Journal of the Palaeontological Society of India
Volume 58(2), December 2013: 251-258

ISSN 0522-9630

THALLOPHYTIC ALGAE FROM THE KROL FORMATION (EDIACARAN PERIOD), LESSER HIMALAYA, INDIA

ARADHANA SINGH and **VIBHUTI RAI**

CENTRE OF ADVANCED STUDY IN GEOLOGY
UNIVERSITY OF LUCKNOW, LUCKNOW-226007, INDIA
Email: aradhanarim@rediffmail.com

ABSTRACT

Thallophyte fossils have been discovered from the Krol 'C' Member of the Krol Formation (Ediacaran Period) in the Garhwal Synform of the Lesser Himalaya, India. The fossils described are recovered from the petrographic thin sections of the chert lithounits. Comparable thallophytic algal fossils (Red alga) were previously recorded from the Doushantuo Formation of China and a late Neoproterozoic age was assigned to the fossil bearing strata. We herewith describe the taxonomic details along with the possible biotope in which these fossils occur. The exceptionally well preserved fossils show a body plan where even cellular organization clearly depicts multicellularity. The present record owes its significance to exceptional preservation of evolved algae (eukaryote) which is preserved at cellular level in the silicified lithology (bedded black chert) with fine morphological details at the higher level of strata (Krol 'C' Member). Previous microfossil records are known from the Infrakrol and Krol 'A' Member of the Krol Formation which mainly show either the existence of fossils with cyanobacterial (prokaryote) affinity and giant acanthomorphic acritarchs or a few ill-preserved thallophytic algal remains identified as *Wengania globosa*. The paper discusses the biostratigraphic significance of the newly discovered thallophytic fossils in the light of Neoproterozoic evolutionary history.

Keywords: Thallophytes, Garhwal Synform, Multicellularity, Krol Formation, Ediacaran

INTRODUCTION

In the early evolution of life, the Neoproterozoic time interval represents some major evolutionary changes in the biosphere. These changes are recorded in the form of evolutionary steps where the pre-existing life forms are evolved into advanced life forms at each step with maximum acceleration recorded at the end of Neoproterozoic. The final phase of the Neoproterozoic time interval shows the occurrence of major biotic diversity and more complex body plans that eventually gave rise to the biotic explosion as represented in types of biota and their number at the crucial Precambrian-Cambrian boundary.

Against the above background, the present finding becomes significant as a record of multicellularity and advanced biotic forms such as thallophytic algal fossils from the Krol Formation of the Lesser Himalaya, which represents a succession of purported Ediacaran age. The only other record of such fossils is from the Doushantuo Formation of China. The present paper incorporates the details of the thallophytic algal remains earlier reported by (Rai and Singh 2003). Subsequently, a few other reports (Tiwari and Pant, 2004; Shukla *et al*., 2005; Singh, 2006) described similar fossils from the different strata of the Krol succession.

The Krol specimens show similarity with the genus *Thallophyca* Zhang (1989) particularly in the morphology of the thallus which is here differentiated into cortex and medulla. Tissue differentiation of the thalli suggests that the genus *Thallophyca* represents a primitive metaphyte. Thallophytes have a simple body plan (thallus plant) with no leaves, stems and roots. These multicellular fossils indicate that by 600-542 Ma ago (end phase of the Proterozoic), algae were at their radiation stage. The Krol succession has earlier yielded a number of palaeobiotic forms that reflect an evolutionary phase during deposition of the strata. These entities include large acanthomorphic acritarchs besides calcareous algae, stromatoporoids, Ediacaran metazoans and vendotaenid algal fossils. Perhaps, a new ecological niche, as a result of post-Marinoan deglaciation, may have provided the suitable environmental conditions that stepped up the evolution amongst the algal groups.

Looking into the palaeogeographic position of the Krol belt and the Yangtze block of south China during the Ediacaran period, it appears that either there was a common basin or there was a common sea in between where similar floristic and faunistic conditions were prevailing. Although the Chinese records are from the phosphorite and the present record of India is from the chert lithologies, this deviation may be due to depositional framework. Detailed biostratigraphic scheme can possibly be drawn in light of various palaeobiogeochemical signatures of the two basins, and the present record can throw light on a syntectonic evolution of the two basins.

It is envisaged that the Ediacaran radiation was a major step in the evolutionary explosion of palaeobiological communities. It is indeed surprising to note that out of 30 phyla of living animals, only 2 (Cnidaria and Porifera) are found in the Ediacaran rocks and the rest 28 are known from the Cambrian rocks. The present record of thallophyte fossils seems to represent a group of organisms which could be potential precursor to the evolutionary explosion at the Precambrian-Cambrian transition.

GEOLOGICAL SETTING OF THE STUDY AREA

In the studied section of the Garhwal Synform along the Rishikesh-Nilkanth road (Nala cutting section), the bedded black cherts of the Krol 'C' Member are present within the limestone (Fig. 3). It consists of a sequence of massive jointed, bluish-grey limestone which gives a putrid smell on breaking. Zebra structures are present. In the upper part of the sequence, crystalline vugs are developed, indicating evaporitic conditions. Presence of stromatolites, gypsum, bird's eye and oolitic structures are indicative of deposition in intertidal to

Fig. 1a. Photograph showing the section in the area.

Fig. 1b. Photograph showing the chert layer (arrow) within the carbonate horizons.

dolomites, organic-rich wackstone shale succession with a few stromatolitic horizons and angular conical stromatolites. The succession also has cherty/silty dolomite siltstone sequence with upper horizons showing chert nodule layers. The Krol C carbonates terminate with a brecciated horizon with a regional sequence boundary. The broad environmental characterisation suggests shallow sub-tidal to lagoonal environmental setting.

The Thallophytic algal fossils described herein have been recorded from the Krol 'C' Member of the Inner Krol Belt of the Garhwal Synform of the Lesser Himalaya. Exposures of the Krol and Tal Groups in the Lesser Himalaya are shown in Fig.2. The fossiliferous samples were collected along the Rishikesh-Nilkanth road (Nala cutting section) as shown in Fig. 1a and 1b. Flaser and lenticular bedding is well developed in the Krol 'C' Member of this section. This unit is grouped along with the Krol 'D' Member and the Krol 'E' Member as the Upper Krol Limestone.

