The Palaeobotanist 57(2008) : 359-378
0031-0174/2008 $2.00

Ediacaran microbiota from the Baliana and Krol groups, Lesser Himalaya, India

†MANOJ SHUKLA[1], V.K. MATHUR[2], RUPENDRA BABU[1] AND D.K. SRIVASTAVA[2]

[1]*Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.*
[2]*Geological Survey of India, Northern Region, Sector E, Aliganj, Lucknow 226 024, India.*

(Received 17 April, 2008; revised version accepted 11 July, 2008)

ABSTRACT

Shukla M, Mathur VK, Babu R & Srivastava DK 2008. Ediacaran microbiota from the Baliana and Krol groups, Lesser Himalaya, India. The Palaeobotanist 57(3) : 359-378.

The different lithofacies of Infra Krol Formation of Baliana Group, Chambaghat and Mahi formations of Krol Group exposed in eight synclines of the Krol Belt in Lesser Himalaya have yielded rich Ediacaran microfossil assemblage. It is the first comprehensive account of excellent preservation of microfossils from these synclines. The assemblage comprises forty-one (41) taxa; three groups of the organic-walled microfossils (OWM)- A. algae (cyanobacteria and rhodophytes), B. protists and C. unknown affinities of biological forms, viz. multicellular cylindrical tubular and vase shaped microfossils (VSM). Studied litho-units include the black carbonaceous shale of Infra-Krol Formation of the Baliana Group; the phosphatic black chert lenticles and shale partings associated with quartz arenite of Chambaghat (Krol Sandstone) and black chert nodules associated with argillaceous limestone and shale of Mahi formations of Krol Group. The microfossil yielding succession conformably overlies the Cap Carbonate - a global marker lithounit of Blaini Formation, the base of the Ediacaran Period. Infra Krol, Chambaghat and Mahi formations underlies the Jarashi and Kauriyala formations of Krol Group which have yielded diversified soft bodied Ediacaran metazoans.

In the reported OWM assemblage, fifteen taxa of prokaryotes are comparable with the extant cyanobacteria belonging to Chroococcales, Entophysidales, Oscillatoriales and Nostocales. The acritarchs belonging to sphaeromorphida and sphaerohystrichomorphida subgroups are represented by twenty-two taxa. The two taxa of multicellular algal thalli (primitive/juvenile stage) of phylum Rhodophyta represents *Wengania* and *Thallophyca*, and single taxon of the two forms represented by vase-shaped microfossils (*Melanocyrillium hexodiadema)* and multicellular cylindrical tubular (*Sinocyclocyclicus guizhouensis*) of unknown affinities.

The recovered assemblage has close affinities with those microfossils known from the Ediacaran sediments exposed in other parts of the world, viz. Australia, Brazil, Canada, China, Finland, Namibia, Norway, Spitsbergen, Svalbard, Sweden, and Russian platform. The Krol Belt assemblage is exclusively characterized by the dominance of distinctive large sized acanthomorphs acritarchs (*Filisphaeridium*, *Echinosphaeridium*, *Tianzhushania*, *Ericiasphaera, Meghystrichosphaeridium* and *Papillomembrana)* followed by medium sized *Goniosphaeridium, Gorgonisphaeridium, Trachyhystrichosphaera, Cymatiosphaeroides, Vandalosphaeridium,* etc.), small spinose acritarchs (*Micrhystridium* and *Paracymatiosphaera*) and a few breakable/characteristic cyanobacteria (*Bavlinella, Salome*, *Obruchevella, Sinocyclocyclicus,* etc.). With meagre radiometric data available for Krol Belt of Lesser Himalaya, the present microfossil assemblage is recognized in establishing the biostratigraphic and environment framework for the investigated successions. The present microbial assemblage corroborates the age of the above succession to Ediacaran Period (630–542 Ma) and also supports the view that these formations were laid down in a tidal flat environment.

Key-words—Cyanobacteria, Acritarchs, Ediacaran biota, Baliana Group, Krol Group, Lesser Himalaya, India.

† Deceased on 6th June, 2006

Changing Scenario in Palaeobotany and Allied Subjects
Editor : J.S. Guleria

भारत में निम्न हिमालय के बलियाना एवं क्रोल समूहों से प्राप्त ईडियाकरन सूक्ष्म जीवजात

मनोज शुक्ल, वी.के. माथुर, रूपेंद्र बाबू एवं डी.के. श्रीवास्तव

सारांश

निम्न हिमालय में क्रोल पट्टी के आठ अभिनतियों में अनावरित बलियाना समूह, चंबा घाट और निम्न क्रोल समूह के माही शैलसमूहों की अलग-अलग शैल संलक्षणियों से प्रचुर ईडियाकरन सूक्ष्मजीवाश्म समुच्चय प्राप्त हुई है। इन अभिनतियों से सूक्ष्मजीवाश्मों का अत्युत्तम परिरक्षण का प्रथम बोधशील लेखा-जोखा है। समुच्चय इकतालीस (41) टैक्सा कार्बनिक दीवारी सूक्ष्मजीवाश्म (ओ.डब्ल्यू.एम.)-ए. के तीन समूहों से सन्निहित है- (ए). शैवाल (सायनोजीवाणु व रोडोफायट), (बी). प्रजीव तथा (सी). जीवविज्ञान प्ररूप की अज्ञात बंधुताओं अर्थात बहुकोशिकीय शंकुकारी नलिकाकार व पात्रनुमा सूक्ष्मजीवाश्म (वी.एस.एम)। अध्ययनीय शैल-इकाईयाँ बलियाना समूह के निम्न क्रोल शैलसमूह के श्याम कार्बनमय शेल; फॉस्फेटी श्याम चर्ट लैन्टीक्लुस तथा चंबा घाट (क्रोल बलुआ पत्थर) के क्वार्ट्ज़ एरेनाइट सहित और मृण्मय चूनापत्थर संघटित श्याम चर्ट ग्रंथिकांए तथा क्रोल समूह के माही शैलसमूहों के शेल सन्निहित हैं। प्राप्त सूक्ष्मजीवाश्म अनुक्रम कार्बोनेट आच्छद उपरिशायी-ब्लैनी शैलसमूह के एक वैश्विक चिह्नक शैल इकाई, ईडियाकरन अवधि का आधार। निम्न क्रोल, चंबा घाट एवं माही शैलसमूह क्रोल समूह के जरशी व कौरियेला शैलसमूह की उपरिशायी हैं जिनसे विविधरूपायित मृदु शरीरी ईडियाकरन उत्तरजंतु मिले हैं।

अभिलिखित ओ.डब्ल्यू.एम. समुच्चयों में प्रोकैरयोट्स की पंद्रह टैक्सा क्रुकोक्केलस, एन्टोफिजीडेल्स, ऑसीलेटोरिएल्स व नॉस्टोकेल्स की मौजूदा सायनोजीवाणु से तुल्य हैं। स्फैरोमॉर्फिडा व स्फैरोहिस्ट्रीकोमॉर्फिडा उपसमूह बाइस टैक्सा निरूपित हैं। फायलम रोडोफायटा के बहुकोशिकीय शैवाल थैल्लि (आदिम/प्राथमिक प्रावस्था) की दो टैक्सा *वैंगेनिया* व *थैल्लोफायका* को रूपायित करती हैं, तथा दो प्रारूपों की एकल वर्गक प्रात्रनुमा सूक्ष्मजीवाश्मों (*मेलनोसायरीलियम हैक्सोडाइडेमा*) और अज्ञात बंधुताओं के बहुकोशिकीय शंकुधारी नलिकाकार (*सिनोसायक्लोक्लिकस गाइज़ोएन्सिस*) द्वारा निरूपित हैं।

प्राप्त समुच्चय की निकट बंधुताएं विश्व के अन्य भागों में अनावरित ईडियाकरन अवसादों से प्राप्त उन ज्ञात सूक्ष्मजीवाश्मों अर्थात आस्ट्रेलिया, ब्राज़ील, कनाडा, चीन, फिनलैंड, नामीबिया, नार्वे, स्पितस्बर्गेन, स्वलबर्ड, स्वीडन एवं रूसी प्लेटफार्म से हैं। क्रोल पट्टी समुच्चय विशिष्टतः सुस्पष्ट दीर्घ आकारी एकेन्थोमार्फ एक्रिटार्च (फिलिस्फैरीडियम, ऐचिनोस्फैरीडियम, टाइनजुशेनिया, इरिसियास्फैरा, मेधीस्ट्रिक्रोस्फैरीडियम एवं पेपिलोमेम्ब्रेना) की प्रभुत्वता द्वारा तदोपरांत मध्यम आकारी (*गोनियोस्फैरीडियम, गॉर्गोनीस्फैरीडियम, ट्रेचीहिस्ट्रीकोस्फैरा, सायमैटियोस्फैरोइड्स* व वंडेलोस्फैरीडियम इत्यादि), लघु शूलमय एक्रिटार्च (मिक्रीस्ट्रीडियम व पैरासायमेटीओस्फैरा) तथा कुछेक टूटने योग्य/लक्षण सायनोजीवाणु (बेल्लीनेल्ला, सैलोम, ऑब्रुचेवेल्ला व सिनोसायक्लिकस इत्यादि) अभिलक्षणित है। निम्न हिमालय की क्रोल पट्टी हेतु उपलब्ध अल्प रेडियोमीटरी आँकड़ा के साथ, विद्यमान सूक्ष्मजीवाश्म समुच्चय अन्वेषित अनुक्रमों हेतु जैवस्तरिक एवं पर्यावरण ढाँचे को स्थापित करने को विख्यात है। मौजूदा सूक्ष्मजीवी समुच्चय ईडियाकरन अवधि (630-542 हजार) की उपर्युक्त अनुक्रम की आयु परिपुष्ट करती है तथा इस विचार का समर्थन करती है कि ये शैलसमूह ज्वारीय सपाट पर्यावरण में बने।

मुख्य शब्द - सायनोजीवाणु, एक्रिटार्च, ईडियाकरन जीवजात, बलियाना समूह, क्रोल समूह, निम्न हिमालय।

INTRODUCTION

THE Neoproterozoic-Early Cambrian succession represented by the Baliana-Krol-Tal groups is well exposed in the various synclines of Krol Belt, Lesser Himalaya, India (Shanker, 1989; Shanker *et al.,* 1993). The Baliana-Krol-Tal succession has close stratigraphic similarity with the Nantuo-Tsanglangpu succession of China (Kumar, 1984; Jiang *et al.,* 2003; Knoll *et al.,* 2006). The black carbonaceous shales and black chert nodules of the upper part of the Infra Krol Formation of the Baliana Group exposed in the Nainital, Garhwal and Mussoorie synclines in Uttaranchal; and Nigalidhar, Kamlidhar, Krol and Pachmunda synclines in Himachal Pradesh (Figs 1, 2–sections a-f, i and j) yielded Organic-walled microfossils (OWMs), i.e. cyanobacteria, acritarch, and *Incertae sedis* (plants/animal) forms i.e. multicellular cylindrical tubular and vase-shaped microfossils (VSMs). The phosphatic chert lenticles and black shale partings associated with quartz arenite of the overlying Chambaghat (Krol Sandstone) Formation, well exposed in Kamlidhar Syncline, H.P. (Figs 1, 2 - section g) yielded similar microbiota besides rhodophytes and forms of unknown affinities (plants/animal), i.e. multicellular cylindrical tubular structure. The black chert nodules associated with argillaceous limestone and shale of Mahi (Lower Krol) Formation of the Krol Group is well exposed in the Kamlidhar, Krol and Pachmunda synclines, H.P. (Figs 1, 2-sections g, h, i and j) yielded OWMs described in present text. The black chert nodules associated with black shale of the Infra Krol Formation in Manora-Hanumangarhi mule track section in Nainital Syncline belong to Mahi Formation as seemingly akin lithounits of Mahi Formation in Kamlidhar, Krol and Pachmunda synclines overlie the Chambaghat Formation (exposed west of Dadhau in H.P. only). Chambaghat Formation overlies the black shale of Infra Krol Formation. The Ediacaran (Terminal Neoproterozoic) microbiota (acanthomorphs and cyanobacteria remains) have previously been studied in Lesser Himalayan sediments of Infra Krol Formation of Baliana Group and Chambaghat & Mahi formations (=Krol A) of Krol Group in Uttaranchal and Himachal Pradesh (Acharyya *et al.,* 1989; Prasad *et al*., 1990; Kumar & Rai, 1992; Tiwari & Knoll, 1994; Tiwari & Pant, 2004; Shukla *et al.,* 2005a, b; Maithy & Kumar, 2007; present study). The Ediacaran macrofossils have also

