Branched microbiota from the bedded black chert of the Krol Formation (Neoproterozoic), Lesser Himalaya, India

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The bedded chert nodules of the lower part of the Krol Formation of Neoproterozoic age, near its type area in Solan District in the Lesser Himalaya, have provided a peep through the Proterozoic window where exceptionally well preserved organic walled microbial fossils show branching in its several forms. The phenomenon of branching is an event which indicates a sudden change in the pattern of life amongst the various morpho-entities of algal-cyanobacterial communities. This phenomenon shows advancement of life-forms towards future diversification in the Phanerozoic history of the earth. The occurrence of branching forms is significant as many of them resemble eukaryotic forms which differ from an earlier stock of prokaryotic cyanobacteria. Apart from branched filaments microfossils comparable to Bangiophyceae, a red alga with typical septate morphology is also recorded. The significance of the biota is discussed in the light of existing records from the Proterozoic successions all over the world.

Key-words — Microbiota, Algae, Krol Formation, Neoproterozoic, India.

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साराँश

भारत में लघु हिमालय के क्रोल शैल-समूह (निओप्रोटीरोजोइक) के स्तरित काले रामसैकाश्म से शाखायुक्त सूक्ष्मजीविता

रजिता गौतम एवं विभूति राय

लघु हिमालय में सोलन जनपद में प्ररूप क्षेत्र के समीप निओप्रोटीरोजोइक क्रोल शैल-समूह के निचले भाग में स्तरित रामसैकाश्म से महत्वपूर्ण सुपरिरक्षित कार्बनिक भित्तिदार शाखायुक्त सूक्ष्मजीवाश्मों के कई प्रादर्श मिले हैं। शाखाविन्यास की यह घटना शैवालीय सियॅनोजीवाणु समुदायों में जीवन के स्वरूप में सहसा परिवर्तन की द्योतक है तथा पृथ्वी के इतिहास में जीवन के स्वरूप में भविष्य में हुई विविधता की ओर संकेत करते हैं। यह परिवर्तन इसलिए भी उल्लेखनीय है क्योंकि इनमें से बहुत से प्रोकैरियोटी सियॅनोजीवाणुओं की अपेक्षाकृत यूकैरियोटी प्रादर्शों से अधिक सदृशता प्रदर्शित करते हैं। बैंगिओफाइसी कुल से तुलनीय शाखायुक्त सूत्रवत् सूक्ष्मजीवाश्मों के अतिरिक्त एक भित्तिदार लाल शैवाल भी अभिलिखित किया गया है। इसके अतिरिक्त विश्व भर से प्रकाशित आँकड़ों के आधार पर उपलब्ध जीविता की विवेचना भी की गई है।

THE Proterozoic history of life on the earth conceals the key to later evolutionary trends in the Phanerozoic. A cursory peep through several Proterozoic windows in the biosphere, occasionally provides significant information about the changing patterns in the life forms. These changes occur either in a series of evolutionary sequences or are sudden and unique and are termed as events. The Precambrian time span represents changes from earliest primitive prokaryotic, cells to higher levels of development through a succession of evolutionary events. One such event in the microbial community is the initiation of branching which provides significant clues about absolute changes from prokaryotic entities to eukaryotic diversification. The significance of such an event is enhanced when the recorded evidences are fewer but conclusive about their biogenic affinity.

Although there is general consensus about the timing related with the earliest evolution of eukaryotic life domain which dates back to approximately 2.1 billion years before present (Han & Runnegar, 1992), its record in microbial community is very limited in the entire Precambrian. Therefore, any such record which has a bearing on evolutionary event needs greater attention.

