud. Geol. Panjab Univ.* **10** : 109-111.

SHRIVASTAVA, R. N. 1972. Fossil lamellibranch from the Lower Tal shales of Mussoorie area, U. P. *Geol. Surv. Ind. Misc. Pub.* **15** : 269-272.

SHRIVASTAVA, R. N. 1973. "Estherids" from Lower Tals, Mussoorie synform, U. P. Himalaya. *Rec. Geol. Sur. India.* **105** (2) : 193-204.

SHRIVASTAVA, R. N. AND MEHROTRA, P. C. 1974. Organic remains, age and environment of the Lower Tal Formation of Mussoorie Synform, U. P. *5th Him. Geol. Seminar Panjab Univ.* 38-39. (Abstract).

SHRIVASTAVA, R. N. AND VENKATARAMAN, K. 1975. Palynostratigraphy of the Blaini Formation. *Bull. Ind. Geol. Assoc.* **8** : 196-199.

TERMIER, H., TERMIER, G. AND VACHARD, D. 1975. Recherches micropaleontologiques dans le Paleozoique superieur du Maroc Central. *Cahiers Micropal.* **4** : 73-78.

TERMIER, H., TERMIER, G. AND VACHARD, D. 1977. On Moravamminida and Aoujgaliida (Porifera, Ischyryspongia) : Upper Paleozoic "Pseudo Fossil Algae". In : *Fossil Algae* (ed. E. Flugel). Springer Verlag, Berlin, 215-224.

TEWARI, A. P. AND MEHDI, S. H. 1964. Geology of Nainital-

Almora Himalaya, U.P. Guide Ex.-No. A-4. *Int. Geol. Cong. XXII Session, New Delhi, India.* 1-19.

TEWARI, B. S. 1969. Nannofossils from the Krols. *Bull. Ind. Geol. Assoc.* **2** : 22.

TEWARI, B. S. 1975. On the stratigraphic position of the Boulder Slate Sequence of the Garhwal Syncline. Bull. Ind. Geol. Assoc. **8** : 200-203.

TEWARI, B. S. 1979. Stratigraphic significance of fossiliferous Blainis with fusulinids from Lesser Himalayas of Kumaon, India. *Bull. Ind. Geol. Assoc.* **12** : 257-258.

TEWARI, B. S. AND GUPTA, V. J., 1978. The stratigraphic position of the Tal Formation of the Lesser Himalaya. *Recent Researches in Geology.* **4** : 128-140.

TEWARI, B. S., KACHROO, R. K. AND GUPTA, V. J. 1976. Discovery of Devonian scolecodonts in the Lesser Himalayan zone of Garhwal, U. P. *Curr. Sci.* **45** : 222-223.

TEWARI, B. S. AND KUMAR, R. 1967. Foraminifera from Nummulitic Beds of Nilkanth and organic remains from Tal Limestone, Garhwal Himalaya. *Pub. Centr. Adv. Stud. Geol. Panjab Univ.* **5** : 121-133.

TEWARI, B. S. AND SINGH, J. 1976. Microfossils and the age of the Subathu Formation of Dogadda, Garhwal Himalayas. *Jour. Geol. Soc. India.* **17** : 409-411.

TEWARI, B. S. AND SINGH, R. Y. 1979. The significance and occurrence of Late Palaeozoic plant remains in the Infrakrol sequence of Nainital, U. P. *Bull. Ind. Geol. Assoc.* **12** : 263-266.

TRIPATHI, C., DUNGRAKOTI, B. D., AND GHOSH. R. N., 1979. Note on discovery of Nummulitics from Dihang Valley, Siang district, Arunachal Pradesh. *Ind. Minerals.* **33** : 43-44.

VALDIYA, K. S. 1964. The unfossiliferous Formation of the Lesser Himalaya and their correlation. *Proc 22nd I. G. C. New Delhi,* **11** : 15-36.

VALDIYA, K. S. 1969. Stromatolites of the Lesser Himalayan carbonate Formations and the Vindhyans. *Jour. Geol. Soc. India.* **10** : 1-25.

VALDIYA, K. S. 1970. Simla Slate, the Precambrian flysch of Lesser Himalaya, its turbidite, sedimentary structure and palaeocurrent. *Geol. Soc. Am. Bull.* **81** : 451-467.

VALDIYA, K. S. 1973. Blaini conglomerates of Himachal Pradesh and Garhwal In : Verma, V. K. et al. (editors) *Recent Researches in Geology.*, part I. Hindustan Publishing Corporation, Delhi.

VALDIYA, K. S. 1975. Lithology and the age of the Tal Formation in Garhwal and its implication on stratigraphic scheme of Krol Belt in Kumaon Himalaya. *Jour. Geol. Soc. India.* **16** : 119-134.

VALDIYA, K. S. 1980a. Discovery of late Palaeozoic brachiopod in the Upper Krol of the Nainital hills, Kumaun Himalaya. *Jour. Geol. Soc. India.* **21** : 97-101.

VALDIYA, K. S. 1980b. Author's reply to comment on Discovery of Late Palaeozoic brachiopod in the Upper Krol of the Nainital hills, Kumaon Himalaya. *Jour. Geol. Soc. India.* **21** : 518-519.

VALDIYA, K. S. 1980c. Stratigraphic scheme of the sedimentary units of the Kumaun Lesser Himalaya. In : *Stratigraphy and Correlations of Lesser Himalayan Formations.* 7-48. Hindustan Publishing Corporation (India). Delhi.

VALDIYA, K. S. (1980d). Stratigraphy of Lesser Himalayan Synthesis. In : *Stratigraphy and Correlations of Lesser Himalayan Formations.* 283-296. Hindustan Publishing Corporation (India), Delhi.

WALTER, M. R. AND PREISS, W. V. 1972. Distribution of stromatolites in the Precambrian and Cambrian of Australia. *Int. Geol. Congr. 24th. Sess. Montreal,* 1972. Sect. I. Precambrian Geology. 85-93.

WATERHOUSE, J. B. AND GUPTA, V. J. 1978. Early permian fossils from Bijni Tectonic unit Garhwal Himalaya. *Recent Researches in Geology.* **4** : 410-437. Hindustan Publishing Corporation, Delhi.

WATERHOUSE J. B. AND GUPTA, V. J. 1979. Early Permian fossils from southern Tibet, like faunas from Peninsular India and Lesser Himalayas of Garhwal. *Jour. Geol. Soc. India.* **20** : 461-464.