AGE

The age of the Krol Formation is mainly derived on the basis of fossil finds and no direct geochronologically constraint dates are recorded for the succession so far. These fossil forms from different horizons of the Krol Belt have lately constrained the succession of the Blaini-Krol-Tal to a broad age group bracketed between 630 and 500 Ma on the basis of the Marinoan-equivalent Blaini diamictite glaciation at the bottom and record of early Cambrian trilobites in the Tal Formation. Historically, Azmi *et al*. (1980, 1981) discovered conodonts from the lower part of the Tal Formation of the Mussoorie Synform, providing one of the earliest definite evidences of the Late Precambrian-Cambrian age for the Tal succession. Singh and Tangri (1976), Singh (1979, 1980), Singh and Rai (1977), Singh and Rai (1983), Rai and Singh (1983) and Rai (1991), on the basis of various

supratidal zone (Shanker *et al*., 1993). In the Garhwal syncline, the Krol group is represented by about 1000 m thick succession of carbonates. The general lithostratigraphy of the Krol Group in outer and inner belts is given in Table 1. Here, the Krol C Member is developed above the Krol B Member conformably and is again conformably overlain by the Krol D Member with a thickness of about 200m. This succession starts with a regional discontinuity above the Krol B Member on an erosional surface with small-scale cross lamination with minor carbonates. This is followed by stromatolitic horizons with domal stromatolites. These horizons are overlain by brecciated carbonates marked by sequence boundary. The general stratigraphic set-up of the Krol-Tal sequence along with the litholog is given in Fig. 4.

The succession continues with Karst surfaces and is subsequently overlain by oolitic microbial

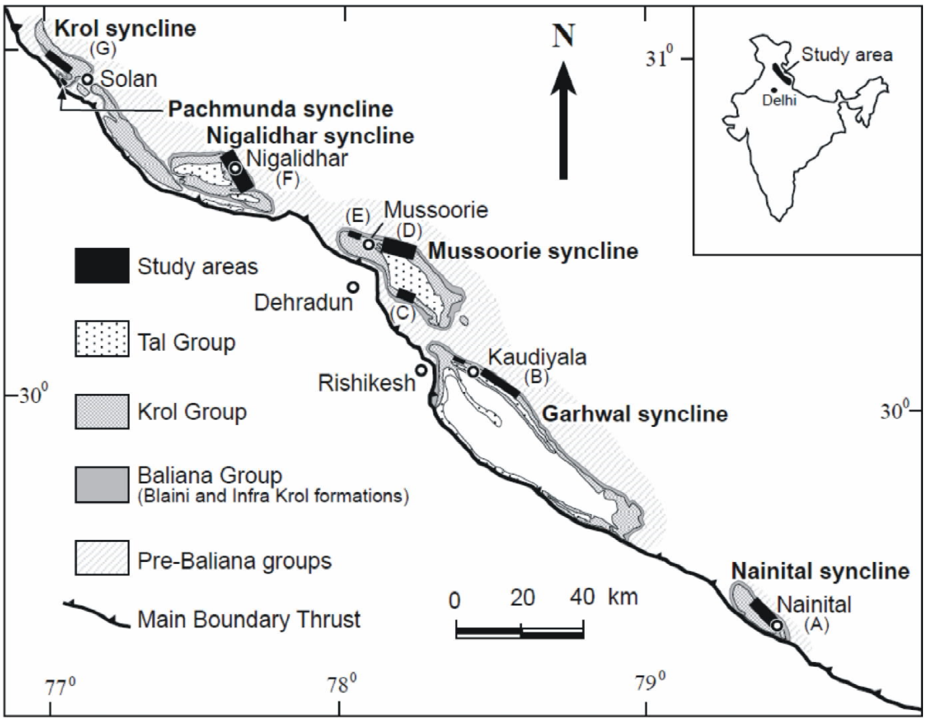

Fig. 2. Map showing exposures of the Krol and Tal groups in the Lesser Himalaya (modified after Singh and Rai, 1983).

Table 1: General lithostratigrapy of the Krol Group in outer and inner sedimentary belts (modified after Bhargava, 1972).

OUTER KROL BELT (Krol to Saindhar Synform) Subathu (Eocene) ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^		**INNER KROL BELT** (Nigalidhar to Nainital Synform) Subathu (Eocene) ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^ Shell Limestone (Cretaceous) ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^ Slate Sequence (Permian) ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^		
		Tal Formation	UPPER (Dhaulagiri Formation)	E Member
				D Member
				C Member
				B Member
				A Member
			Disconformity	
			LOWER (Deo-Ka-Tibba Formation)	Calcareous Member
				Arenaceous Member
				Argillaceous Member
				Chert Member
Krol Formation	Krol 'E' Member	**Krol Formation**	Krol 'E'Member	
	Krol 'D' Member		Krol 'D' Member	
	Krol 'C' Member		Krol 'C' Member	
	Krol 'B' Member		Krol 'B' Member	
	Krol 'A' Member		Krol 'A' Member	
	Krol Sandstone			
Infra-Krol Formation		Infra-Krol Formation		
Blaini Formation		Blaini Formation		
	Sanjauli Formation			Nagthat Formation
Simla Group	Chhaosa Formation	Jaunsar Group		Chandpur Formation
	Kunihar Formation			Mandhali Formation
	Basantpur Formation			
Shali Group		Deoban Group		
Sundernagar (?)		Tiuni (?)		

sedimentological and palaeontological evidences (e.g. columnar stromatolites namely, *Collenia, Conophyton, Baicalia*; archaeocyatha and calcareous algae, namely *Epiphyton*, *Renalcis, Gemma* and *Girvanella*), assigned a Precambrian-Cambrian (Ediacaran-Lower Cambrian) age to the Krol-Tal succession.