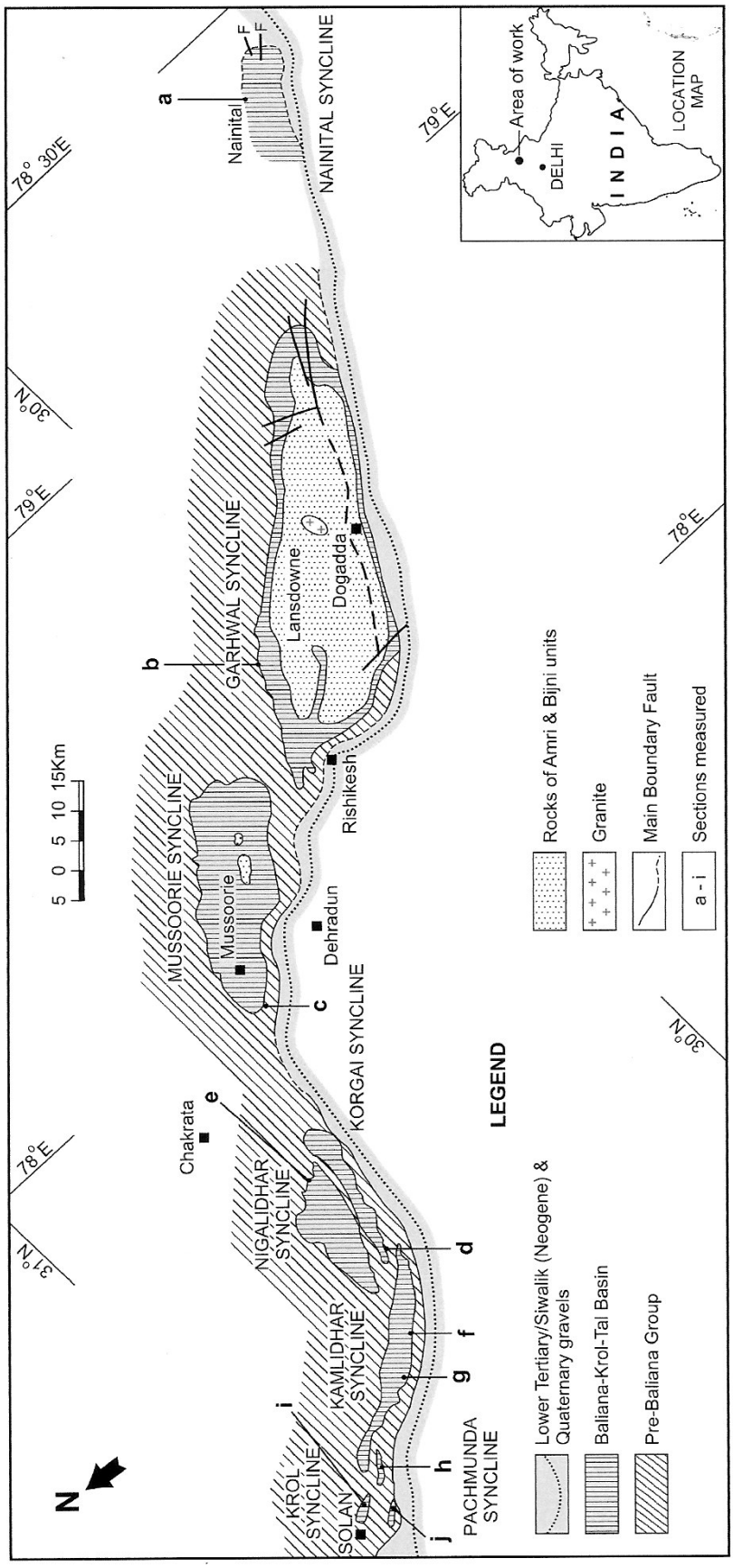
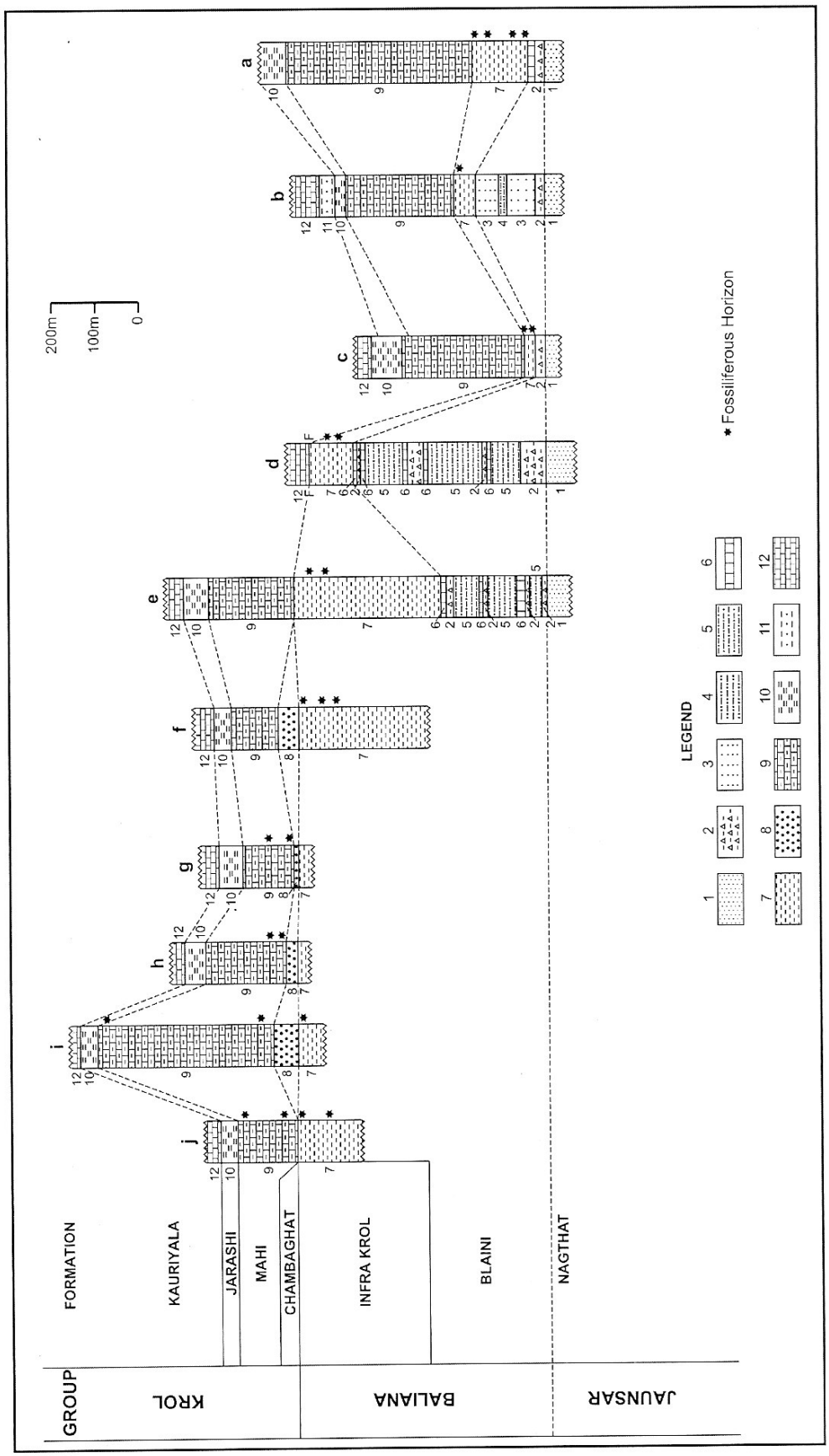


Fig. 1—Geological map of Baliana-Krol-Tal succession, Krol Belt, Lesser Himalaya, India (modified after Auden, 1934; Shanker *et al.*, 1993) showing measured sections.



Legend:1 Quartz arenite with silty partings, 2. Diamictite, 3. Fine to medium quartz arenite, 4. Shale, 5. Shale interbedded with Quartz arenite, 6. Pink limestone, 7. Black and bleached shale with silty partings, 8. Quartz arenite with or without phosphatic shale and chert, 9. Argillaceous limestone interbedded with calcareous shale, 10. Purple and green shale with lenticles of dolomitic limestone, 11. Siltstone interbedded with shale, 12. Blue crystalline limestone. * - Fossiliferous horizon.

Fig. 2—Stratigraphic sections of Baliana and lower part of Krol groups in Krol Belt, Lesser Himalaya, India showing microbiotic horizons. (a) Kilberry-Tanki section, Nainital Syncline, (b) Chilpar section, Garhwal Syncline, (c) Barapathar–Jharipani section, Mussoorie Syncline, (d) Karkhuli-Lathiyana section, Korgai Syncline, (e) Bokala-Shilla section, Nigalidhar Syncline, (f) Mathanan-Chanar section, Kamlidhar Syncline, (g) Jahar–Phagla section, Kamlidhar Syncline, (h) Ochhghat-Nandao section, Kamlidhar Syncline, (i) Chambaghat-Jarashi section, Krol Syncline and (j) Nagoli–Anji section, Pachmunda Syncline (sections f, g, h, i and j tectonically overly the Tertiary sediments).

Forms	Pachmunda	Krol	Kamlidhar	Nigalidhar	Korgai	Mussoorie	Garhwal	Nainital
A. ALGAL REMAINS	*Bavlinella favealata*	*Bavlinella favealata*	*Bavlinella favealata*	*Bavlinella favealata*	*Bavlinella favealata*	*Bavlinella favealata*	*Bavlinella favealata*	*Bavlinella favealata*
	Eoentophysalis gilensis	—	*Eoentophysalis gilensis*	—	—	—	—	—
	Eomicrocoleus crassus	—	*Eomicrocoleus crassus*	—	—	—	—	—
	Eomicrocystis malgica	*Eomicrocystis malgica*	—	—	—	—	—	*Eomicrocystis malgica*
	—	—	—	—	*Eophormidium orculiforme*	—	—	*Eophormidium orculiforme*
	—	—	—	—	—	—	—	*Globophycus rugosus*
	Huroniospora psilata & *H. microreticulata*	*Huroniospora psilata*	—	*Huroniospora psilata*	—	*Huroniospora microreticulata*	*Huroniospora psilata*	*Huroniospora microreticulata*
	Myxococcoides minor	*Myxococcoides minor*	*Myxococcoides minor*	*Myxococcoides minor*	—	—	—	—
	Obruchevella pussiella & *O. valdaica*	*Obruchevella parva, O. pussiella* & *O. valdaica*	*Obruchevella parva*	—	—	—	—	—
	Oscillatoriopsis brebiconvexa	*Oscillatoriopsis brebiconvexa*	*Oscillatoriopsis brebiconvexa*	*Oscillatoriopsis* sp.	*Oscillatoriopsis* sp.	—	—	—
	Palaeonacystis vulgaris	*Palaeonacystis vulgaris*	—	—	—	—	—	—
	Siphonophycus robustum, S. rugosum & *S. septatum*	*Siphonophycus robusturrobustum* & *S. septatum*	*S. kestron, S. robustum* & *S. typicum*	*Siphonophycus kestron, S. robustum*	*Siphonophycus robustum*	—	—	*S. robustum, S. rugosum* & *S. septatum*
	—	—	*Tetraphycus hebeiensis*	—	—	—	—	*Tetraphycus hebeiensis*
	—	—	*Veteronostocale moniliforme*	—	—	—	—	—
	Salome hubeinsis	*Salome hubeinsis*	—	—	—	—	—	—
	Thallophyca ramosa	*Thallophyca ramosa*	*Thallophyca ramosa*	—	—	—	—	—
	—	—	*Wengania globosa* & *W. minuta*	—	—	—	—	—

B. ACRITARCHS	*Sphaeromorphs*	*Granomarginata prima & G. primitiva*	*Granomarginata prima & G. primitiva*	*Granomarginata prima*	*Granomarginata prima & G. primitiva*	*Granomarginata prima*	—	—	*Granomarginata primitiva*
		Leiosphaeridia crassus	*Leiosphaeridia holtedahlii & Leiosphaeridia* sp.	*L. holtedahlii*	*Leiosphaeridia* sp.	*Leiosphaeridia asperta*	—	—	*L. effusa, & L. crassus*
		Margominuscula simplex	—	*Margominuscula simplex*	—	—	—	—	*Margominuscula simplex*
		Microconcentrica incrustata	—	—	—	—	—	—	*Microconcentrica incrustata*
		—	—	*Paracrassosphaera dedalea*	—	—	—	—	*Paracrassosphaera dedalea*
		Satka colonialica	*Satka colonialica*	*Satka colonialica*	—	—	—	—	*Satka colonialica*
	Acanthomorphs	*Archaeohystricho-sphaeridium cellulare*	*Archaeohystricho-sphaeridium cellulare & A. semireticulatum*	—	—	—	—	—	*Archaeohystricho-Sphaeridium cellulare & A. semireticulatum*
		Baltisphaeridium perrarum	*Baltisphaeridium perrarum*	*Baltisphaeridium perrarum*	*Baltisphaeridium* sp.	—	—	—	*Baltisphaeridium perrarum*
		Cymatiosphaeroides kulingii	*Cymatiosphaeroides kulingii*	—	*Cymatiosphaeroides kulingii*	—	—	—	—
		Echinosphaeridium maximum	*Echinosphaeridium maximum*	—	—	—	—	—	—
		—	*Ericiasphaera rigida*	—	—	—	—	—	—
		—	*Filisphaeridium* sp.	—	—	—	—	—	—
		—	—	—	—	—	—	—	*Germinosphaera unispinosa*
		—	*Goniosphaeridium conoideum*	—	—	—	—	—	—
		Gorgonisphaeridium maximum	*Gorgonisphaeridium maximum*	*Gorgonisphaeridium pindyium*	—	—	—	—	*Gorgonisphaeridium maximum*
		—	*Meghhystrichosphaeridium perfectum*	—	—	—	—	—	—
		Micrhystridium echinuatum, Micrhystridium sp.	*Micrhystridium notatum*	*Micrhystridium lanceolatum*	*Micrhystridium regulare*	*Micrhystridium* sp.	—	—	*M. eatonensis, M. echinuatum & M. regulare*
		—	*Papillomembrana compata*	—	—	—	—	—	—
		Paracymatiosphaera Annularis	*Paracymatiosphaera Annularis & regularis*	—	—	—	—	—	—
		Tianzhushania spinosa	*Tianzhushania spinosa*	—	—	—	—	—	—
		Trachyhystrichosphaera vidalii	*Trachyhystrichosphaera aimica*	—	—	—	—	—	*Trachyhystrichosphaera vidalii*
		Vandalosphaeridium reticulatum	*Vandalosphaeridium reticulatum*	*Vandalosphaeridium reticulatum*	—	—	—	—	—
C. INCERTAE SEDIS		*Melanocyrillium hexodiadema*	*Melanocyrillium hexodiadema*	*Melanocyrillium hexodiadema*	—	—	—	—	*Melanocyrillium hexodiadema*
		Sinocyclocyclicus guizhouensis	*Sinocyclocyclicus guizhouensis*	—	—	—	—	—	—

