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New microfossils from the Meso-Neoproterozoic Deoban Limestone, Garhwal Lesser Himalaya, India

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ABSTRACT

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Forty-five additional microfossils are being described from the Meso-Neoproterozoic Deoban Limestone (Formation). Microfossils are preserved in black bedded chert, occurring as thin lenses and bands intercalated with dolostones. The assemblage comprises both filamentous as well as coccoid forms. The assemblage is dominated by cyanobacterial population along with a number of microfossils belonging to other affinities represented by bacterial, algal, fungal and acritarchean forms. Out of the fortyfive forms there are forty-four species belonging to 33 genera and one micro-organism is informally described as Form 'A'. Five taxa are described as new genera.

Additional Deoban forms are as follows:

Cyanobacteria—*Archaeoellipsoides minor, A. major, Palaeopleurocapsa* sp., *Scissilisphaera gradata, Scissilisphaera* sp., *Coniunctiophycus gaoyuzhuangense, Archaeophycus* sp., *Gloeodiniopsis lamellosa, Palaeomerismopedia misrai* gen. & sp. nov., *Siphonophycus septatum, S. robustum, S. solidum, S. typicum, Polytrichoides lineatus, Oscillatoriopsis amadeus, O. obtusa, O. breviconvexa, Rhicnonema antiquum, Nostocomorpha* sp., *Eomicrocoleus crassus, Cyanonema* sp., *Palaeolyngbya catenata, Circumvaginalis* sp., *Obruchevella parva, O. valdaica, O. minor* and *Glomovertella glomerata.*

Incertae sedis—*Paleosphaeridium zonale, Germinosphaera* sp., *Myxococcoides chlorelloides, Myxococcoides stragulescence, Palaeococcus indicus* gen. & sp. nov., *Dumbellina deobanensis* gen. & sp. nov., *Maithea indica* gen. & sp. nov., *Eophycomyces herkoides, Bulgenia septata* gen. & sp. nov. and Form 'A'.

Acritarchs—cf. *Cymatiosphaeroides* sp., *Micrhystridium* sp., *Favosphaeridium favosum, Trachysphaeridium* sp., *Leiosphaeridia crassa, L. jacutica, Caudosphaera* sp. and cf. *Ovulum saccatum.*

The Deoban Microfossil Assemblage is characterised by dominance of mat building cyanobacterial population, exhibiting evolutionary conservatism. Extensive size variation from specimens of less than one micron to 265 microns in case of coccoids and from less than one micron to 48 microns among filamentous forms indicate the most favourable preservational conditions for silicification of the biota.

There are a number of forms, which show some resemblance with extant chlorophycean, bacterial and rhodophycean forms. Presence of large sized sphaeromorphs ranging in diameter from 105 to 265 μm and rare occurrence of acanthomorph or spinose acritarch (represented by *Micrhystridium* sp.) and small sized, moderately developed spirally coiled filaments of *Obruchevella* support a pre-Vendian age to the Deoban microfossil assemblage.

Key-words—Deoban Limestone, Meso-Neoproterozoic, Microfossils, Lesser Himalaya, Black chert, India.

भारत के गढ़वाल लघु हिमालय के मीज़ो-निओप्रोटीरोजोइक देवबन चूना पत्थर से प्राप्त नवीनतम सूक्ष्मपादपाश्म

पूर्णिमा श्रीवास्तव एवं एस. कुमार

सारांश

मीज़ो-निओप्रोटीरोजोइक देवबन चूना पत्थर (शैलसमूह) से पैंतालीस अतिरिक्त सूक्ष्मपादपाश्म अभिलक्षणित किए गए हैं। ये सूक्ष्मपादपाश्म काले संस्तरित चर्ट में सुसंरक्षित हैं, जो डोलोस्टोन में अन्तर्विष्ट पतले लेंसों तथा पट्टियों की भाँति प्रतीत होते हैं। समुच्चय में तन्तुमय तथा गोलाभ दोनों ही रूप विद्यमान हैं। समुच्चय में जीवाणुविक, शैवालीय, कवकीय तथा एक्रीटार्क युक्त रूपों के साथ-साथ साइनोजीवाणुओं की प्रचुरता है। पैंतालीस रूपों में से चौवालीस प्रजातियाँ 33 वंशों से सम्बन्धित हैं तथा एक सूक्ष्मजीव रूप 'ए' की भाँति अनियमित रूप से अभिलक्षणित है। पाँच वर्गकों को नए वंशों के रूप में अभिलक्षणित किया गया है।