GEOLOGICAL SETTING

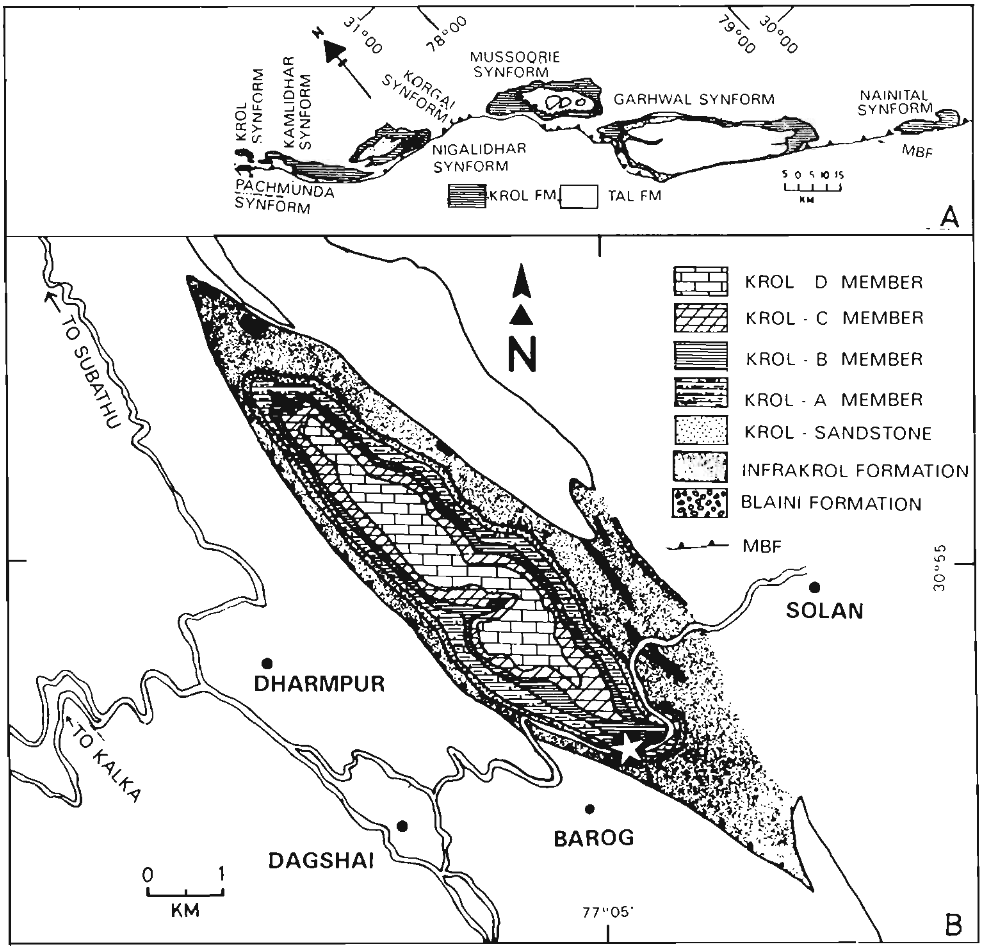
Geographical distribution and extent

The name 'Krol Group' was given by Medlicott (1864) to the calcareous suite of rocks exposed in the Krol Hill (lat. 30°57' N; long. 77° 06' E), north of Solan in Himachal Pradesh. Auden (1934) proposed the term 'Krol Belt' for this suite of rocks which form one of the important geological sequences in the Lesser Himalaya (Text-figure 1A). The 'Krol Belt' is exposed as a sequence of synformally folded sedimentaries between Kunihar Valley in Himachal Pradesh in the north-west and Nainital in the east. The Krol and the Pachmunda synforms in Himachal Pradesh form the western extremity of the Krol Belt. The other major exposed synforms occurring from west to east are Khanog, Rajgarh, Saindhar, Kamlidhar, Nigalidhar, Korgai, Mussoorie, Garhwal and Nainital synforms. The Outer Krol Belt comprises Pachmunda, Krol, Khanog, Rajgarh and Saindhar synforms while rest from Nigalidhar to Nainital are included under the Inner Krol Belt.

Lithostratigraphy

The Krol Belt includes the Blaini, Infrakrol, Krol and Tal Formations in ascending order constituting one conformable sequence. However, the Tal Formation does not occur in the Krol Belt of the Solan area. A detailed lithostratigraphy of the above formations as exposed in the Solan area (particularly in the Pachmunda Synform, Text-figure 1B) is as follows :

Blaini Formation – It is a marker horizon of the entire Krol Belt on account of its unique lithology of conglomerate/diamictite, grading upwards into carbonate beds. It consists of a lower Diamictite Member and an upper Calcareous Member.



Text-figure 1 — Location map of the fossiliferous horizons; **A**. Study area, **B**. Geological map of the Krol Belt, **C**. Geological map of the Pachmunda Synform (after Auden, 1934) showing fossil yielding horizon (marked by star).