Fig. 3—Distribution of the Organic-walled microfossils from the Infra Krol-Mahi (Krol A) successions of different synclines, Himalaya.

been described from the Krol Group (Mathur & Shanker, 1989, 1990; Shanker & Mathur, 1992; Shanker *et al.,* 1997, 2004; Mathur & Srivastava, 2004). The present microfossil assemblage also occurs in the Neoproterozoic sediments (ca. 1000-542 Ma) of Arizona, Australia, Brazil, Canada, China, Finland, Greenland, India, Namibia, Norway, Spitsbergen, Svalbard, Sweden, and Russian Platform (Bloeser *et al.,* 1977; Yin & Li, 1978; Tynni & Donner, 1980; Awramik *et al.,* 1985; Zhang, 1989; Knoll, 1996, 2003; Yankauskas *et al.,* 1989; Pyatiletov & Rudavaskaya, 1990; Vidal, 1976, 1990; Kolosova, 1991; Butterfield *et al.,* 1994; Maithy & Babu, 1997; Zhang *et al.,* 1998; Yuan & Hofmann, 1998; Xiao & Knoll, 1999; Samuelsson & Butterfield, 2001; Yin, 2001; Samuelsson *et al.,* 1999; Zhou *et al.,* 2002; Grey *et al.,* 2003; Yin *et al.,* 2004; Nagy & Porter, 2005; Prasad *et al.,* 2005). The implications of the microbial finding, both protists and prokaryotes, based on the morphology and chemo fossil data in associated well dated samples are very significant in building biostratigraphy (Fensome *et al.,* 1990; Knoll, 1996, 2003; Jenkins *et al.,* 1992; Zang & Walter, 1992a, b; Sarjeant & Stanchiffe, 1994; Zang, 1995; Yin & Gao, 1995; Vidal & Moczydlowska, 1997; Knoll & Sergeev, 1995; Samuelsson & Butterfield, 2001; Prasad & Asher, 2001; Grey *et al.,* 2003; Gäucher *et al.,* 2005). The ecological and environmental factors were responsible to the complexity and diversification of the microphytofossils and their relics (Horodyski *et al.,* 1977; Vidal & Nystuen, 1990; Vidal & Knoll, 1982; Green *et al.,* 1988; Hofmann & Jackson, 1991; Knoll *et al.,* 1991; Germs, 1995; Kah & Knoll, 1996; Vidal & Moczydlowska, 1997; Grey & Corkeron, 1998; Gäucher *et al.,* 2005). The lineage of the cyanobacteria and other algae with eumetazoan, because of the sufficient amount of oxygen released through photosynthesis is responsible to rapid evolution and diversification in Terminal Neoproterozoic Period (Peterson & Butterfield, 2005).

The aim of the present study is to analyze the microfossils data for regional as well as global correlation and evaluate palaeoenvironments of the sediments in this area.

MATERIAL AND METHODS

The surface samples of silicified carbonaceous black shale associated with chert nodules belonging to different formations of Baliana and Krol groups, were collected by two of us (VKM and DKS) from the eight synclines of the Krol Belt, Lesser Himalaya, India (Figs 1 & 2). The microfossil studies were carried out at Birbal Sahni Institute of Palaeobotany, Lucknow by two of us (MS and RB). All taxa described below are recovered in both petrographic thin sections and residues using standard maceration techniques. Centrifuge and sieving have not been applied during maceration to avoid disintegration of biological remains. Petrographic thin sections were prepared along the bedding planes of the rocks. The specimens are well-preserved and dark brown in colour. The detailed systematic descriptions of the uncommon microbial elements are being given here only while other published taxa (Shukla *et al*., 2005a, b) are tabulated in Fig. 3. The slides have been examined and micro photographed in 100 X (under immersion oil) through transmitted optical light in Olympus BH2 microscope. All the slides and micro photographed negatives are deposited at the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow, India.

GROUP	FORMATION	LITHOLOGY	AGE	
KROL	KAURIYALA (= Krol C, D and E)	Calcareous shale, limestone, dolomite, siltstone, dolomitic limestone interbedded with shale, siltstone, quartz arenite and black lenticular chert, massive bluish grey limestone with or without gypsum	EDIACARAN	NEOPROTEROZOIC
	JARASHI (= Krol B)	Purple and greenish shale with thin limestone with or without gypsum		
	MAHI (= Krol A)	Argillaceous limestone interbedded with shale and marl		
	CHAMBAGHAT (= Krol Sandstone)	Quartz arenite		
BALIANA	INFRA KROL	Bleached and black pyritous shale with thin siltstone		
		Pinkish limestone, diamictite interbedded with quartz arenite and shale		
	BLAINI		CRYOGENIAN	
		Unconformity		
JAUNSAR	NAGTHAT	Quartz arenite and thin siltstone		

Fig. 4—Generalised stratigraphic set up of the Baliana-Krol Succession in Uttaranchal and Himachal Pradesh, Krol Belt, Lesser Himalaya, India (after Shanker *et al.,* 1993).

GEOLOGICAL SETTING

The Neoproterozoic Baliana and Krol groups rest unconformably over the Early Neoproterozoic Jaunsar/Simla Group. The Baliana Group is divisible into the Blaini and Infra Krol formations. The Blaini Formation represented by diamictite interbedded with quartz arenite and shale is generally capped by pink limestone. The Infra Krol Formation comprising of black and bleached shale ± cherty nodules with thin silty layers conformably overlies the Blaini Formation. The Krol Group conformably overlies the Infra Krol Formation and comprises four formations in the ascending order namely; Chambaghat (Krol Sandstone), Mahi (Lower Krol), Jarashi (Middle Krol) and Kauriyala (Upper Krol). The Chambaghat Formation comprises quartz arenite with or without lenticles of phosphatic chert and shale. It is restricted in the northwestern part of the Krol Belt. Mahi (Lower Krol) Formation is represented by argillaceous limestone interbedded with greenish grey shale and siltstone. Jarashi Formation comprises purple and greenish shale with lenticles of dolomitic limestone and gypsum beds. In the Garhwal and Nainital synclines the upper part of this formation shows shale – siltstone intercalations with rhythmic and lenticular bedding. Kauriyala Formation comprises bluish grey limestone, microbial dolomite with black lenticular chert and thin calcareous shale, siltstone and quartz arenite partings.

The Baliana and Krol groups cover the time interval from Early Neoproterozoic to Ediacaran (Terminal Neoproterozoic) Period. It is significant that the pink carbonate overlying the uppermost diamictite of Blaini Formation correlates well with the Cap Carbonate above the Marinoan tillites of Australia and Nantau tillites of China. Pink carbonate forms the base of the Ediacaran Period (Knoll *et al.*, 2006). The generalized lithostratigraphic succession of the Baliana-Krol-Tal succession in Uttaranchal and Himachal Pradesh, Krol Belt is shown in Fig. 4.

SYSTEMATICS

A. Cyanobacterial (Prokaryotes) remains

Kingdom—Eubacteria Woese & Fox, 1977

Phylum—Cyanophyta Stanier *et al.,* 1978

Class—Coccocogoneae Thuret, 1875

Order—Chroococcales Wettstein, 1924

Family—Chroococcaceae Nägeli, 1849

Genus—*Palaeoanacystis* Schopf, 1968

Type species—*Palaeoanacystis vulgaris* Schopf, 1968

Palaeoanacystis vulgaris Schopf, 1968

(Pl. 1.11)

Description—Colony, sphaeroidal-subsphaeroidal, 90.5-92 µm, mucilaginous sheath indistinct around the colony, counted 20-25 cells, cells usually spherical in shape, some cells polygonal owing to distortion and compression, psilate, 8-8.2 µm, wall thick, 0.5-1 µm, smooth surface, wall single layered.

Remarks—The present form is morphologically similar to the known *Palaeoanacystis vulgaris* Schopf reported from the Bitter Springs Formation, Australia (Schopf, 1968), Belcher Islands, Canada (Hofmann, 1976), ill preserved from the Bagalkot Formation, Kaladgi Group (Viswanathiah *et al.,* 1978, 1984; Venkatachalapathy & Ravindra, 1984); Bababudan Formation, Dharawar Supergroup (Viswanathiah & Venkatachalapathy, 1980), Voblapur Group (Venkatachalapathy & Basavaraju, 1986), Patherwa Formation of Semri Group (Nautiyal, 1983), Kushalgarh Formation, Delhi Supergroup (Mandal *et al.,* 1984); Infra Krol Formation, Krol Belt, Nainital Synform and Buxa Dolomite Formation, Buxa Group (cited references in Shukla *et al.,* 2006).

Class—Hormogoneae Thuret, 1875

Order—Nostocales Wettstein, 1924

Family—Oscillatoriaceae Nägeli, 1849

Genus—*Obruchevella* (Reitlinger) Yakshin & Luchinina emend. Knoll, 1992

Type species—*Obruchevella delicata* Reitlinger, 1948

Obruchevella valdaica (*Schepeleva ex Aseeva*) Yankauskas *et al.,* 1989

(Pl. 1.10, 14)

PLATE 1

(Bar showing the magnification mentioned in each fig.)

1. *Salome hubeinsis* Zhang, Slide BSIP No. 13492.
2. *Salome hubeinsis* Zhang, Slide BSIP No. 13492.
3. *Salome hubeinsis* Zhang, Slide BSIP No. 13492.
4. *Thallophyca ramosa* (Zhang) Zhang *et al.,* Slide BSIP No. 13492.
5. *Salome hubeinsis* Zhang, Slide BSIP No. 13492.
6. *Sinocyclocyclicus guizhouensis* Xue *et al.,* Slide BSIP No. 13492.
7, 8. *Obruchevella pussiella* Golovenok & Belova, Slide BSIP No. 13500.
9. *Salome hubeinsis* Zhang, Slide BSIP No. 13492.
10. *Obruchevella valdaica* (Schepeleva ex Aseeva) Yankauskas *et al.,* Slide BSIP No. 13492.
11. *Palaeoanacystis vulgaris* Schopf, Slide BSIP No. 13492.
12. *Thallophyca ramosa* (Zhang) Zhang *et al.,* Slide BSIP No. 13492.
13. *Salome hubeinsis* Zhang, Slide BSIP No. 13500.
14. *Obruchevella valdaica* (Schepeleva ex Aseeva) Yankauskas *et al.,* Slide BSIP No. 13495.
15. *Salome hubeinsis* Zhang, Slide BSIP No. 13492.