Reports of the Ediacaran fauna, conodonts, inarticulate brachiopods, gastropods and trilobites by different workers (Azmi, 1983, 1987; Azmi *et al*., 1980; Kumar *et al*., 1983; Tripathi *et al*., 1984; Bhatt *et al*., 1983, 1985; Joshi and Mathur, 1987; Joshi *et al*., 1989; Mathur *et al*., 1988; Mathur and Joshi, 1989; Mathur and Shanker, 1989, 1990; Shanker and Mathur, 1990, 1992; Shanker *et al*., 1997) from different units of the Krol-Tal succession also indicate a Late Precambrian-early Cambrian age for the succession. Lately, the age assignment of the Krol has been confirmed by the study of Organic-Walled Microfossils (OWM's) from the cherts of the Krol horizons and correlating them with the

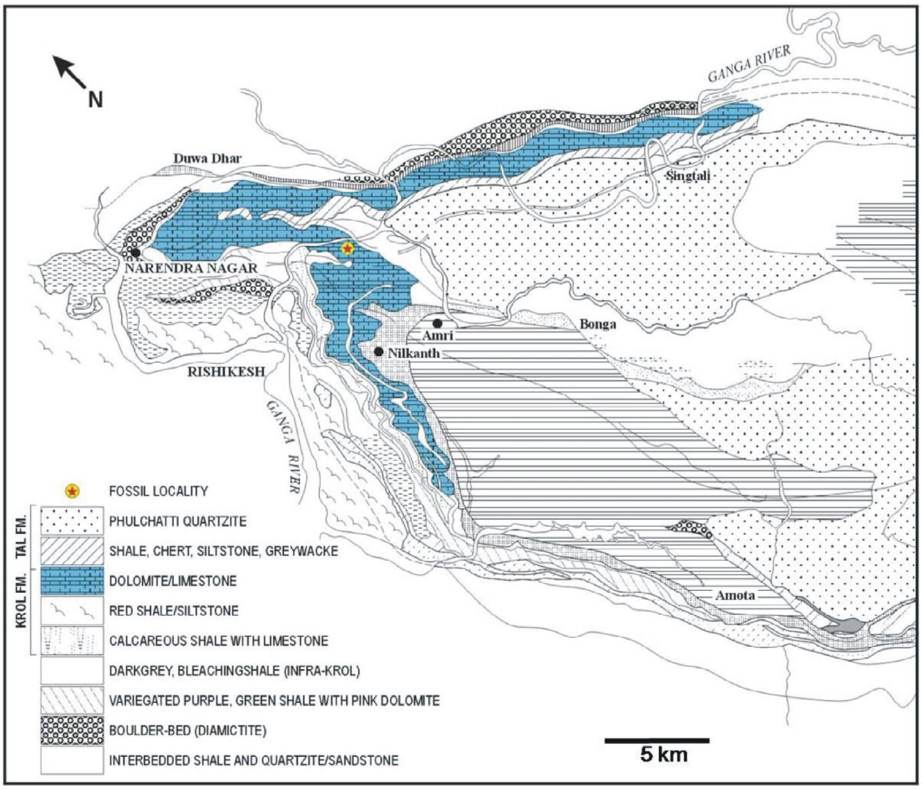

Fig. 3. Geological map of a part of the Garhwal Synform (modified after Kumar *et al*., 1981).

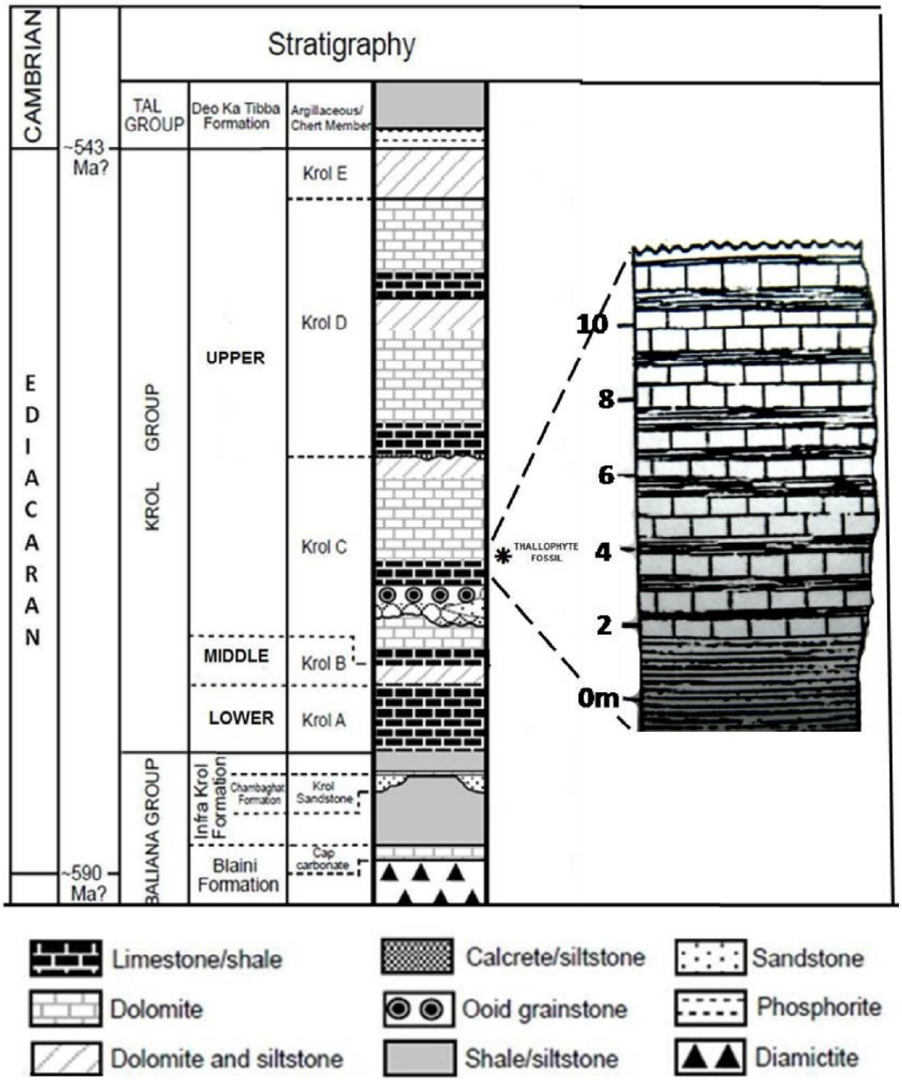

Fig. 4. Stratigraphic set-up of the Krol-Tal sequence (modified after Jiang *et. al*., 2002). The