Table 1–Nomenclatural classification of the Krol Belt as proposed by different workers

Oldham (1888)	Auden (1934)		Bhattacharya & Niyogi (1971)		Shanker *et al.* (1993)		Present study	
Upper Krol Limestone	Krol E	KROL SERIES	Krol E Formation	KROL GROUP	Kauriyala Formation (Upper)		Krol 'E' Member	KROL FORMATION
	Krol D		Krol D Formation				Krol 'D' Member	
	Krol C		Krol C Formation				Krol 'C' Member	
Red Shales	Krol B		Krol B Formation		Jarashi Formation (Middle)		Krol 'B' Member	
Lower Krol Limestone	Krol A		Krol A Formation		Mahi Formation (Lower)		Krol 'A' Member	
	Krol Sandstone		Krol Sandstone		Chambaghat Formation		Krol Sandstone	
	Infrakrol		Infrakrol Formation		Infrakrol Formation	BALIANA GP.	Infrakrol Formation	
	Blaini		Blaini Formation		Blaini Formation		Blaini Formation	

Infrakrol Formation – This unit is essentially made up of shales and slates. Auden (1934) described the slates of Infrakrol type to be so intimately connected with the Blaini as to be mapped as Blaini. Shanker *et al.* (1993) have grouped the Blaini and Infrakrol formations together under the Baliana Group. According to Bhattacharya and Niyogi (1971) the formation is made of rhythmic alternation of silt-shales, siltstones and very fine-grained sandstones. The shales are carbonaceous, particularly in the upper part of the formation.

Krol Sandstone – The Infrakrol Formation gradually transcends into the Krol Sandstone. Bhargava (1976) assigned it as a member unit within the Krol Formation while Bhattacharya and Niyogi (1971) called it the Krol Sandstone Formation. Shanker *et al.* (1993) have proposed the name Chambaghat Formation for this unit. This Formation is made up of sandstone, orthoquartzite and lenses of sandy units. Small pellets and lenticles of phosphorite occur along the bedding.

Krol Formation – Oldham (1888) divided the Krol succession into three sub-stages – Lower Krol Limestone, Red Shales and Upper Krol Limestone. Auden (1934) called it the 'Krol Series' and divided it into five units. Bhattacharya and Niyogi (1971) considered each sub-unit to be a formation under the Krol Group. Shanker *et al.* (1993) proposed a new nomenclature for the already existing lithounits. Table 1 gives a detailed account of the nomenclature proposed by various workers. However, the conventional nomenclature similar to the one proposed by Auden (1934) is being followed here. The depositional environment of the Krol Formation represents a shallow tidal sea, under oxygenated conditions, with deposits of intertidal-supratidal zone being abundant (Awasthi,1970; Kharkwal & Bagati,1976; Singh & Rai,1980; Singh *et al.*, 1980). Bhattacharya and Niyogi (1971) considered the rocks of Krol Group to be representing an environment of mixed clastic and carbonate deposits under a stable tectonic set-up.

Krol 'A' Member – This unit is made up of calcareous shales, siltstones and limestone. The shales are grey to greenish-grey in colour. The limestone is argillaceous at places. Limestone and shale occur in alternate bands. Black chert occurs within the shale/carbonate horizons as thin beds or nodules. The calcareous shales indicate deposits of open, shallow, tidal sea. There was probably an influx of fine-grained terrigenous material from the land. Minor lenses of gypsum indicate shallow conditions with low to moderate energy. Small-scale ripple marks, rhythmites, parallel bedding, cross-bedding, scour and fill, etc. are all indicative of shallow marine environment with continuous current and wave action. The deposition seems to have occurred in subtidal-intertidal zone (Singh *et al.*, 1980).

Krol 'B' Member – It is essentially made up of red shales. Thin, subordinate bands of green shale, cherty limestone and dolomites are also present.

Krol 'C' Member – This unit is essentially calcareous, made up of massive, jointed, bluish-grey carbonate which gives a putrid smell on breaking.

Krol 'D' Member – It is characterised by alternations of carbonate and shales. Lenticular cherts occur within the carbonate beds. This unit shows stromatolitic horizons and algal mats which continue upward into Krol 'E' unit.

Krol 'E' Member – The horizons containing stromatolites and algal mats grade upwards from Krol D into this unit. It is made of argillaceous carbonate and calcareous shale, the latter occurring in subordinate amounts.