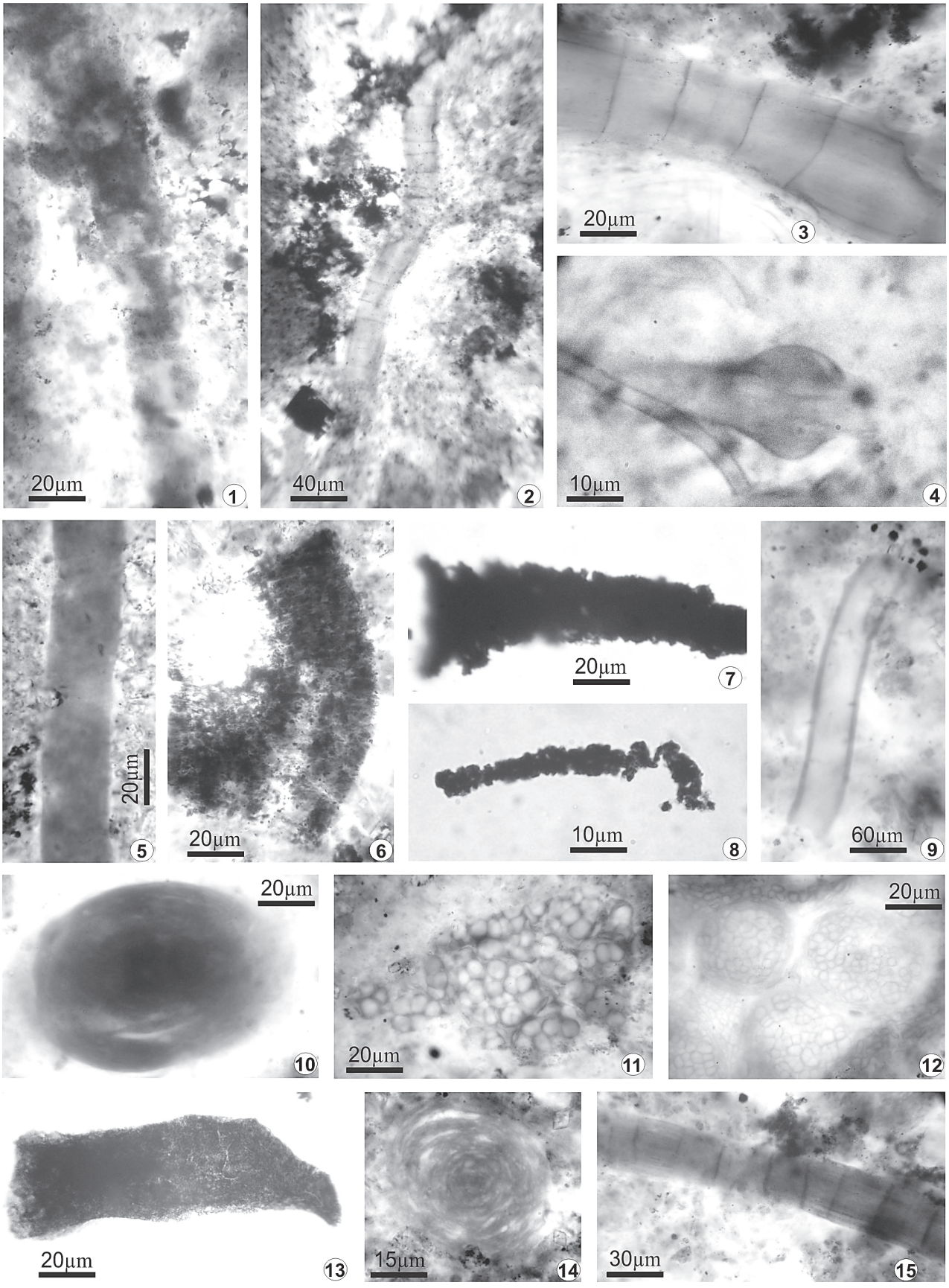

20µm
1
40µm
2
20µm
3
10µm
4
20µm
5
20µm
6
20µm
7
10µm
8
60µm
9
20µm
10
20µm
11
20µm
12
20µm
13
15µm
14
30µm
15

PLATE 1

Description—Compressed clumpy microfossils with sub circular outline, 36-88 µm, comprising long, tightly coiled whorls, aseptate filament of the unicellular form, width in range of 4-10 µm and upto several hundred milimicrons in length; central portion of coiled mass commonly missing, arrangement of coils more or less concentric, with successive whorls in well preserved specimens crossing at small acute angles; some specimens with expending coils apparently arranged with coaxial whorls.

Remarks—The present form is morphological similar to *Obruchevella valdaica* which is known from the Upper Riphean sediments of the Siberian Platform (Yankauskas *et al.,* 1989; Mankiewicz, 1992), Thule Supergroup, Greenland (Samuelsson *et al.,* 1999); Bhander and Buxa Dolomite groups in India (Prasad & Asher 2001; Prasad *et al.,* 2005; Shukla *et al.,* 2006). Similar form (*Volyniella cylindrica*) was described from the upper Riphean sediments of Hailuoto Formation, Finland (Tynni & Donner, 1980). A stray record of this taxon is known from the Baffin Island (ca. 1200-750 Ma) sediments of Bylot Supergroup, Canada (Hofmann & Jackson, 1994). Similar empty helically coiled trichome/mucilaginous sheaths described as a *Volyniella valdaica* from the Upper Riphean – Early Cambrian sediments of the Siberian Platform (Aseeva, 1974), is recognized by Yankauskas *et al*. (1989) as a n. comb. "*Obruchevella valdaica"*. However, Ragozina and Sivertseva (1990) have also recorded similar forms by from Vendian sediments of the Valdai series, northwestern Arkhangelsk District, and retained as *Volyniella valdaica* Aseeva.

Obruchevella pussiella Golovenok & Belova, 1983

(Pl. 1.7, 8)

Description—Tightly coiled trichome with walls of adjacent whorls touching each other, whorls, 10-20 µm length, diameter 05-10 µm, number of coils more than 10, diameter of filament 0.5-1 µm, aseptate, unicellular in nature.

Remarks—The present form is morphologically similar to *Obruchevella pussiella,* reported from Vendian sediments, Russian Platform (Golovenok & Belova, 1983). However, the diameter of the trichome in the present specimens is lesser than *O. minuta* from the Yukan Territory, Canada (Allison & Awramik, 1989) and *O. blandita* from Svanberfjellet, Svalbard (Butterfield *et al.,* 1994). There is no acridium like characteristic feature of the *Siphonophycus/ Oscillatoriopsis* in the present specimens.

Genus—*Salome* Knoll, 1982

Type species—*Salome svalbardensis* Knoll, 1982

Salome hubeinsis Zhang, 1986

(Pl. 1.1-3, 5, 9, 13, 15)

Description—Trichome incomplete, 30-70 µm, some time trichome surrounded by multiple sheath mucilaginous, uniseriate, unbranched, individual cell disc-shaped with rounded-subconical, diminution of trichome, terminal diameter apices, slightly constructed between the adjacent cells, no heterocysts/akinetes found along the trichome length, thick mucilaginous sheath present.

Remarks—It is identical to the known *Salome hubeinsis* Zhang reported from Late Sinian sediments of Doushantuo Formation, China (Zhang, 1986; Zhang *et al.,* 1998). An akin form (empty sheath of Oscillatoriales) has been described as *Eomicrocoleus crassus* from the Middle Proterozoic sediments Dismal Lakes Group, Arctic Canada (Horodyski & Donaldson 1980), Infra-Krol Formation in Solan of Himachal Pradesh and Nainital of Uttaranchal (see cited reference Tiwari & Pant, 2004). The present form is brown in colour, inner sheath ranging 20-60 µm in diameter that envelops trichome and a distinct tendency to crease or break transversely at irregular intervals along the length of filament. Varied shaped fractured and a zigzag streak line along the length of septa (Pl. 1.1, 5) are formed due to plasmolysis in harsh conditions. But in cross section such structures are not seen except pigmented part which is considered here as a trichome. Trichomes are rarely preserved (Awramik *et al.,* 1985). Some species of this genus, known from different places, have been placed earlier in the present species (Zhang *et al.,* 1998). The *Oscillatoriopsis longa* is also akin to these forms based on the empty sheath (Butterfield *et al.,* 1994).

All the merged various species of this genus are described by aforesaid workers should be retained as formed initially because they represent varied preservational gametophytic stages of a life period (cycle) which is also very short in extant algal forms.

PLATE 2

(Bar showing the magnification mentioned in each fig.)

1. *Trachyhystrichosphaera aimica* Hermann, Slide BSIP No. 13503.
2-3. *Ericiasphaera rigida* Zhang *et al.*, Slide BSIP No. 13504.
4-5. *Cymatiosphaeroides kulingii* Knoll, Slide BSIP No. 13492.
6, 12. *Papillomembrana compata* Zhang *et al.*,, Slide BSIP No. 13492.
7-9. *Goniosphaeridium conoideum (*Kolosova) Zhang *et al.*, Slide BSIP No. 13492.
*10. *Gorgonisphaeridium maximum* (Yin) Knoll, Slide BSIP No. 13498.
11, 13-14. *Echinosphaeridium maximum* (Yin L.) Knoll, Slide BSIP No. 13494 13497.

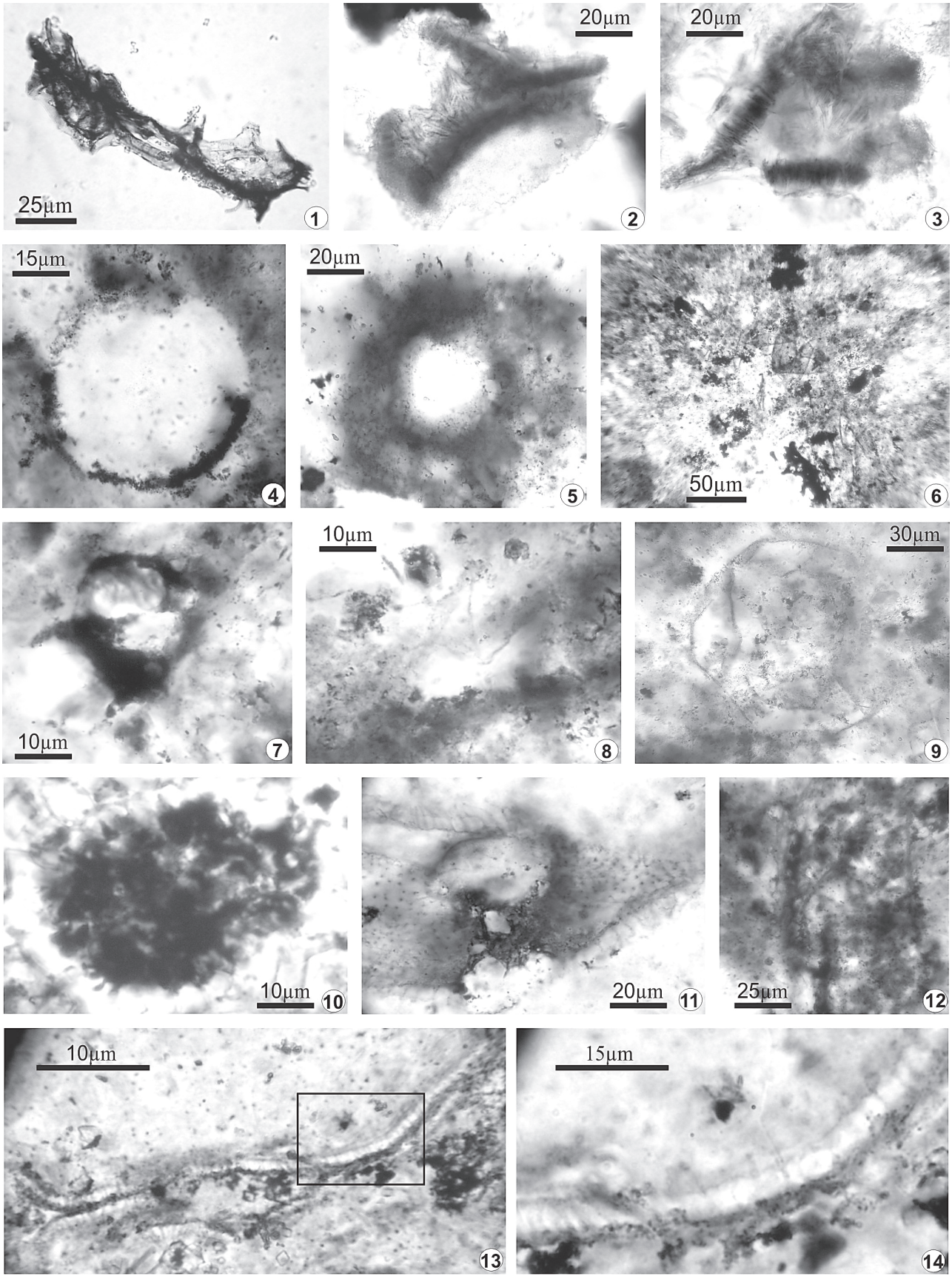

25μm
1
20μm
2
20μm
3
15μm
4
20μm
5
50μm
6
10μm
7
10μm
8
30μm
9
10μm
10
20μm
11
25μm
12
10μm
13
15μm
14

PLATE 2

Genus—*Thallophyca* (Zhang, 1989) Zhang *et al.,* 1998

Type species—*Thallophyca ramosa* (Zhang, 1989) Zhang *et al.,* 1998

Thallophyca ramosa (Zhang, 1989) Zhang *et al.,* 1998

(Pl. 1.4, 12)

Description—Thalli two types, i.e. 1. unicellular, symmetrical solid bulbous with pedicel, 2. subsphaeroidal clusters entangled in multicellular mass, length 780 µm, width 560 µm, subspherical-spherical medullarly cells forming reticulation similar to pseudoparenchymatous cells, ranging 10-20 µm in size, thick cortex of elongated cells compressed tangentially to thallus surface is also noticed.