records from equivalent horizons from various parts of the world (Zhang *et al*., 1998). Tewari (1988) reported vendotaenid algae from the Krol 'A' Member of the Mussoorie Synform confirming a Late Proterozoic age for the sequence. Venkatachala *et al*. (1990), Tiwari and Azmi (1992) on the basis of organic-walled microfossils suggested a Late Proterozoic age for the sequence. Kumar and Rai (1992) on the basis of the presence of forms comparable to *Obruchevella* suggested an Upper Riphean to Vendian age for Krol 'A' Member. Tiwari and Knoll (1994), Tiwari (1996), Tiwari and Pant (2004) reported large acanthomorphic acritarchs and other diagnostic microfossils from the Infra Krol Formation, on the basis of which they suggested an Early Vendian age for the sequence. Gautam and Rai (1997 a, b) recorded branched microbiota and large acanthomorphic acritarchs from the Krol Formation and assigned a Terminal Proterozoic age to the succession. They have compared it with a few known branched algal forms suggesting a step further in the evolutionary ladder.

DISCUSSION

In the evolutionary history of life, Ediacaran Period represents a major punctuation mark, as the Proterozoic biotic elements gave rise to new niches for the Phanerozoic type of flora and fauna with the beginning of the Cambrian. Major evolutionary changes in the biosphere occurred with the increase in abundance and diversity of life forms. It is surprising to observe that out of 30 phyla of living biota, only 2 (Cnidaria and Porifera) are found in the Ediacaran rocks and the rest 28 are known from the Cambrian rocks.

As suggested by Prof. Preston Cloud of the university of California at Santa Barbara, important clues to biological evolution reside in the geochemical records of the sediments. Single-celled organisms have been the dominant life forms throughout much of the earth history. Prokaryotes began to diversify as far back as 3.5 billion years ago. Single-celled eukaryotes may have evolved at about the same time, but they appeared in the fossil record about 1.8 billion years ago. Later evolutionary phases indicate a very restricted pattern with only a few key events, such as the occurrence of *Bangia*, the green algae, and development of simple carbonaceous morphotypes in the fossil record. The post-Marinoan glacial time span shows accelerated growth and development in biotic community as is revealed by the flora and fauna of the Ediacaran times. The global rise in temperature, following the snowball event of the Marinoan, acted as an environmental switch which provided the newer ecological niches that eventually served as the platform for biological experiments in nature. In this environment, the existence of multicellular thallophytes and associated tissues from the chertified horizons of the Krol 'C' Member are unique to the time span they represent and can now be considered as the key biotic forms for biostratigraphic correlation on a global scale. They also reveal the flourishing of multicellular benthophytes in the shallow Neoproterozoic seas and confirm the conclusion that 'an evolutionary radiation took place in metaphytes during the Ediacaran times (Yin, 1985; Zhang, 1989).

Most thalloid forms are sessile benthos with recognizable basal and upper parts of the thallus. Some leaf-shaped and nodular forms may have been passively mobile. The cytomorphological study of these fossil tissues and their comparison with the modern rhodophytes demonstrate that most of these fossils are lower plants with differentiated tissues. *Thallophyca corrugata* differs from other species of this genus by the shape of the thallus and the characteristic features of the cortical cells.

The fossils are believed to have been preserved *in place* or only *slightly transported*. Thus, they assist in understanding the sedimentary environment of the chertified horizons of the Ediacaran Krol 'C' Member of the Krol Formation. The relatively small size of these fossils may reflect their relatively low level of multicellularity or the stress of the unique environment in which they lived, or both (Xiao *et al*., 1998).

A detailed study of this microbial assemblage provides new information on early stages of metaphytic evolution during Neoproterozoic sedimentation. A large number of thin sections were examined for the present study. In thin section, thalli occur in nodular, branching, crustose or leaf-shaped forms. They occur in simple colonies of undifferentiated cells to branched forms with well-differentiated tissues. The general view of their habitat in thin section of chert can be observed in Fig. 5A. Thallus consists of 2 distinct portions, the cortex and the medulla. The cortex is composed of elongated cells oriented tangentially to the thallus surface. Cortical cells are morphologically distinct from medullary cells and are smaller. Medullary tissue is pseudoparenchymatous with diverging, vertically oriented cell rows. Cells are 4 to 5 µm in size and are commonly spheroidal or ellipsoidal in shape. Spherical cavities surrounded by several layers of the medullary cells are common and occur near the cortex. Special cell groups surrounded by medullary cells are present randomly like small islands known as "cell islands". They are different from the surrounding cells and are larger than the medullary cells.

SYSTEMATIC DESCRIPTION

Kingdom **Plantae**
Phylum **Rhodophyta**
Genus ***Thallophyca*** Zhang, 1989, emend. Zhang *et al.,* 1998

(*Type Species*: *Thallophyca corrugata* Zhang and Yuan, 1992)

Thallophyca corrugata Zhang and Yuan, 1992, emend. Zhang *et al.,* 1998
(Figs. 5A-D, 6D-F)

Thallophyca corrugata Zhang and Yuan, 1992, p. 16, fig. 8A-D; Zhang *et al.,* 1998, p. 45, figs. 17.7, 18, 19.1, 19.2.

Horizon and Locality: Krol 'C' Member, Garhwal Synform, Uttarakhand, India.

Material: 15 specimens are recorded.