AGE CONFIGURATION

Holland (1908) correlated the unfossiliferous systems of the Outer Himalaya with that of the peninsular India and gave it the name Purana. He was of the view that the system was wholly or partly Precambrian. Pilgrim and West (1928) placed the Krol Formation above the lower Gondwana while Auden (1934), Gansser (1964) and Krishnan (1968) considered the Krol Belt to be Palaeozoic-Mesozoic in age. Singh (1976) proposed a model giving the age for the Krol-Tal succession at Nainital as Late Precambrian-Cambrian. Singh and Rai (1977) and Singh and Rai (1983) on the basis of biological evidences gave the age of the Krol-Tal succession as Vendian-Lower Cambrian.

Ghosh and Srivastava (1962) reported trilete and pteridophytic spores from the Infrakrol-Krol, suggesting a Permo-Triassic age for this sequence. Tewari and Singh (1979) reported plant fossils like *Annularia, Gangamopteris, Glossopteris, Calamites,* etc. strengthening the view that Infrakrol were Permian in age. But deposits suggesting euxinic conditions render this find doubtful. Singh (1981) was of the view that the unit of Tewari and Singh must be an independent unit within the Subathu-Dogadda zone. On the basis of a well-developed stromatolitic assemblage (*Conophyton, Colonella* and *Baicalia*) from the Nainital area Singh and Rai (1977, 1980) considered the Krol Formation to be Proterozoic in age. Later Singh and Rai (1983) discovered archaeocyatha and calcareous algae, namely, *Epiphyton, Renalcis, Gemma* and *Girvanella* suggesting a Vendian age for the Krol Formation. Rai and Singh (1983) discovered trilobites from the Tal Formation indicating Lower Cambrian age for the succession. On the basis of above contentions a Precambrian-Cambrian age has been assigned to the Krol Belt. There are other fossil records on the basis of which a Late Precambrian to Early Cambrian age has been proposed for the Krol-Tal sequence (Shanker *et al.*, 1993).

FOSSIL YIELDING LOCALITY

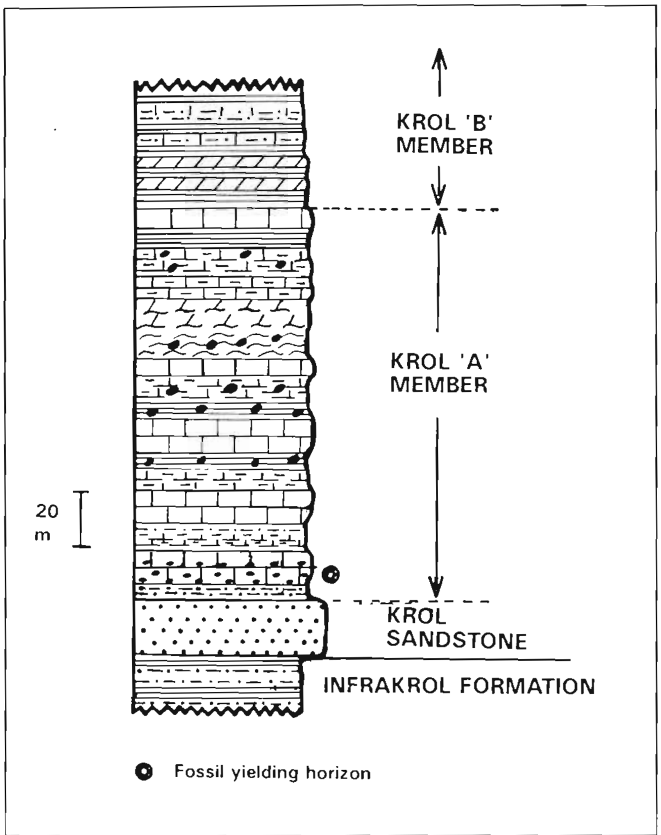
The lower part of the Krol 'A' Member is well exposed on the southern slopes of the Pachmunda hills along the National Highway No. 22 between Barog and Solan (Anjighat) (Text-figure 1C). About 5 meters above the orange coloured Krol Sandstone occurs a bedded calcareous horizon interlayered with black siltstone. Within the calcareous beds a number of black chert nodule bearing layers (Text-figure 2) are present. These black chert nodules have yielded the branched filamentous forms besides a highly developed cyanobacterial and acritarch assemblage.

Repository – The discussed fossil material in respective thin sections is deposited with the museum of the Department of Geology, University of Lucknow, Lucknow. The number of the thin section along with England Finder co-ordinates are given in the description of the plate.