Remarks—This form (Pl. 1.12) was also reported earlier from the phosphate rocks of Doushantuo Formation, China (Zhang 1989), Chambaghat Sandstone Formation of Krol Group, Himachal Pradesh (Shukla *et al.,* 2005a). *T. ramosa* and *T. simplica* described from the Doushantuo Formation, China (Zhang, 1989) considered biosynonymy of *T. ramosa* and have exclusively been compared with extant Solenoporaceae of Gigantiales/Ceraminales of Rhodophyta (Zhang *et al.,* 1998). Similar form comparable to extant Corallinales order is also described in Paleozoic sediments (Johnson, 1960). The subsphaeroidal body (cavity) with long cylindrical tail (pedicel) is figured from the Draken Conglomerate, NY Friesland, Svalbard (Knoll, 1982). The present empty sphaeroidal cavity with cylindrical tail interpreted here as undeveloped/primitive carposporangia? (Pl. 1.4) which is an important character of the red algae. Forms look like VSMs without characteristic feature (collar) are possible immature sporangia of any taxon of Rhodophyta.

B. Acritarchs

Subgroup—Sphaeromorphida Timofeev, 1966

Genus—*Leiosphaeridia* (Eisenack 1958) emend. Downie & Sarjeant, 1963

Type species—*Leiosphaeridia baltica* Eisenack, 1958

Leiosphaeridia sp. Yao *et al.,* 2005

(Pl. 3.6)

Description—Vesicle sub-spherical to sphaeroidal in outline, size 135 µm in diameter, irregularly folded, wall thick, 1-2 µm surface perforated.

Remarks—Morphologically similar form is reported from ca. Sinian–Vendian sediments Yurtus and Xishanblaq formations of the Mochia-Khutuk section in southern Tianshan and northern margin of Tarim Block, south China (Yao *et al.,* 2005).

Subgroup—Sphaerohystrichomorphida Timofeev, 1966

Genus—*Cymatiosphaeroides* Knoll, 1984

Type species—*Cymatiosphaeroides kulingii* Knoll, 1984

Cymatiosphaeroides kulingii Knoll, 1984

(Pl. 2.4-5)

Description—Sphaeroidal vesicles, double walled, inner wall robust, finer granulated less than 1 µm, vesicle size 70-140 (125) µm, maximum diameter with outer membrane 64 µm, solid cylindrical processes arisen from inner wall or membrane, regularly distributed over vesicle, process size 5 µm in length, no interconnecting septa and division of vesicle into polygonal field by septa or membrane.

Remarks—Morphologically similar form is reported in sediments ranging from ca 800-543 Ma of different countries like Scotia Group of Nordaustlandet, Svalbard (Knoll, 1984), Chuar Group of Arizona and Uinta Mountains of Utah (Vidal & Ford, 1985), Tindir Group Canada (Allison & Awramik, 1989). The *Cymatiosphaera membranacea* Kirjanov from Lower Cambrian Upper Dominopol subsuite of Volynia USSR had been questioned and is basically redesigned /postulated (Knoll, 1984) under a new genus *Cymatiosphaeroides* after critical studies of taxon *Cymatiosphaera* Wetzel reported in Palaeozoic sediments, and is akin to the present form described as *Cymatiosphaera* from the Bhander Group (Prasad *et al.,* 2005).

PLATE 3

(Bar showing the magnification mentioned in each fig.)

1-2. *Tianzhushania spinosa* (Yin and Li) Yin C & Liu, Slide BSIP No. 13497.
3-4. *Meghystrichosphaeridium perfectum (Kolosova)*, Slide BSIP No. 13492.
5, 11. *Filisphaeridium* sp., Slide BSIP Nos 13493, 13494.
6. *Leiosphaeridia* sp. Yao *et al.,* Slide BSIP No. 13494.
7. *Paracymatiosphaera regularis* Wang, Slide BSIP No. 13492.
8. *Paracymatiosphaera annularis* Wang, Slide BSIP No. 13499.
*9. *Bavlinella faveolata* (Schepeleva) Vidal, Slide BSIP No. 13502.
10. *Micrhystridium notatum* Volkova, Slide BSIP No. 13492.
*12. *Vanadlosphaeridium reticulatum* (Vidal) Vidal 13504.
*13. *Obruchevella parva* Reitlinger, Slide BSIP No. 13496.
*14. Algal mat *cf. Siphonophycus septatum* (Schopf) Hofmann & Jackson; *S. robustum* (Schopf) Knoll, Slide BSIP No. 13501.

*Taxa already described (Shukla *et al.*, 2005a, b)

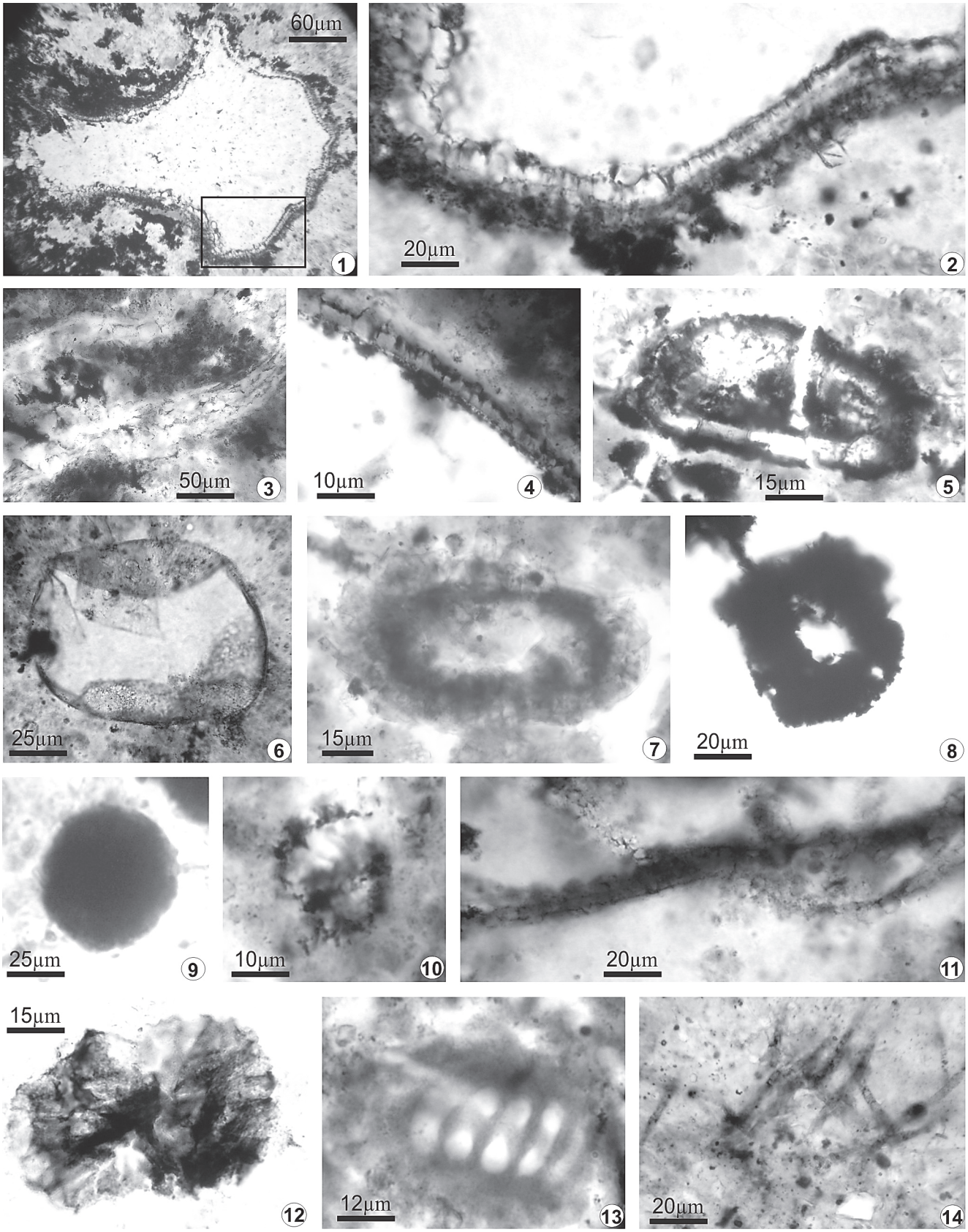

60µm
1
20µm
2
50µm
3
10µm
4
15µm
5
25µm
6
15µm
7
20µm
8
25µm
9
10µm
10
20µm
11
15µm
12
12µm
13
20µm
14

PLATE 3

Genus—*Echinosphaeridium* Knoll, 1992

Type species—*Echinosphaeridium maximum* (Yin L., 1987) Knoll, 1992

Echinosphaeridium maximum (Yin L.) Knoll, 1992

(Pl. 2.11, 13-14)

Description—Large sphaeroidal vesicles, 250 µm (commonly 500> µm), closely spaced, process; short, 3-6 µm long and 2-3 µm wide at the base, hollow and sharply conical, imparting an echinate appearance to the vesicle, presence of thin outer membrane at the tips of processes.

Remarks—The present specimen is morphologically similar to *Echinosphaeridium maximum* (Yin L.) Knoll, 1992a reported from metasedimentary cherts of Baklia Formation, Scotia Group, Prins Karls Forland, Svalbard (Knoll, 1992b); Sinian sediments of different regions in southern China (Yin & Gao, 1995); Infra-Krol Formation, Krol belts in Solan, Himachal Pradesh (Tiwari & Knoll, 1994) and Doushantuo Formation, Hubei and Guizhou provinces, China (Zhang *et al.,* 1998; Yuan & Hofmann, 1998). However, this form has been doubted in monographic studies on microfossils in Neoproterozoic sediments of the Svanberfjellet Formation, Spitsbergen (Butterfield *et al.,* 1994). *Trachyhystrichosphaera triangula* is confined hollow small sized spines, low density and bigger than the *E. Maximum* in size reported from the Pertatataka Formation, Australia (Zang & Walter, 1992a). Whereas, *Trachyhystrichosphaera triangula* confined solid spines is reported from the Svanberfjellet Formation, Spitsbergen (Butterfield *et al.,* 1994).

Genus—*Ericiasphaera* Vidal, 1990

Type species—*Ericiasphaera spjeldnaesii* Vidal, 1990

Ericiasphaera rigida Zhang *et al.,* 1998

(Pl. 2.2-3)

Description—Vesicles somewhat sphaeroidal, 90-140 µm in diameter, bearing numerous evenly spaced processes, processes homomorphic, straight, effectively solid, sometimes a very thin lamina observed, brittle, cylindrical with a slightly conical base and blunt tip spines, 5-11 µm long and 1 µm wide. Process orientation are coordinated, embedded in common mucilaginous sheath or envelop, numbers of the species were recorded. The present form is two in numbers.

Remarks—The present form is identical to the known *Ericiasphaera rigida* from the chert sediments of Upper Doushantuo Formation (ca. 600-550 Ma) of the Tianjiayuanzi section, western Hubei Province, China (Zhang *et al.,* 1998). *Oscillatoriopsis media* Mendelson and Schopf (1982) with spines like structures described from the chert nodules of the Infra-Krol Formation of Krol Belt based on diagenesis affect on the outer surface of the forms (Tiwari & Azmi, 1992; Tiwari, 1996; Tiwari & Pant, 2004) closely resembles the present form. The O*scillatoriopsis* is simple empty mucilaginous sheath that can not be easily decayed and altered like spiny structures owing to presence of complex organic substance during unfavourable conditions.

Genus—*Filisphaeridium* (Staplin *et al*.) emend. Sarjeant and Stanchiffe, 1994

Type species—*Filisphaeridium setasessitante* Staplin *et al.*, 1965

Filisphaeridium sp. Zhang *et al.,* 1998

(Pl. 3.5, 11)

Description—Vesicles sphaeroidal-sub cylindrical, 50-100 µm in diameter, bearing numerous, closely spaced, solid, flexible hair like processes, 5-8 µm in size. Single form was recorded in the assemblage.

Remarks—The present form is identical to *Filisphaeridium* sp. reported in chert sediments of Doushantuo Formation, China (Zhang *et al.,* 1998). A similar comparable form, *Briareus borealis* known from the metasedimentary cherts of Baklia Formation, Scotia Group Prins Karls Forland, Svalbard (Knoll, 1992b) and is larger than present form.

Genus—*Goniosphaeridium* (Eisenack) emend. Turner, 1994

Type species—*Goniosphaeridium polygonale* (Eisenack) Eisenack, 1969

*Goniosphaeridium conoideum (*Kolosova) n. comb. Zhang *et al.,* 1998

(Pl. 2.7-9)

Description—Vesicle sub-spherical to sphaeroidal in outline, measuring 100-200 µm in diameter, bearing sparse spines (6-15 nos. along perimeter), prominent spines, 30-50 µm long and 10-15 µm wide at the base, simple sometimes bifurcate, hollow, freely communicating with vesicle interior and gradually tapering to sharply pointed tip.

Remarks—This form is a new comb. of the *Goniosphaeridium conoideum,* reported from the chert of upper part of the Doushantuo Formation, China (Zhang *et al.,* 1998). It is smaller in size than the earlier described forms (G. *acuminatum* and *G. cratum*) from the Doushantuo Formation, China (Zhang *et al.,* 1998); coeval shale of Siberian Platform (Kolosova, 1991), Pertatataka Formation of Australia (Zang & Walter, 1992a).