Description: This species of *Thallophyca* is characterized by leaf like or fan shaped thalli differentiated into distinct outer cortical and inner medullary zones (Fig. 5A). Cortical zone is composed of multilayered spheroidal cells that are smaller than medullary cells (Fig. 5B). The thallus is curved and wrinkled at the periphery. The upper part of the thallus is caved in to the medullary region that divides thalli into lobes (Fig. 6D-E). These lobes of the thalli consist of pseudoparenchymatous cell rows which are oriented in an upward diverging "fountain" like pattern. The cortical cells are arranged perpendicular to the thallus surface. Cell "islands" are composed of many spheroidal cells that are larger than the surrounding medullary cells. The thickness of the cortex ranges between 15 to 20 µm. The periphery of the medullary region contains empty cavities surrounded by cell rows. The thalli have dimensions ranging from length x width = 175X125 µm to 300X300 µm which is much smaller than the Doushantuo specimens. This size range is much smaller than the Doushantuo specimens and is almost half the size of their smallest specimen. Most of the medullary cells are spheroidal ranging in diameter from 4 to 5 µm or are elongated parallel to growth= 4X2 µm. Cells in cell islands are 2 to 6 µm in diameter.

Remarks: *Thallophyca corrugata* differs from other species of this genus by the leaf-like or fan-shaped thalli and the characteristic spheroidal cortical cells which are smaller than medullary cells. Zhang *et al*. (1998) has emended *Thallophyca corrugata* to embrace *Thallophyca phylloformis* Zhang and Yuan, 1992. So both *Thallophyca corrugata* and *Thallophyca phylloformis* are synonymous.

Occurrence and *Stratigraphic Range*: Doushantuo Formation, South China, Terminal Proterozoic.

Thallophyca ramosa Zhang, 1989, emend. Zhang *et al.,* 1998
(Figs. 5E-F, 6B-C)

Thallophyca ramosa Zhang, 1989, p. 125, figs. 6-8, 11A-C, 12; Zhang *et al.,* 1998, p. 45, figs. 15.6, 15.7, 16, 17.1-17.6, 24.

Horizon and Locality: Krol 'C' Member, Garhwal Synform, Uttarakhand, India.

Material: 10 specimens are recorded.

Description: Disc like, nodular or branched thalli differentiated internally into distinct outer cortical and inner medullary cells. The cortical cells are morphologically distinct and smaller than medullary cells. Cortical cells are elongated and compressed tangential to thallus surface. The thickness of the cortex is about 20 µm. Medullary cells are variable in shape and size commonly spheroidal or ellipsoidal with diverging cell rows. The cell "islands" are morphologically distinctive groups of large cells, spheroidal or irregular in shape and are distributed in the entire medullary region (Fig. 6C). The thalli have dimensions ranging from length X width = 100 X 90 µm to 200 X 150 µm. Medullary cells are spheroidal 4-5 µm in diameter or elongated parallel to growth. Cells in cell "islands" are 2 to 6 µm in diameter.

Remarks: The differentiation of the thallus of *Thallophyca ramosa* into cortex and medulla indicates its multicellular organization. In Doushantuo specimens, thallus dimensions range from 0.78X0.56 mm. The size is much smaller than the Doushantuo specimens. Medullary cells are spheroidal about 2-9 µm in diameter. Cells in cell "islands" are 6-11 µm in diameter. Zhang *et al*., 1998 has emended *Thallophyca ramosa* to embrace *Thallophyca simplica* described by Zhang, 1989. On the basis of morphology and tissue types, it appears close to the Rhodophyta.

Occurrence and Stratigraphic Range: Doushantuo Formation, South China, Terminal Proterozoic.

Unnamed Multicellular Alga
(Figs. 7A-D)

Unnamed Form A, Zhang, 1989, p. 129, figs. 13D and E; Zhang *et al.,* 1998, p. 48, figs. 22.5, 22.6.

Horizon and Locality: Krol 'C' Member, Garhwal Synform, Uttarakhand, India.

Material: 10 specimens are recorded.

Description: The present specimens are composed of parenchymatous tissue which mainly comprises compactly arranged, polygonal, rectangular cells about 4-10 µm in diameter (Fig. 7C). The polygonal cell clusters are enclosed in vesicle-like bodies which are separated from one another by sheath-like bodies. However, the rectangular cells occur one over another and give a pseudotubular shape.

Remarks: The present specimens of multicellular alga resemble the specimens of multicellular alga reported from the Doushantuo Formation, South China by Zhang *et al.* (1998) in colonies of loosely aggregated, undifferentiated cells which constitute the simplest multicellular organisation.

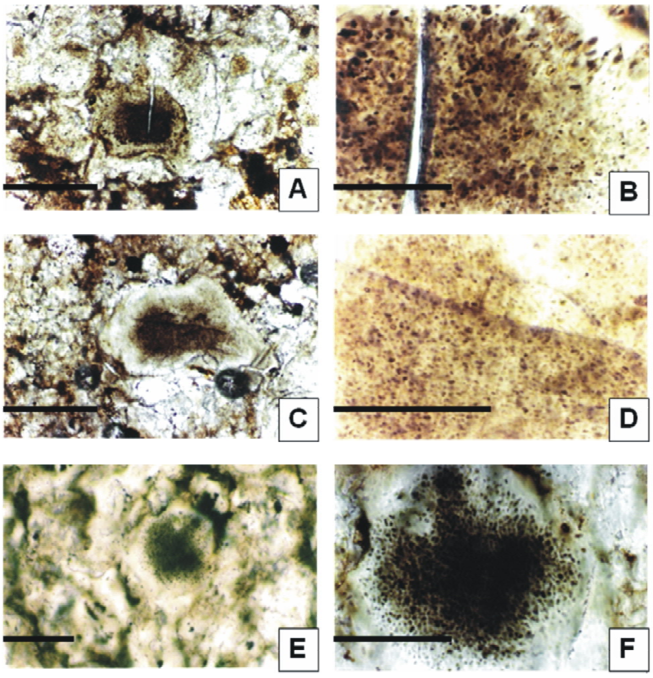

Fig. 5 : **A**: Slide No. Rai-5; Co-Ordinates 7.3X54.4; England Finder No. N46/4; Scale=200µm.

Thallophyca corrugata Zhang and Yuan, 1992, emend. Zhang *et al.,* 1998; Thallus differentiated into distinct outer cortical and inner medullary cells.