TAXONOMIC NOTES

Archaeorestis is the first recorded genus of branched, filamentous microbial fossils from Precambrian (Barghoorn & Tyler, 1965). Some other genera of branched filaments are *Palaeosiphonella* (Licari, 1978), *Ramivaginalis* (Nyberg & Schopf, 1984), *Palaeovaucheria* (Hermann, 1981) and *Proterocladus* (Butterfield *et al.*, 1994). Besides, there are few more records of branching forms of uncertain taxonomic identity, viz., "branched septate microorganisms" (Schopf *et al.*, 1977), "branched tubes with ellipsoidal inclusions" (Lo, 1980), "narrow tubular sheaths in common organic matrix or enclosed by a larger tubular sheath" (Nyberg & Schopf, 1984) and "Filamentous Form 'A' " (Kumar & Srivastava, 1991).

The paucity of record and poor preservation of internal structure have made the correlation of these branched fossil forms with extant cyanobacteria or other algal groups difficult. Licari (1978) compared *Palaeosiphonella cloudii* with *Vaucheria* (Chrysophyta) and *Derbesia* (Chlorophyta), while Lo (1980) tried to correlate "branched tubes with ellipsoidal inclusions" with forms belonging to Stigonemataceae (Cyanophyceae) or small eukaryotes



Text-figure 2– Lithocolumn showing the fossiliferous chert horizons of Krol 'A' Member, Krol Formation, Lesser Himalaya (Solan area).

or fungal hyphae. Some of these forms may also be falsely branched and show an affinity to forms of the Family Scytonemataceae of Division Cyanophyta.

The bedded black cherts from the Krol 'A' Member of the Krol Formation in the Kandaghat area near Solan (from the Krol Synform) have yielded a rich assemblage of microfossils which include filamentous forms, coccoidal forms, acritarchs and certain problematic or bizarre forms (Kumar & Rai, 1992). In the presently studied section of the Pachmunda Synform, the filamentous forms constitute the largest group of microbial assemblage representing a wide variety of morpho-types. Generally empty sheaths of filaments are preserved but occasionally trichomes, with or without an enveloping sheath, are also preserved. Quite a number of forms exhibit septation. However, the phenomenon of branching is very rare and significant as it may indicate a change from a prokaryotic mode of life to eukaryotic one. Some rare branching forms recorded from this assemblage are described here in detail. Due to the occurrence of only a single specimen of each morphologic type, except Form A, no definite taxonomic position has been ascribed to these forms.

Form A

Pl. 1, figs 5, 6, 7

Tubular, branched, convoluted form with bulbous swellings; wall thin, psilate, light brown in colour. Plate 1, fig. 6 has a thread-like structure running through the central part of the filament. Remnants of cross walls visible at places. Branching lateral, at an angle of 51°. Width of main filament 13-15 µm, that of branches 8-11 µm. Length not definitely ascertained due to broken ends but preserved length about 200 µm. Plate 1, fig. 5 shows a second specimen of the above type with regular constrictions and swellings. Dark lensoid bodies/cellular material can be seen occurring at regular intervals. Branch arises from the main filament through budding or protruberance. The width of branches ranges between 6 to 10 µm due to pinching and swelling morphology. The form shows perfect stages of branching from the appearance of protruberance or budding to fully developed branches. A third specimen of the same type (Pl. 1, fig. 7) shows a thick broken main filament

PLATE 1 ⟶

All photographs are from petrographic thin sections. Scale in all forms equals 15 microns.

1. Form 'B' (Slide No. BR17A/1, England Finder No. P48/4) Branched filament showing trichome preserved within an enveloping sheath.
2. Form 'E' (Slide No. BR3A/4, England Finder No. N26/3) *Bangia*-like, septate specimen. Pseudo-branched morpholgy is apparent.
3. Form 'C' (Slide No. BR3A/4, England Finder No. Q28/1-Q27/1)Branched form showing infilling of the filament cavity.
4. Form 'D' (Slide No. BR3A/4, England Finder No. U24/1) Straight broken filament showing 'V'-shaped branching or splitting.
5. Form 'A' (Slide No. BR3A/4, England Finder No. S23/4) Branched form with dark, lensoid bodies seen within the filament.
6. Form'A'(Slide No. BR27A/1, England Finder No. U26/0) Branched, convoluted form.
7. Form 'A' (Slide No. BS96/12, England Finder No. J27/0) Well developed branch emerging from a thick filament showing a possible 'neck' like part in the left portion of the main body. Dark lensoid body is present in the upper part of the branch.
8. Form 'D' (Slide No. BS96/8, England Finder No. L24/4) Branched Form showing resemblance with *Ramavaginalis uralensis*.