Genus—*Meghystrichosphaeridium* Zhang *et al.,* 1998

Type species—*Meghystrichosphaeridium chandianensis* Chen & Liu, 1986

Meghystrichosphaeridium perfectum (Kolosova) n. comb. Zhang *et al.,* 1998

(Pl. 3.3-4)

Description—Vesicle sub-spherical to sphaeroidal in outline, size 40-50 µm (originally 42-200 µm in diameter), bearing numerous regularly spaced processes, 8-12 µm in length, hollow, spine sharp to blunt on the margin and at base and sometimes folds present.

Remarks—The morphologically similar form is also reported from the Vendian-Sinian sediments, i.e. eastern Siberian Platform (Kolosova, 1991); Doushantuo Formation, China (Zhang *et al.,* 1998) and Buxa Dolomites, Lesser Himalaya (Shukla *et al.,* 2006).

Genus—*Micrhystridium* (Deflandre) Lister, 1970

Type species—*Micrhystridium inconspicum* (Deflandre) Deflandre, 1937

Micrhystridium notatum Volkova, 1969

(Pl. 3.10)

Description—Vesicle sub-spherical to sphaeroidal in outline, size 20-25 µm (originally 16- 33 µm in diameter), bearing numerous irregularly spaced processes, 3-5 µm in length, 1-2 µm in width, solid hollow, sometimes solid, spine sharp to blunt on the margin and at base and sometimes folds present.

Remarks—The present form is morphologically similar to *Micrhystridium notatum* Volkova recorded from the early Cambrian sediments of northwest Russian Platform (Volkova, 1969) and Precambrian-Phanerozoic strata of the central Australia (Sergeev, 1989).

Genus—*Papillomembrana* (Spjeldnaes) Vidal emend. Zhang *et al.,* 1998

Type species—*Papillomembrana compata* (Spjeldnaes) Vidal emend. Zhang *et al.,* 1998

Papillomembrana compata Zhang *et al.,* 1998

(Pl. 2.6, 12)

Description—Large vesicle, sub-spherical to sphaeroidal in outline, measuring 518 µm (280-350 µm), bearing numerous evenly spaced an tightly arranged process, processes 30-42 µm long, 9-13 µm wide at base, and 3-7 µm apart, hollow and openly communicating with vesicle interior, flexible, cylindrical with little or no distal taper, and bluntly conical at distal end, proximal contract and bulbous (sometimes bifurcated distal end, connection between vesicles cavity and processes is not evident).

Remarks—This form was originally described from the upper Proterozoic sediments of southern Norway (Spjeldnaes, 1963; Vidal & Nystuen, 1990) and metasedimentary cherts of Baklia Formation, Scotia Group Prins Karls Forland, Svalbard (Knoll, 1992b). Morphology of this taxon was compared with Dasycladacean affinities based on sphaeroidal structures (Spjeldnaes, 1963). Vidal (1990) subsequently found vesicle bearing large processes in the Biskopäs Conglomerate (upper Precambrian), Norway and recognized this taxon as a *Papillomembrana*. The recovered *Papillomembrana* taxon from the phosphoritic cherts of Doushantuo Formation, China having both characters (sphaeroidal cell like structures and terminated large sized spines on the body) and was emended for this form (Zhang *et al.,* 1998). Twice sized identical to this form is also recorded from the Doushantuo Formation (Yuan & Hofmann, 1998).

Genus—*Paracymatiosphaera* Wang, 1985

Type species—*Paracymatiosphaera regularis* Wang, 1985

Paracymatiosphaera regularis Wang, 1985

(Pl. 3.7)

Description—Radially arranged spherical cell like units, rim of the spines, 6-13 µm, outer envelop 12-45 µm, dense spines structures surrounded by another envelop, sometimes envelop disrupted, solitary with slightly granular surface textures, spine like surface structures setaceous like, spine size 3-6 µm, equal diameter some spines of greater diameter, ratio of diameter of the cell wall and envelop 1 : 2.

Remarks—Morphologically similar form is reported from the SW China and contiguous area (Wang, 1985), Suijingtuo Formation, Hubei Province and Niutitang Formation, Guizhou, China (Yin *et al.,* 1992; Yin *et al.,* 2004), and a similar form, i.e. *Comasphaeridium annulare* (Wang) n. comb. is also recorded from the Xishanblaq formations of the Tarim, north-west China (Yao *et al.,* 2005). Akin taxon *Cymatiosphaera membrancea* (rim width and vacuole dimension ratio = 1 : 4) described from the Chulaktau and Kotak Formation of central Kazakhstan (Sergeev, 1989), is twice time bigger than present form.

Paracymatiosphaera annularis Wang, 1985

(Pl. 3.8)

Description—Vesicle subspherical to sphaeroidal in outline measuring 9-38 µm, average 16-20 µm, outer envelop 12-40 µm, the ratio is about 4 : 5, distinct regular radially arranged short densely processes, 1.5-3 µm in length, and 0.50 µm width, countable process 40 or more.

Remarks—Morphologically similar form is reported from the middle-upper Proterozoic and lower Phanerozoic sediments of southwest China and Contiguous area (Wang, 1985), Neoproterozoic - lower Cambrian sediments of Suijingtuo Formation, Hubei Province, Yargiaping Formation, Hunnan and Niutitang Formation, Guizhou, China (Yin *et al.,* 1992; Yin *et al.,* 2004). Similar forms (genera) have also been reordered from the Cambrian sediments belonging to Xishanblaq formations (Tarim, North-west China) considered as *Comasphaeridium annulare* (Wang) n. comb. (Yao *et al.,* 2005).

Genus—*Tianzhushania* (Yin L & Li, 1978) emend. Yin C & Liu, 1988

Type species—*Tianzhushania spinosa* (Yin L & Li, 1978) emend. Yin C & Liu, 1988

Tianzhushania spinosa (Yin & Li) emend. Yin C & Liu, 1988

(Pl. 3.1-2)

Description—Vesicles spherical, size 350-750 µm, consist multilayered, processes penetrate these layers, arise from the external membranes (primary vesicle wall), conical spines on the surface, 6 µm long, 4-6 µm broad at the base, hollow, process bearing inner vesicle enveloped by the thin smooth layer.

Remarks—Morphologically similar form is reported from Precambrian-Cambrian sediments of China (Yin & Li, 1978; Yin & Liu, 1988). This form is the most characteristic in Doushantuo and other Neoproterozoic formations, China (Zhang *et al.,* 1998). A morphological similar fossil *Trachyhystrichosphaera* sp. is also known from the late Precambrian metasedimentary chert of the Scotia Group, Prins Karls Forland, western Svalbard (Knoll, 1982) and unnamed specimens of unknown affinities from the Infra-Krol Formation, Lesser Himalaya (Tiwari & Knoll, 1994) were earlier kept in the present genus (Zhang *et al.,* 1998).

Genus—*Trachyhystrichosphaera* (Timofeev & Hermann = German) Hermann and Jankauskas in Yankauskas *et al.,* 1989

Type species—*Trachyhystrichosphaera aimica* Hermann (in Timofeev *et al.,* 1976) German *et al*., 1989

Trachyhystrichosphaera aimica Hermann, 1976

(Pl. 2.1)

Description—Vesicles spherical, elongated due to preservation, irregularly folded, 100-180 µm in length and 40-60 µm in with, wall moderately thick, finely granular, 14 processes counted, hollow, conical and sparsely placed, 6-10 µm long, 4-6 µm broad at the base.

Remarks—Morphologically similar form reported from Upper Riphean to Early Neoproterozoic sediments of the Siberia and Russian Platform (Hermann in Timofeev *et al.,* 1976; Yankauskas *et al.,* 1989), early Neoproterozoic sediments, eastern Officer Basin, Australia (Zang, 1995) and Ediacaran Buxa dolomites, Siang District, Arunachal Lesser Himalaya, India (Shukla *et al.,* 2006).

C. *Incertae sedis*

Genus—*Sinocyclocyclicus* Xue *et al.,* 1992

Type species—*Sinocyclocyclicus guizhouensis* Xue *et al.,* 1992

Sinocyclocyclicus guizhouensis Xue *et al.,* 1992

(Pl. 1.6)

Description—Cylindrical structures similar to trichome, 460 µm long and 200 µm wide, containing slightly convex cross-walls, partitioned tubular structures unit 15-17 µm long, along much of the fossils, having some grainated organic substance in the central portion and hyaline along the periphery. Two numbers of the species were recorded.

Remarks—This form is earlier recorded from the Lower Cambrian Shuijingtuo Formation of Miaohe, Zingui, Hubei Province of China (Yin *et al.,* 1992). Similar form considered as a skeletal fossils from the Upper Sinian Doushantuo Formation, Weng'an Guizhou Province, China, interpreted as stacked ossicles in crinoid columnal (Xue *et al.,* 1992) and recently described as sheath of the biological entities from the Doushantuo Formation of Yangtze Gorges, China (Zhang *et al.,* 1998). The width of the present recorded form is less than the earlier described by aforesaid workers. Similar skeletonised algal tube has been reported from the terminal Proterozoic sediments of Nama Group (Grant *et al.,* 1991). Such type of tubes are formed possibly through natural decaying of the intracellular organelles and the drying of mucilaginous sheath entombed in sediments.

DISCUSSION AND CONCLUSION

The recovered forty-one (41) taxa of Ediacaran Assemblage (Fig. 3) represents twenty-two taxa of protists (sphaeromorphs and acanthomorphs), seventeen taxa of algae (15 taxa of prokaryotes, viz. coccoidal and filaments with or without mucilaginous sheath including helically coiled forms along with two taxa of the rhodophytic algae), and single taxon of the two forms of the unknown affinities, i.e. multicellular cylindrical tubular structures and vase-shaped microfossils (VSMs), have been recovered from the eight synclines belonging to upper part of the Infra-Krol Formation of the Baliana Group, Chambaghat and Mahi formations of Krol Group exposed in the Krol Belt, Lesser Himalaya (Figs 1, 2). The detected prokaryotes taxa are comparable with extant cyanobacteria belonging to chroococcacales, entophysidales, oscillatoriales and nostocales (Desikachari) while protists taxa are comparable with sphaeromorphida and sphaerohystrichomorphida subgroups of acritarchs (Mendelson & Schopf, 1992). Fig. 3 shows the microbial assemblage reported from the three formations, viz. Infra-Krol Formation of Nainital Syncline, Chambaghat (Krol Sandstone) Formation belonging to Kamlidhar Syncline (Shukla *et al.,* 2005a, b) and Infra-Krol and Mahi formations of remaining six synclines of the Krol Belt (present study). The sphaeromorphs, both simple and ornamented dominates followed by mesosphaeromorphic acanthomorphs and medium sized cyanobacterial remains in extreme eastern end of the Krol Belt, i.e. Nainital Syncline (Fig. 2, section a). Large sized acanthomorphs and broad sized filaments/trichomes of cyanobacteria dominate in western end, viz. Pachmunda and Kamlidhar synclines (Fig. 2, sections g, i and j) over the assemblage of eastern end (Fig. 2, section a). Additionally, low amount of the two taxa of multicellular algal thalli (primitive/

juvenile stage) of Phylum Rhodophyta and single multicellular cylindrical tubular structures of unknown affinities are only restricted in west end of Krol Belt. The vase-shaped microfossils (*Melanocyrillium hexodiadema)* are recorded with abundant OWMs bearing sediments of the eight synclines. In present assemblage, the recovered diversified fossil microbiotic composition (cyanobacteria and acritarchs particularly acanthomorphs) mostly compares well with known assemblage from the Neoproterozoic sediments deposited globally (Shukla *et al.,* 2005b, Table 1).

The microfossils yielding succession conformably overlies the pink carbonate of Blaini Formation. It is significant that the pink carbonate overlying the uppermost diamictite of Blaini Formation correlates well with the Cap Carbonate above the Marinoan tillites of Australia and Nantau tillites of China. Cap Carbonate forms the base of the Ediacaran Period (Knoll *et al.* 2006). The Blaini Formation yielded low density bloom forming OWMs (see cited references in Maithy *et al.,* 1995) indicating sudden change possible spring blooms that might be seasonal/annual tides which is well supported by Knoll *et al.* (2006). Infra-Krol Formation of the Mussoorie and Garhwal synclines are confined in central part of the Krol Belt yielded rare and ill preserved Ediacaran planktonic *Bavlinella* (colonial form) indicating deepening of the basin during this period. It is closely respondent to any natural drastic/episodic changes (deeper burial and thermal alteration) during sedimentation. The similar reports had been earlier referred from Australia, China, Namibia, and Svalbard (Knoll, 1982, 1984; Zang, 1995; Grey *et al.,* 2003; Gäucher *et al.,* 2005). Chambaghat and Mahi formations yielded most distinctive Ediacaran protists assemblage comprising large sized acanthomorphs (*Filisphaeridium, Echinosphaeridium, Tianzhushania, Ericiasphaera, Meghystrichosphaeridium* and *Papillomembrana*) and published taxa (Shukla *et al*., 2005b) described in the text and published data indicate moderate to deep ocean shelves basin. Similar phenomenon is also seen/ suggested in tidal flat Neoproterozoic sediments from the different parts of the world, viz. Norway, Svalbard, Spitsbergen, Canada (Vidal & Nystuen, 1990; Knoll, 1982, 1984, 1992a, b, 1994; Hofmann & Jackson, 1991; Kah & Knoll, 1996; Lipps, 2006).