B: Slide No. Rai-5; Co-Ordinates 7.3X54.4; England Finder No. N46/4; Scale=50µm.

Thallophyca corrugata Zhang and Yuan, 1992, emend. Zhang *et al.,* 1998; Magnified view of 1A showing cell islands

C: Slide No. Rai-5; Co-Ordinates 20.1X59.7; England Finder No. T59/2; Scale=200µm.

Thallophyca corrugata Zhang and Yuan, 1992, emend. Zhang *et al.,* 1998; Cortical cells are present tangential to the thallus surface.

D: Slide No. Rai-5; Co-Ordinates 20.1X59.7; England Finder No. T59/2; Scale=100µm.

Thallophyca corrugata Zhang and Yuan, 1992, emend. Zhang *et al.,* 1998; magnified view of 1C.

E: Slide No. Rai-4; Co-Ordinates 13.7X56.3; England Finder No. P53/3; Scale=100µm.

Thallophyca ramosa Zhang, 1989, emend. Zhang *et al.,* 1998; Cortical cells are present tangential to the thallus surface.

F: Slide No. Rai-4; Co-Ordinates 13.7X56.3; England Finder No. P53/3; Scale=100µm.

Thallophyca ramosa Zhang, 1989, emend. Zhang *et al.,* 1998; Magnified view of 1E.

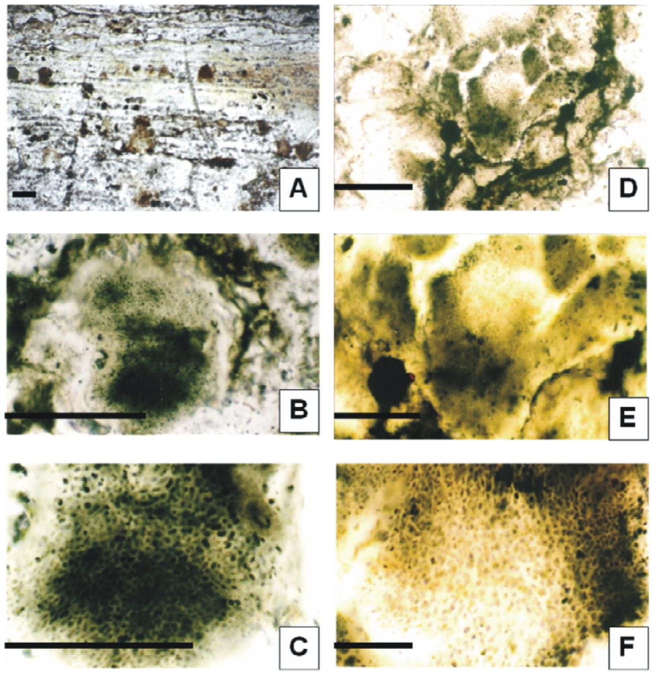

Fig. 6: **A**: Slide No. Rai-7; Co-Ordinates 19.1X51.8; England Finder No. I58/2; Scale=200µm.

Thallophytes; General view of thin section of chert showing colonial organization of Thallophytes.

B: Slide No. Rai-1; Co-Ordinates 7.8X46.4; England Finder No. E47/3; Scale=200µm.

Thallophyca ramosa Zhang, 1989, emend. Zhang *et al.,* 1998; Leaf shaped thallus.

C: Slide No. Rai-1; Co-Ordinates 7.8X46.4; England Finder No. E47/3; Scale=100µm.

Thallophyca ramosa Zhang, 1989, emend. Zhang *et al.,* 1998; Small cortical cells

surrounding the medullary cells.

D: Slide No. Rai-3; Co-Ordinates 21.2X57.3; England Finder No. Q61/3; Scale=200µm.

Thallophyca corrugata Zhang and Yuan, 1992, emend. Zhang *et al.,* 1998; The upper part of the thallus is caved in that divide thalli into lobes.

E: Slide No. Rai-3; Co-Ordinates 21.2X57.3; England Finder No. Q61/3; Scale=100µm.

Thallophyca corrugata Zhang and Yuan, 1992, emend. Zhang *et al.,* 1998; Magnified view of lobes.

F: Slide No. Rai-3; Co-Ordinates 21.2X57.3; England Finder No. Q61/3; Scale=50µm.

Thallophyca corrugata Zhang and Yuan, 1992, emend. Zhang *et al.,* 1998; Magnified view of lobe.

Occurrence and Stratigraphic Range: Doushantuo Formation, South China, Terminal Proterozoic.

Fig. 5

ACKNOWLEDGEMENTS

The authors express their heartfelt thanks to several colleagues and co-workers who were instrumental in carrying out the present studies. In particular, they are thankful to Prof. I.B. Singh for introducing VR to the field of Krol-Tal geology, to Prof. A. K. Jauhri for encouragement, to Ms. Neetima Sateeja for help in the field work and to Ms. Purnima Sharma and Droupti Yadav for help at various stages of preparation of the manuscript. Prof. K. K. Agarwal, Head, Department of Geology, University of Lucknow is thankfully acknowledged for providing the necessary facilities of the department to carry out the present work. Financial assistance from UGC in the form of a Major Research Project sanctioned to VR is thankfully acknowledged.

REFERENCES

Azmi, R.J. 1983. Microfauna and age of Lower Tal Phosphorite of Mussoorie Syncline, Garhwal Lesser Himalaya. *Himalayan Geology,* **11**: 373-409.

Azmi, R.J. 1987. Global prospects of small shelly fauna of Krol-Tal of Garhwal Lesser Himalaya, India. *Conference Volume Geology of Krol Basin in Garhwal, Garhwal University*, 39-44.