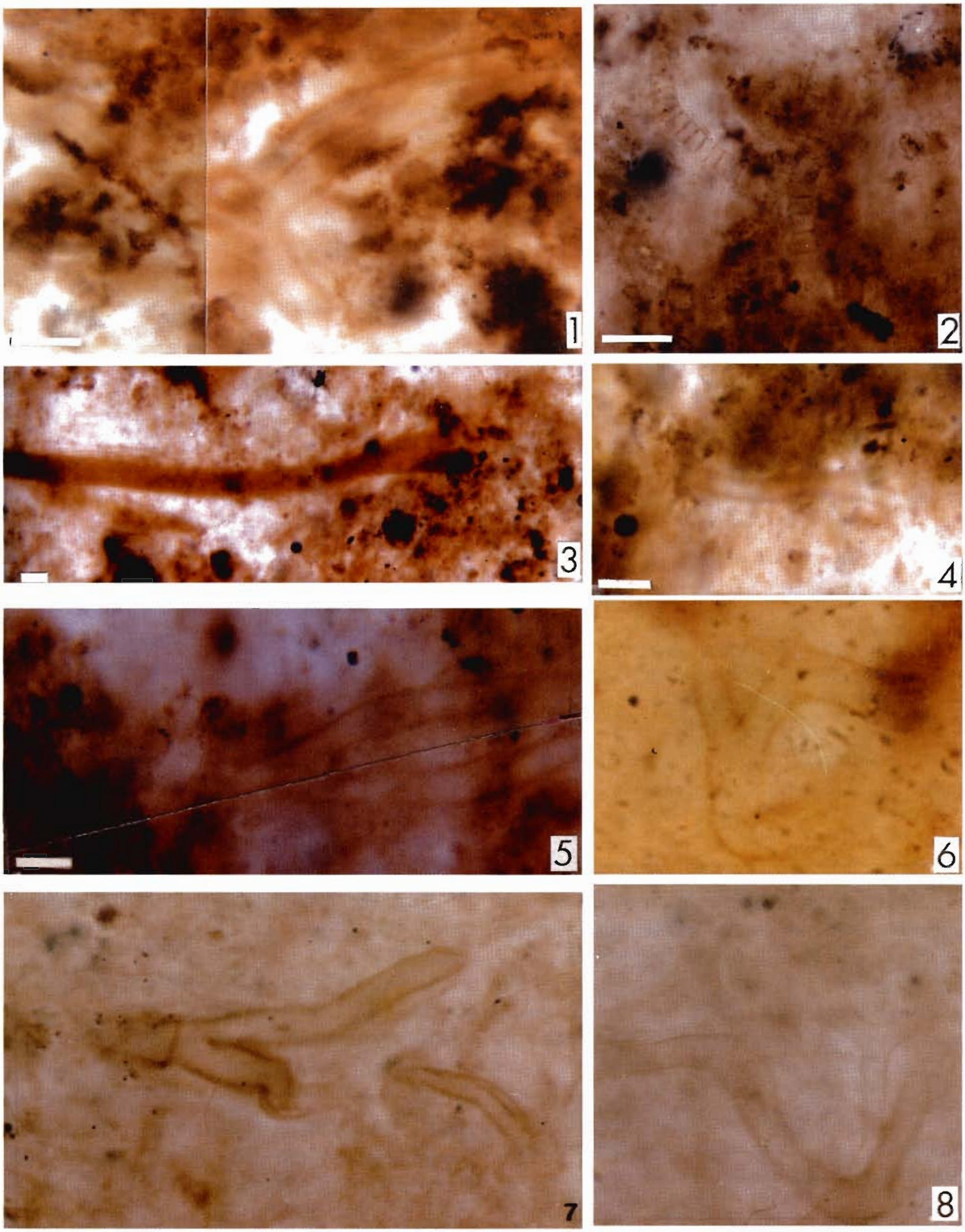


PLATE 1

of 13 μm width. It is separated from the branches by a distinct septa. The branches are broken, curved and 8-11 μm in width. A dark lensoid body is visible in the upper branch.