Based on nature of morphology, ratio of the coccoidal and filament forms, cyanobacteria are assumed as the best indicator of the ecological conditions during that time (Knoll *et al.,* 1991). Mucilaginous sheath indicate adverse conditions in the depositional environment (Vidal, 1976; Horodyski *et al.,* 1977; Knoll *et al.,* 1991; Mansuy & Vidal, 1983). However, the helically coiled morphology of *Obruchevella* (Mankiewicz, 1992), is also indicative of harsh and dry condition (regression stage).

The above microfossil assemblage occurs, in all cases, over the older Varanger tillites and below the diverse Ediacaran fauna (Knoll & Walter, 1992; Zang, 1995). The overlying Jarashi and Kauriyala formations of the Krol Group contain diverse Ediacaran metazoans indicate tidal flat environment (Mathur & Shanker, 1989, 1990; Shanker & Mathur, 1992; Shanker *et al.,* 1997, 2004; Mathur & Srivastava, 2004).

The analysis of previous information on Ediacaran biota, chemostratigraphy and diverse protists including prokaryotes (in present studies) from Baliana and Krol groups indicate that the deposition of this succession took place in intertidal or supratidal region and it had occasional contact with open sea, which is indicated by the presence of open sea planktons (solitary sphaeroidal cells and group of the cells forming small sized colonies—*Bavlinella, Huroniospora, Eoentophysalis* belonging chroococcacean cyanobacteria and acritarchs). This contact may be due to occasional flooding which is responsible to break old and form the new sand barriers by channels through catastrophic/episodic changes like high tides that affect in appearance and disappearance of the biological communities. The palaeobiological evidences do not represent any post geodynamics effect on the morphology of the OWMs in present assemblage because of the short lifecycle of these biological entities and is considered as the best tool for recognition of terminal Proterozoic rocks of China and Australia just after glaciations (Knoll & Walter, 1992; Zhou *et al.,* 2006).

Acknowledgements*—The authors are most thankful to Dr N.C. Mehrotra, Director, Birbal Sahni Institute of Palaeobotany, Lucknow, and Drs K.N. Mathur, P.N. Razdan, Senior Deputy Director Generals, Northern Region, Geological Survey of India respectively for the laboratory facilities and kind permission to take up this collaborative work. We are also thankful to Dr Rahul Garg Scientist 'F' for his inspiration and Mr Veeru Kant Singh Scientist 'B' for the technical support during finalization of present paper.*

REFERENCES

Acharyya SK, Raha PK, Das DP, Moitra AK, Shukla M & Bansal R 1989. Late Proterozoic microbiotic from the Infra Krol rocks from Nainital Synform, U.P. Himalaya, India. Indian Journal of Geology 61: 137-147.

Allison CW & Awramik S 1989. Organic-walled microfossils from earliest Cambrian or Latest Proterozoic Tindir Group rocks, northwest Canada. Precambrian Research 43: 253-294.

Aseeva EA 1974. On the spiral and ring-like forms in the upper Precambrian deposits of Podolina. Paleontology Shornik 11: 95-98 (in Russian).

Awramik SM, Mcmenamin DS, Yin C, Zhang D & Zhang S 1985. Prokaryotic and eukaryotic microfossil from the Proterozoic and Phanerozoic transition sediments in China. Nature 31: 655-658.

Auden JB 1934. Geology of the Krol Belt. Records of the Geological Survey of India 67: 357-409.

Bloeser B, Schopf JW, Horodyski R & Breed B 1977. Chitinozoans from the Late Precambrians of the Grand Canyon, Arizona. Science 195: 676-679.

Butterfield NJ, Knoll AH & Swett K 1994. Palaeobiology of the Neoproterozoic Svanberfjellet Formation, Spitsbergen. Fossil and Strata 34: 1-84.

Fensome RA, Williams GL, Barss MS, Freeman JM & Hill JM 1990. Acritarchs and fossil Prasinophytes: An index to genera, species and intraspecific taxa. American Associations Stratigraphy Palynologists Foundation, Contributions Series 25: 771.

Gäucher C, Frimmel HE & Germs GJB 2005. Organic walled microfossils and biostratigraphy of the upper part of Nolloth Group (Namibia): Implications for latest Neoproterozoic glaciations. Geological Magazine 142: 539-559.

German TN, Mikhailova NS & Yankauskas TV 1989. Systematicheskoe opisanie mikrofossilii (systematic description of microfossils): *In*: Yankauskas TV (Editor)—Mikrofossilii Dokembriya SSSR (Precambrian microfossils of the SSSR): 34-151. Leningrad Nauka.

Germs GJB 1995. Implications of sedimentary facies and depositional environment analysis of the Nama Group in southwest Africa. *In*: Miller RM (Editor)—Evolution of the Damara Orogen of southwest Africa/Namibia Geological Society of South Africa Special Publications 11: 89-114.

Golovenok VK & Belova MY 1983. Rifeyskaya mikroflora V kremnyakh iz malginskoy svity Yudomo - Mayskogo progiba (The Riphean microflora in the cherts from the Malgin formation in the Yudoma-Maya Basin) Palaeontologicheskiy Zhurnal 2: 92-96 (English translation: Palaenotological Journal: 85-90.

Grant SWF, Knoll AH & Germs GJB 1991. Probable calcified metaphytes in the Latest Proterozoic Nama Group: Origin, diagenesis and implications. Journal of Paleontology 65: 1-18.

Green JW, Knoll AH, Golubic S & Swett K 1988. Microfossils from Oolites and Pisolites of the stromatolitic carbonates of the Upper Proterozoic limestone-dolomite 'Series' East Greenland. Geological Magazine 126: 567-585.

Grey K & Corkeron M 1998. Late Neoproterozoic stromatolites in Glaciogenic succession of the Kimberley region, western Australia: Evidence for a younger Marinoan glaciations. Precambrian Research 92: 65-87.

Grey K, Walter MR & Calver CR 2003. Plankton and isotope changes at Neoproterozoic Acraman impact Ejecta layer. Geology 31: 459-462.

Hofmann HJ 1976. Precambrian microflora, Belcher Islands of Canada, significance and systematics. Journal of Palaeontology 50: 1040-1073.

Hofmann HJ & Jackson GD 1991. Shelf facies microfossils from the Uluksan Group (Late Proterozoic) Bylot Supergroup, Baffin Island, Canada. Journal of Paleontology 65: 361-382.

Hofmann HJ & Jackson GD 1994. Shale facies microfossils from the Proterozoic, Bylot Supergroup, Baffin Island, Canada. The Palaeontological Society Memoir 37: 1-39.

Horodyski RJ, Bloeser B & Vander Haar S 1977. Laminated algal mats from a coastal lagoonal, Laguna Moormona, Baja California, Mexico. Journal of Sedimentology Petrology 47: 680-696.

Horodyski RJ & Donaldson IA 1980. Microfossils from the Middle Proterozoic Dismal Lakes Group, Arctic Canada. Precambrian Research 11: 125-157.

Jenkins RJ, Mckirdy DM, Foster CB, O'leary T & Pell SD 1992. The record and stratigraphic implications of organic-walled microfossils from the Ediacaran (Terminal Proterozoic) of South Australia. Geological Magazine 129: 401-410.

Jiang G, Sohl LE & Christie-Blick N 2003. Geology, Neoproterozoic Stratigraphic comparison of the Lesser Himalaya (India) and Yangtze Block (south China): Palaeogeographic implications. Geology 31: 917-920.

Johnson JH 1960. Paleozoic Solenoporaceae and related red algae. Quarterly of the Colardo School of Mines 55: 177.

Kah LC & Knoll AH 1996. Micro-benthic distribution of Proterozoic tidal flats: Environmental and Taphonomic consideration. Geology 24: 78-82.

Knoll AH & Sergeev VN 1995. Taphonomic and evolutionary changes across the Mesoproterozoic-Neoproterozoic Transition. Neues Jahrbuch für Géologie and Paläontologie. Abhandeungen 19: 289-302.

Knoll AH & Walter MR 1992. Latest Proterozoic stratigraphy and earth History. Nature 356: 673-678.

Knoll AH 1982. Microfossils based biostratigraphy of the Precambrian Hecla Hock sequence, Nordaustlandet, Svalbard. Geological Magazine 119: 269-279.

Knoll AH 1984. Microbiotic of the late Precambrian Hunnberg Formation, Nordaustlandet, Svalbard. Journal of Paleontology 58: 121-162.

Knoll AH 1992a. Microfossils from the Late Precambrian Draken Conglomerate, NY Fries land Spitsbergen. Journal of Paleontology 56: 755-790.

Knoll AH 1992b.Vendian microfossils in metasedimentary cherts of the Scotia Group, Prins Karls Forland, Svalbard. Palaeontology 56: 751-774.

Knoll AH 1994. Proterozoic and early Cambrian protists: evidence for accelerating tempo. Proceedings of the National Academy of Sciences USA 91: 6743-6750.

Knoll AH 1996. Archeaen and Proterozoic paleontology. *In*: Jansonious J & McGregor DC (Editors)—Palynology Principles and applications American Associations of Stratigraphic Palynologists Foundation 1: 51-80.

Knoll AH 2003. Life on a young planet. Princeton, Princeton University Press.

Knoll AH, Javaux EJ, Hewitt D & Cohen P 2006. Eukaryotic organisms in Proterozoic oceans-Philosophical Transactions of the Royal Society of London B, London 361(1470): 1023-1038.

Knoll AH, Swett K & Marks J 1991. Palaeobiology of Neoproterozoic tidal flat/lagoonal complex in the Draken Conglomerate Formation, Spitsbergen. Journal of Paleontology 65: 531-570.

Kolosova SP 1991. Late Precambrian acanthomorphic acritarchs from the eastern Siberian Platform. Algologiya 1: 53-59.

Kumar G 1984. The Precambrian-Cambrian boundary beds, NW Himalaya, India and Boundary Problem. Proceedings of the Vth Indian Geophytological Conference, Lucknow; Special Publication: 98-111.

Kumar S & Rai V 1992. Organic-walled microfossils from the bedded chert of Krol Formation (Vendian) Solan, Himachal Pradesh, India. Journal of the Geological Society of India 39: 229-234.

Lipps JH 2006. Major features of Protistan evolution: controversies, problem and few Answers. Anuário do Instituto de Geosciencencias UFRJ 29: 55-80.

Maithy PK & Babu R 1997. Upper Vindhyan biota and Precambrian/ Cambrian Boundary. Palaeobotanist 46: 1-6.

Maithy PK, Babu R, Kumar G & Mathur K 1995. New cyanophycean remains from the Blaini Formation (Terminal Neoproterozoic Sequence) of Mussoorie Syncline, Lesser Himalaya, India. Palaeobotanist 43: 39-44.

Maithy PK & Kumar G 2007. Biota in the Terminal Proterozoic succession on the Indian subcontinent-a review. *In*: Vickers-rich P & Komarower P (Editors)—Rise and the fall of the Ediacaran fauna. Geological Society of London Special Publication 286: 315-330.

Mandal J, Maithy PK, Barman G & Verma KK 1984. Microbiota from the Kushalgarh Formation, Delhi Supergroup, India. Palaeobotanist 32: 1-19.

Mankiewicz C 1992. *Obruchevella* and other microfossils in Burgess Shale: Preservation and Affinity. Journal of Palaeontology 66: 717-729.

Mansuy C & Vidal G 1983. Late Proterozoic Brioverian microfossils from France: taxonomic affinity and implications of plankton productivity. Nature 302: 606-607.

Mathur VK & Shanker R 1989. First record of Ediacaran fossils from the Krol Formation of Nainital Syncline. Journal of the Geological Society of India 34: 245-254.

Mathur VK & Shanker R 1990. Ediacaran medusoides from Krol Formation, Nainital Syncline, Lesser Himalaya. Journal of the Geological Society of India 36: 274-278.

Mathur VK & Srivastava DK 2004. Record of Terminal Neoproterozoic Ediacaran fossils from Krol Group, Nigalidhar Syncline, Sirmaur District, Himachal Lesser Himalaya. Journal of the Geological Society of India 64: 231-232.

Mendelson CV & Schopf JW 1982. Proterozoic microfossils from the Sukhaya Tungusk, Shorikha, and Yudoma formations of the Siberian platform, USSSR. Journal of Paleontology 56: 42-83

Mendelson CV & Schopf JW 1992. Proterozoic and Early Cambrian acritarchs. *In*: Schopf JW & Klein C (Editors)—The Proterozoic biosphere – Multidisciplinary study: 219-232. Cambridge (University. Press Cambridge).