Azmi, R.J., Joshi, M.N. and Juyal, K.P. 1980. Discovery of the Cambro-Ordovician conodonts from the Mussoorie Tal Phosphorite and its significance in correlation of the Lesser Himalaya. *XI*

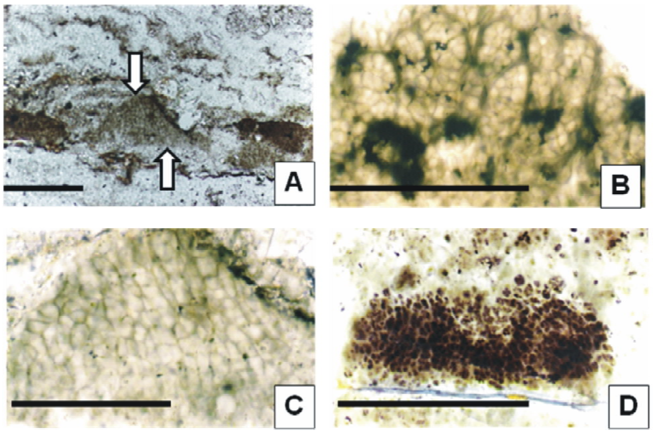

Fig. 7. **A**: Slide No. Rai-12; Co-Ordinates 8.0X47.2; England Finder No. F47/3; Scale=200µm.

General view of thin section of chert. Arrows indicate position of multicellular alga.

B: Slide No. Rai-19; Co-Ordinates 13.9X48.3; England Finder No. G53/3; Scale=100µm.

Multicellular alga; Rectangular and polygonal cells 4-12 µm in diameter. The polygonal cells are compactly packed in vesicle like bodies.

C: Slide No. Rai-12; Co-Ordinates 7.9X47.2; England Finder No. F47/1; Scale=100µm

Multicellular alga; Rectangular (and polygonal) cells 4-12 µm in diameter. These cells occur in elongated parallel form giving a pseudo-tubular shape.

D: Slide No. Rai-17; Co-Ordinates 7.2X50.0; England Finder No. J46/2; Scale=100µm.

Thallophyte; Medullary portion of Thallophyte.

Repository: All the thin sections and specimens have been kept at the museum of the Department of Geology, University of Lucknow, Lucknow, Uttar Pradesh, India.

Himalayan Geology Seminar on Palaeontology and Biostratigraphy of the Himalaya, W.I.H.G. Dehradun, 4-5 (abstract).

Azmi, R.J., Joshi, M.N. and Juyal, K.P. 1981. Discovery of Cambro-Ordovician conodonts from the Mussoorie Tal Phosphorite and its significance in correlation of Lesser Himalaya. *In: Sinha, A.K. (ed.) Contemporary Geoscientific Researches in Himalaya,* **1**: 245-250.

Bhargava, O. N. 1972. A reinterpretation of the Krol Belt. *Himalayan Geology*, **2**, 47-81.

Bhatt, D.K., Mamgain, V.D. and Misra, R.S. 1985. Small Shelly Fossils of Early Cambrian (Tommotian) Age from Chert-Phosphorite Member, Tal formation, Mussoorie Syncline, Lesser Himalaya, India and their Chronostratigraphic Evaluation. *Journal of the Palaeontological Society of India,* **30**: 92-102.

Bhatt, D.K., Mamgain, V.D., Misra, R.S. and Srivastava, J.P. 1983. Shelly Microfossils of Tommotian Age (Lower Cambrian) from the Chert- Phosphorite Member of Lower Tal formation, Maldeota, Dehradun Distt, U.P. *Geophytology,* **13**(1): 116-123.

Gautam, R. and Rai, V. 1997 a. Branched microbiota from the bedded black chert of the Krol Formation (Neoproterozoic), Lesser Himalaya, India. *Palaeobotanist,* **46**(1, 2): 32-40.

Gautam, R. and Rai, V. 1997 b. Large acanthomorphic acritarchs: their evolution, diversification and extinction across the Neoproterozoic - a case history from the Krol Formation, Lesser Himalaya, India. *30th Annual Meeting of the American Association of Stratigraphic Palynologists on Evolution of the Marine Phytoplankton, Woods Hole, Massachusetts*, **18** (abstract).

Jiang, G., Christie-Blick, N., Kaufmann, A. J., Banerjee, D.M., Rai. V. 2002. Sequence Stratigraphy of the Neoproterozoic Infra Krol Formation and Krol Group, Lesser Himalaya, India. *Journal of Sedimentary Research*, **72**: 524-542.

Joshi, A. and Mathur, V.K. 1987. Report of Cruziana type trace fossils from the Arenaceous Member of Tal formation, Mussoorie Synform. *Indian Minerals*, **41**(2): 61-65.

Joshi, A., Mathur, V.K. and Bhatt, D.K. 1989. Discovery of Redlichid trilobites from the Arenaceous Member of Tal Formation, Garhwal Syncline, Lesser Himalaya, India. *Journal Geological Society of India*, **33**(6): 538-546.

Kumar, G., and Dhaundiyal, J.N. 1981. Stratigraphy and Structure of "Garhwal Synform", Garhwal and Tehri Garhwal Districts, Uttar Pradesh, : A Reappraisal. *Himalayan Geology*, **9**(1): 18-41.

Kumar, G., Raina, B.K. and Jangpangi, B.S. 1983. Lower Cambrian body and trace fossils from the Tal Formation, Garhwal Synform, and U.P., INDIA. *Journal of the Palaeontological Society of India*, **28**: 106-111.

Kumar, S. and Rai, V. 1992. Organic-Walled Microfossils from the Bedded Black Chert of the Krol Formation (Vendian), Solan Area, H.P., India. *Journal Geological Society of India*, **39**: 229-234.

Leiming Yin, 1985; Microfossils of the Doushantuo Formation in the Yangtze Gorge District, Western Hubei. *Palaeontologia Cathayana*, **2**: 229-252.

Mathur, V.K. and Shanker, R. 1989. First record of Ediacaran fossils from the Krol Formation of Naini Tal Syncline. *Journal Geological Society of India*, **34**: 245-254.

Mathur, V.K. and Joshi, A. 1989. Record of inarticulate brachiopods from the Arenaceous Member of the Tal Formation, Lesser Himalaya, India. *Current Science*, **58**(8): 446-448.

Mathur, V.K. and Shanker, R. 1990. Ediacaran Medusoids from the Krol Formation, Nainital Syncline, Lesser Himalaya. *Journal Geological Society of India*, **36**: 74-78.