These forms are comparable to *Archaeorestis schreiberensis* (Barghoorn & Tyler, 1965). The difference lies in the granular filament wall is in the type specimen whereas the present specimens have a thin psilate wall and greater tube diameter.

Form B

Pl. 1, fig. 1

Non-septate, tubular form with branched trichome preserved within an enveloping sheath; sheath smooth, about 2 mm space between the trichome and sheath; trichome wall thin, indistinct. Branching 'Y'-shaped, lateral; cellular portions not preserved; branched junctions show greater sheath thickness; width varies from 11 to 16 mm for the filament and about 5 mm for the trichome.

This form shows a close resemblance with an unnamed illustrated form of Nyberg and Schopf (1984, fig. 11F). Their form shows numerous narrow tubular structures which are occasionally branched and enclosed within an organic matrix/ larger tubular sheath. The present specimen, however, shows only a single branched trichome preserved within the sheath.

Form C

Pl. 1, fig. 3

Non-septate, branched, broken filament with unclear margins, merging somewhat with the background; colour dark brown; surface appears mottled. Only short stub of branch is preserved as the specimen is broken. The main filament flares out or widens just before branching; width of filament 15 μm while that of branches 13-15 μm. Length of the preserved specimen is 410 μm. This form occurs surrounded by a cluster of filamentous forms. A filament overlaps this form and deceptively appears as an offshoot of the main filament.

The branching may be false being a result of rupture and flattening of the main filament during preservation. However, the width of the branches being equal to that of main filament such a conclusion seems doubtful. As only one specimen is recorded, its taxonomic position cannot be ascertained. The form is compared with *Palaeosiphonella* (Licari, 1978). Both these forms show similarity in being branched, siphonaceous filaments. The analogy with these modern algal forms strengthens the view that Form C is a eukaryotic alga. However, due to the absence of any well-preserved internal, cellular structure the taxonomic position of this form is uncertain.

Form D

Pl. 1, figs 4, 8

Non-septate, branched filament with thin psilate walls; branching dichotomous, with the dividing portions being broad, curved, like a tuning fork. Main filament (Pl. 1, fig. 8) 6-7 μm wide, constricted to 4 μm just before dividing. Ends broken, hence, length not definitely ascertained. Wall slightly thickened at the point of branching, very light brown in colour and merges with the background. A convoluted curved filament can be seen overlapping the form. The other specimen shown in Pl.1, fig. 4 shows 'V'-shaped splitting of the main tube with ends broken.

This form is comparable to *Ramavaginalis uralensis* (Nyberg & Schopf, 1984). They have ascribed this form to cyanobacteria belonging to either Scytonemataceae or Stigonemataceae. Since the trichomes are not preserved, true affinity can not be ascertained.

Form E

Pl. 1, fig. 2

Curved, septate, long filaments, occasionally appear to be branched; septa distinct, particulate, alternate septa visible on changing the focus. Cells cylindrical, 6 μm wide and 2.5 to 3 μm long. Walls thin, granular. Termini where seen tapering, rounded.

The form is highly curved being aligned in such a manner as to appear branched. The septa show a complex morphology in that alternate septa are visible at a particular focus. It may thus be deduced that alternate septa with an opening or pore occur in between complete septa ensuring cellular continuity.

This complexity in the morphology of the form represents a high degree of evolutionary development. The specimen shows a close resemblance with bangiophyte red alga (Butterfield *et al.*, 1990) where along the length of the filament, the cross partitions (or septa) also alternately occur as complete or with a central opening (hole). However, the specimens of Butterfield *et al.* (1990) exhibit a multiseriate structure with greater diameter of filament and modified basal ends.

DISCUSSION AND CONCLUSIONS

1. The occurrence of a diversified cyanobacterial and algal community in the Krol 'A' Member of the Krol Formation (Pachmunda Synform) indicates a major evolutionary step in the Neoproterozoic succession of the Lesser Himalaya.
2. A very rare biological phenomenon, i.e., initiation of branching in filamentous microbial community is recorded for the first time from the Neoproterozoic sequences of the Lesser Himalaya.
3. This phenomenon of branching is common in modern eukaryotic community. However, a few cyanobacteria also show branching. Comparison of the fossil material has been made with the modern branched algal-cyanobacterial forms.
4. The presence of well developed septate forms showing affinity with red and green algae indicates that in the present assemblage most of the branched filamentous forms are possibly eukaryotic in nature.

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