Nagy RM & Porter SM 2005. Palaeontology of Uinta Mountain Group. *In*: Dehler CM *et al.* (Editors)—Uinta Mountain Geology: Utah Geological Association Publication 33: 49-62.

Nautiyal AC 1983. Algonkian (Upper to Middle) microorganisms from the Semri Group of Son Valley (Mirzapur District) India. Geoscience Journal 4: 169-198.

Peterson KJ & Butterfield NJ 2005. Origin of the eumetazoan: Testing ecological predictions of molecular clocks against the Proterozoic fossil record. Proceeding of the National Academy of Sciences 192: 9547-9552.

Prasad B & Asher R 2001. Acritarch biostratigraphy and lithostratigraphic classification of Proterozoic and Lower Paleozoic sediments (Pre-Unconformity Sequence) of Ganga Basin, India. Palaeontographica Indicia 5: 1-153.

Prasad B, Maithy PK, Kumar G & Raina BK 1990. Precambrian-Cambrian acritarchs from the Blaini-Krol-Tal Sequence of Mussoorie Syncline, Lesser Himalaya, India. Memoir Geological Society of India 16: 19-32.

Prasad B, Uniyal SN & Asher R 2005. Organic walled microfossils from the Proterozoic, Vindhyan Supergroup of Son Valley, Madhya Pradesh, India. Palaeobotanist 54: 13-60.

Pyatiletov VG & Rudavaskaya VV 1990. Acritarchs of the Yudoma complex. *In*: Sokolov BS & Iwanoski AB (Editors)—Vendian System, Akademika Nauka, SSSR. Palaeontology 1: 179-187 (Moscow).

Ragozina AL & Sivertseva IA 1990. Microfossils of the Valdai Series in the northwestern Arkhansk District. *In*: Sokolov BS & Iwanoski AB (Editors)—Vendian System, Akademika Nauka, SSSR. Palaeontology 1: 165-170 (Moscow).

Samuelsson J & Butterfield NJ 2001. Neoproterozoic fossils from the Franklin Mountains Canada; stratigraphic and paleoecological implications. Precambrian Research 107: 235-251.

Samuelsson J, Dawes PR & Vidal G 1999. Organic-walled microfossils from the Proterozoic Thule Supergroup, Northwestern Greenland. Precambrian Research 96: 1-24.

Sarjeant WAS & Stanchiffe RPW 1994. The *Micrhystridium* and *Veryhachium* complexes (acritarcha: acanthomorphitae and polygonomorphitae): a taxonomic reconsideration. Micropaleontology 40: 1-77.

Schopf JW 1968. Microflora, of the Bitter Springs Formation, Late Precambrian, central Australia. Journal of Paleontology 42: 651-688.

Sergeev VN 1989. Microfossils from transitional Precambrian-Phanerozoic strata of the central Australia. Himalayan Geology 13: 269-278.

Shanker R 1989. The Mussoorie Phosphate base of the India. In phosphate Deposits of the world 2. *In*: Notholt AJG *et al.* (Editors)—Phosphate rock resources: 443-448.

Shanker R, Bhattacharya DD, Pande AC & Mathur VK 2004. Ediacaran biota from the Jarsi (Middle Krol) and Mahi (Lower Krol) formations, Krol Group, Lesser Himalaya, India. Journal of the Geological Society of India 63: 649-654.

Shanker R, Kumar G, Mathur VK & Joshi A 1993. Stratigraphy of Blaini, Infra Krol, Tal Succession, Krol Belt, Lesser Himalaya, India. Journal of Petrology Geology 2: 99-136.

Shanker R & Mathur VK 1992. The Precambrian-Cambrian Sequence in Krol Belt and Additional Ediacaran fossils. *In*: Venkatachala BS *et al.* (Editors)—Proceeding of Birbal Sahni Birth *et al.* Centenary Palaeobotanical Conference. Geophytology 22: 27-39.

Shanker R, Mathur VK, Kumar G & Srivastava MC 1997. Additional Ediacaran biota from the Krol Group, Lesser Himalaya, India and their significance. Geosciences Journal XVIII(1): 79-94.

Shukla M, Babu R, Mathur VK & Srivastava DK 2005a. Microbial remains from Chambaghat Formation, Krol Group, Himachal Lesser Himalaya, India and their significance. Current Science 88: 1223-1225.

Shukla M, Babu R, Mathur VK & Srivastava DK 2005b. Additional Terminal Proterozoic organic-walled microfossils from the Infra Krol Formation, Nainital Syncline, Lesser Himalaya, Uttaranchal, India. Journal of the Geological Society of India 65: 197-205.

Shukla M, Tewari VC, Babu R & Sharma A 2006. Microfossils from the Neoproterozoic Buxa Dolomite, West Siang District, Arunachal Lesser Himalaya, India and their significance. Journal of Palaeontological Society of India 51: 57-73.

Spjeldnaes N 1963. A new fossil (*Papillomembrana* sp.) from Upper Precambrian of Norway. Nature 200: 63-64.

Timofeev BV, Hermann TN & Mikhailova NS 1976. Microphytofossils of the Precambrian, Cambrian and Ordovician. Nauka, Leningrad: 1-106 (in Russian).

Tiwari M 1996. Palaeobiology of late Proterozoic (Vendian) microbiota evidences from the Infrakrol Formation of Lesser Himalaya. *In*: Pandey J *et al.* (Editors)—Contributions 15th Indian Colloquium on Micropalaeontology and Stratigraphy: 559-566.

Tiwari M & Azmi RJ 1992. Late Proterozoic organic-walled microfossils from the Infra Krol of Solan, Himachal Lesser Himalaya, an additional age constraint in the Krol Belt succession. Palaeobotanist 39: 387-394.

Tiwari M & Knoll AH 1994. Large acanthomorphic acritarchs from the Infra Krol Formation of the Lesser Himalaya and their significance. Himalayan Geology 5: 193-201.

Tiwari M & Pant CC 2004. Neoproterozoic silicified microfossils in Infra Krol Formation of Lesser Himalaya, India. Himalayan Geology 25: 1-21.

Tynni R & Donner J 1980. A microfossil and sedimentation study of the Late Precambrian Formation of Hailuoto, Finland. Bulletin of Geological Survey of Finland 311: 1-18

Venkatachalapathy V & Basavaraju M 1986. Microorganic remains from Voblapur Group (Dodguni area) Karnataka, south India. *In*: Samanta BK (Editor)—Proceedings of 11th Colloquium on Micropalaeontology and Stratigraphy 54: 178-184.

Venkatachalapathy V & Ravindra G 1984. Microplanktonic assemblage from the core specimens of the Iron Ore Formation from the southern parts of Tanigeball area, Chikmagalur District, Karnataka. *In*: Badve RM *et al.* (Editors)—Proceedings of 10th Indian Colloquium on Micropaleontology and Stratigraphy: 41-50.

Vidal G 1976. Late Precambrian microfossils from the basal sandstone units of Visingso beds, Southern Sweden. Fossils and Strata 9: 57.

Vidal G 1990. Giant acanthomorph acritarchs from upper Proterozoic in southern Norway. Palaeontology 33: 287-298.

Vidal G & Ford TD 1985. Microbiota from the Late Proterozoic Chuar Group (Northern Arizona) and Uinta Mountain Group (Utah) and their chronostratigraphic implications. Precambrian Research 28: 349-389.

Vidal G & Knoll AH 1982. Radiations and extinctions of plankton in late Proterozoic and early Cambrian. Nature 296: 57-60.

Vidal G & Moczydlowska VM 1997. Biodiversity, speciation, and extinction trends of Proterozoic and Cambrian phytoplankton. Paleobiology 23: 230-245.

Vidal G & Nystuen JP 1990. Micropaleontology, depositional environment and biostratigraphy of upper Proterozoic Hedmark Group, southern Norway. American Journal of Sciences 290A: 170-211.

Viswanathiah MN & Venkatachalapathy V 1980. Microbiota from the Bababudan Iron Formation, Karnataka. Journal of the Geological Society of India 21: 16-20.

Viswanathiah MN, Venkatachalapathy V & Naresh TK 1978. Microbiota from Bilgi Quartz arenite of the Bagalkot Formation, Kaladgi Group, Karnataka. *In*: Rasheed DA (Editor)—Proceedings of the 7th Indian Colloquium on Micropalaeontology and Stratigraphy: 475-488.

Viswanathiah MN, Venkatachalapathy V & Raghunath T 1984. Microfossils from the Salagundi Conglomerate of Bagalkot Formation, Kaladgi Group, south India. *In*: Badve RM *et al.* (Editors)—Proceedings of 10th Indian Colloquium on Micropaleontology and Stratigraphy: 51-60.

Volkova NA 1969. Acritarchs of the northwest Russian Platform. *In*: Rozanov *et al.* (Editors)—Tommotian stage and the Cambrian Lower Boundary problem. Academia Science Moscow: 86-88, 259-273 (Translation Amerind Publ. Co. Ltd, New Delhi, 1981).

Wang F 1985. Middle-Upper Proterozoic and lower phanerozoic microfossil assemblage from SW China and contiguous areas. Precambrian Research 29: 33-43.

Xiao S & Knoll AH 1999. Fossil preservation in the Neoproterozoic Doushantuo Phosphorite, Lagerstätte, south China. Lethaia 32: 219-240.

Xue YS, Tang TF, Tian F & Yu CL 1992. Discovery of the oldest skeletal fossils from upper Sinian Doushantuo Formation in Weng'an Guizhou and its significance. Acta Palaeontologica Sinica 31: 330-339.

Yankauskas TV, Mikhailova, NS & German TN 1989. Microfossilii Dokembriya, SSSR (Precambrian microfossils of the USSR). Transdii. Instut. Géologie. Geochronologie. Dokembriya SSSR Akad. Nauka, Leningrad: 188 (in Russian).

Yao J, Xiao S, Yin L, Li G & Yuan X 2005. Basal Cambrian microfossils from the Yurts and Xishanblaq formations (Tarim, north-west China): Systematic revision and biostratigraphic correlation of *Micrhystridium*-like acritarchs. Paleontology 48: 687-708.

Yin C & Gao L 1995. The early evolution of the acanthomorphic acritarchs in China and their biostratigraphical implication. Acta Geologica Sinica 69: 360-371.

Yin C & Liu G 1988. The microfloras. *In*: Zhao Z (Editor)—The Sinian system of Hubei, China: 91-100. University of Geosciences, Press Wuhan (in Chinese with English abstract).

Yin C 2001. Discovery of *Papillomembrana compata* in Weng'an, Guizhou with discussion on the correlation of large acanthomorphic acritarchs and the age of Doushantuo Formation. Journal of stratigraphy 25: 253-258 (in Chinese with English abstract).

Yin C, Bengston S & Zhao Y 2004. Silicified and phosphatized *Tianzhushania* sphaeroidal microfossils of possible animal origin from the Neoproterozoic of south China. Acta Palaeontologica Poland 49: 1-12.

Yin C, Zhao Y & Linzhi G 1992. Microfossils from the cherts of Lower Cambrian Suijingtuo Formation at Miaohe Zingui, Hubei Province. Acta Geologica Sinica 66: 371-380.

Yin L & Li Z 1978. Precambrian microfossils of southwest China. Memoir, Nanjing Institute Geology and Palaeontology, Academia Sinica 10: 41-102

Yuan Xunlai & Hofmann HJ 1998. New microfossils from Neoproterozoic (Sinian) Doushantuo Formation, Wengan, Guizhou Province, Southwestern, China. Alcheringa 22: 189-222.

Zang W 1995. Early Neoproterozoic sequence stratigraphy and acritarchs, biostratigraphy, Eastern Officer Basin, south Australia. Precambrian Research 74: 119-175.

Zang W & Walter MR 1992a. Late Proterozoic and Cambrian microfossils and biostratigraphy, Amadeus Basin, central Australia. American Association Australias. Palaeontology 12: 1-132.

Zang W & Walter MR 1992b. Late Proterozoic and Early Cambrian microfossils and biostratigraphy, northern Anhui and Jiangsu, central-eastern China. Precambrian Research 57: 243-323.

Zhang Y 1989. Multicellular Thallophytes with differentiated tissues from late Proterozoic phosphate rocks of south China. Lethaia 22: 113-132.

Zhang Z 1986. New material of filamentous fossil cyanophytes from the Doushantuou Formation (Late Sinian) in eastern Yangtz Gorges. Scientia Geologica Sinica 1: 30-37.

Zhang Y, Yin L, Xiao S & Knoll AH 1998. Permineralised fossils from the Terminal Proterozoic Doushantuo Formation, south China. Journal of Palaeontolology. Supplement Memoir 72: 1-52.

Zhou CX, Kathleen GM, Xiao S & Yuan X 2006. The diversification and extinction of Doushantuo-Pertatataka acritarchs in south China: causes and biostratigraphic significance. Geological Journal 42: 229-262.

Zhou C, Brassier MD & Xue Y 2002. Three dimensional phosphatic preservation of giant acritarchs from the Terminal Proterozoic Doushantuo Formation in Guizhou and Hubei provinces, south China. Palaeontology 44: 1157-1178.