Mathur, V.K., Joshi, A. and Kumar, G. 1988. Trace fossils from Cambrian Tal Formation, Himachal Lesser Himalaya, India and their stratigraphic significance. *Journal of the Geological Society of India*, **31**(5): 467-475.

Rai, Vibhuti 1991. The Krol-Tal Sequence of Lesser Himalaya. *Journal Geological Society of India*, **38**(6): 636.

Rai, Vibhuti and Singh, Aradhana 2003. Discovery of Thallophytic Red Algal Fossils from the Krol Formation (Neoproterozoic), Lesser Himalaya. *XIX Indian Colloquium on Micropalaeontology and Stratigraphy and Symposium on recent developments in Indian Ocean palaeoceanography and palaeoclimate, Banaras Hindu University, Varanasi.* Abstract, 134.

Rai, Vibhuti and Singh, I.B. 1983. Discovery of Trilobite impression in the Arenaceous Member of Tal Formation, Mussoorie area, India. *Journal of the Palaeontological Society of India*, **28**: 114-117.

Shanker, R. and Mathur, V.K. 1990. The Precambrian-Cambrian sequence in Krol Belt and Ediacaran fossils. *Workshop on Precambrian-Cambrian boundary with special reference to Ediacaran fossils at Nainital.* (Abstract)

Shanker, R. and Mathur, V.K. 1992. Precambrian-Cambrian sequence in Krol Belt and additional Ediacaran fossils. *Geophytology*, **22**: 27-39.

Shanker, R., Kumar, G., Mathur, V.K. and Joshi, A. 1993. Stratigraphy of Blaini, Infra-Krol, Krol and Tal succession, Krol Belt, Lesser Himalaya. *Indian Journal of Petroleum Geology*, **2**(2): 99-136.

Shanker, R., Mathur, V.K., Kumar, G and Srivastava, M.C. 1997. Additional Ediacaran biota from the Krol Group, Lesser Himalaya and their significance. *Geoscience Journal., Nav Jyoti Scientific Publications, Lucknow*, **XVIII**: 79-94.

Shukla, M., Babu, R., Mathur, V. K. and Srivastava, D. K. 2005. Microbial remains from the Chambaghat Formation, Krol Group, Himachal Lesser Himalaya, India and their significance. *Current Science*, **88**(8): 1223-1225.

Singh, Aradhana 2006. Biosedimentology and palaeobiology of the Terminal Proterozoic Krol Formation, Lesser Hiamalaya, India. *Unpublished Ph.D., Department of Geology, University of Lucknow, Lucknow.*

Singh, I.B. 1979. Environment and age of the Tal formation of Mussoorie and Nilkanth areas of Garhwal Himalaya. *Journal Geological Society of India*, **20**: 214-225.

Singh, I.B. 1980. Sedimentological evolution of the Krol belt sediments. *Himalayan Geology*, **8**(2): 657-683.

Singh, I.B. and Rai, Vibhuti 1977. On occurrences of Stromatolites in the Krol Formation of Nainital area and its implications on the age of Krol Formation. *Current Science*, **46**: 736-738.

Singh, I.B. and Rai, Vibhuti 1983. Fauna and biogenic structures in Krol-Tal succession (Vendian-Early Cambrian), Lesser Himalaya: their biostratigraphic and palaeoecological significance. *Journal of the Palaeontological Society of India*, **28**: 67-90.

Singh, I.B. and Tangri, A.K. 1976. Some observations on the sedimentology of the Blaini Formation, Himachal and U.P. Himalayas. *Proceedings of the 125th Anniversary Celebrations, G.S.I. Symposium, Lucknow.*

Tewari, V.C. 1988. Discovery of Vendotaenides from India. In *Indo-Soviet Symp, WIHG (Dehradun)*. (Abstract)

Tiwari, Meera 1996. Precambrian Cambrian boundary microbiota from the Chert Phosphorite Member of Tal Formation in the Korgai Syncline, Lesser Himalaya, India. *Current Science*, **71**(9): 559-566.

Tiwari, Meera and Azmi, R.J. 1992. Late Proterozoic organic-walled microfossils from the Infrakrol of Solan, Himachal Lesser Himalaya: an additional age constraint in the Krol Belt succession. *Palaeobotanist,* **39**(3): 387-394.

Tiwari, Meera and Pant, C.C. 2004. Neoproterozoic silicified microfossils in Infra Krol Formation, Lesser Himalaya, India. *Journal of Himalayan Geology*, **25**(1): 1-21.

Tiwari, Meera and Knoll, A.H. 1994. Large acanthomorphic acritarchs from the Infrakrol Formation of the Lesser Himalaya and their stratigraphic significance. *Journal of Himalayan Geology*, **5**(2): 193-201.

Tripathi, C., Jangpangi, B.S., Bhatt, D.K., Kumar, G. and Raina, B.K. 1984. Early Cambrian brachipods from Upper Tal Mussoorie Syncline, Dehradun Distt, U.P. India. *Geophytology*, **14**(2): 221-227.

Venkatachala, B.S., Shukla, M., Bansal, R. and Acharyya, S.K. 1990. Upper Proterozoic Microfossils from the Infra Krol Sediments, Nainital Synform, Kumaon Himalaya, India. *Palaeobotanist*, **38**: 29-38.

Xiao Shuhai, Zhang, Y. and Knoll, A.H. 1998. Three-dimensional preservation of algae and animal embryos in a Neoproterozoic phosphorite. *Nature*, **391**: 553-558.

Zhang, Y. 1989. Multicellular Thallophytes with differentiated tissues from Late Proterozoic phosphate rocks of South China. *Lethaia*, **22**: 113-132.

Zhang, Y. and Yuan Xunlai 1992. New data on Multicellular thallophytes and fragments of cellular tissues from Late Proterozoic phosphate rocks, South China. *Lethaia*, **25**: 1-18.

Zhang, Y., Yin Leiming, Xiao Shuhai and Knoll, A.H. 1998. Permineralized fossils from the Terminal Proterozoic Doushantuo Formation, South China. *Journal of Palaeontology*, **72**(4): 1-52.

Manuscript Accepted August 2013