अतिरिक्त देवबन रूप निम्नलिखित हैं-

साइनोजीवाणु—*आर्कियोइलिप्सॉयडीज माइनर, ए. मेजर, पेलियोप्लूरोकैप्सा* प्रजाति, *सीजिलीस्फ़ेयरा ग्रेडाटा, सीजिलीस्फेयरा,* प्रजाति, *कोनिअंकटाइयोफ़ाइकस गाओयूझुआंगेन्सी, आर्कियोफाइकस* प्रजाति, *ग्लोइयोडाइनियॉप्सिस लैमेलोसा, पेलियोमेरिस्मोपीडिया मिश्राइ* वंश एवं नवप्रजाति, *साइफ़ोनोफ़ाइकस सेप्टेटम, एस. रोबस्टम, एस. सोलिडम, एस. टाइपिकम, पॉलीट्राइकॉयडीज़ लाइनिएटस, ऑसिलेटारियाप्सिस एमेडियस, ओ. ओबट्यूज़ा, ओ. ब्रीविकॉनवेक्सा, राइक्नोनीमा एन्टीक्कुम, नॉस्टोकामोफ़ा* प्रजाति, *इओमाइक्रोकोलियस क्रेंसस, साइनोनीमा* प्रजाति, *पेलियोलिंगबिया कैटीनाटा, सरकमवेजाइनेलिस* प्रजाति, *ओब्रुचिवेला पार्वा, ओ. वाल्डेका, ओ. माइनर* तथा *ग्लोमोवर्टेला ग्लोमेराटा*।

अनिश्चित स्थानी—*पेलियोस्फ़ेयरीडियम ज़ोनेल, जर्मिनोस्फ़ेयरा* प्रजाति, *मिक्सोकोकॉयडीज़ क्लोरीलॉयडीज़, मिक्सोकोकॉयडीज स्ट्रागुलेसेंस, पेलियोइओकोकस इण्डिकस* वंश एवं नवप्रजाति, *डम्बेलिना देवबनेन्सिस* वंश एवं नवप्रजाति, *माइतिया इण्डिका* वंश एवं नवप्रजाति, *इओफ़ाइकोमाइसिस हर्क्वायडीज़, बुल्जीनिया सेप्टाटा* वंश एवं नवप्रजाति तथा रूप 'ए'।

एक्रीटार्क—*साइमेटियोस्फ़ेयरॉयडीज़* प्रजाति से तुलनीय, *माइक्रिस्ट्राइडियम* प्रजाति, *फ़ेवोस्फ़ेयरीडियम फ़वोसम ट्रेकीस्फ़ेयरीडियम* प्रजाति, *लेइयोस्फ़ेयरीडिया क्रासा, एल. जेक्यूटिका, कॉउडोस्फेयरा* प्रजाति तथा *ओव्यूलम सैक्केटम* से तुलनीय।

देवबन सूक्ष्मपादपाश्म वैकासिक संरक्षण प्रदर्शित करने वाले मैट निर्मित करने हेतु उत्तरदायी साइनोजीवाणुओं द्वारा अभिलक्षणित हैं। कोक्वायड्स के अन्तर्गत प्रादर्शों में परिवर्तनशीलता एक माइक्रॉन से लेकर 265 माइक्रॉन से कम है जबकि तन्तुमय रूपों के मध्य यह एक माइक्रॉन से लेकर 48 माइक्रॉन से कम है, जो जीवजात के सिलिकाभवन हेतु सर्वाधिक उपयुक्त संरक्षणीय स्थितियाँ इंगित करती है।

ऐसे अनेक रूप हैं, जो विद्यमान क्लोराफ़ाइसियन, जीवाणुविक तथा रोडोफ़ाइसियन रूपों के साथ सादृश्य प्रदर्शित करते हैं। 105 से 265 माइक्रॉन के व्यास के बड़े आमाप के गोलाशय रूपों (स्फ़ेयरोमार्फ़) की उपस्थिति तथा एक्रेन्थोमार्फ़ अथवा स्पाइनोज एक्रीटार्क (*माइक्रहिस्ट्राइडियम* प्रजाति द्वारा निरूपित) की अत्यल्प उपस्थिति तथा *ओब्रुचिवेला* का छोटे आमाप तथा इसके शनैः-शनैः विकसित सर्पिलतः कुण्डलित तंतुओं से देवबन सूक्ष्मपादपाश्म समुच्चय हेतु प्रारंभिक वेण्डियन आयु की पुष्टि होती है।

संकेत शब्द—देवबन चूनापत्थर, मीज़ो-निओप्रोटीरोज़ोइक, सूक्ष्मपादपाश्म, लघु हिमालय, काला चर्ट, भारत.

INTRODUCTION

THE Proterozoic successions occupy large areas in the Himalaya, which attain impressive thickness measurable in several kilometers. There are many reports of the presence of stromatolites in the carbonate horizons but microfossils are poorly recorded. The earliest record of microfossils from the petrographic thin sections of black-bedded cherts is by Kumar and Singh (1979) from the Meso-Neoproterozoic Deoban Limestone of the Garhwal Lesser Himalaya. Subsequently, Shukla *et al.* (1987) reported 14 species from the Deoban, most of which are of cyanobacterial affinity. Kumar and Srivastava (1992) gave a more detailed account of the Deoban Microfossil Assemblage and described 28 species belonging to sixteen

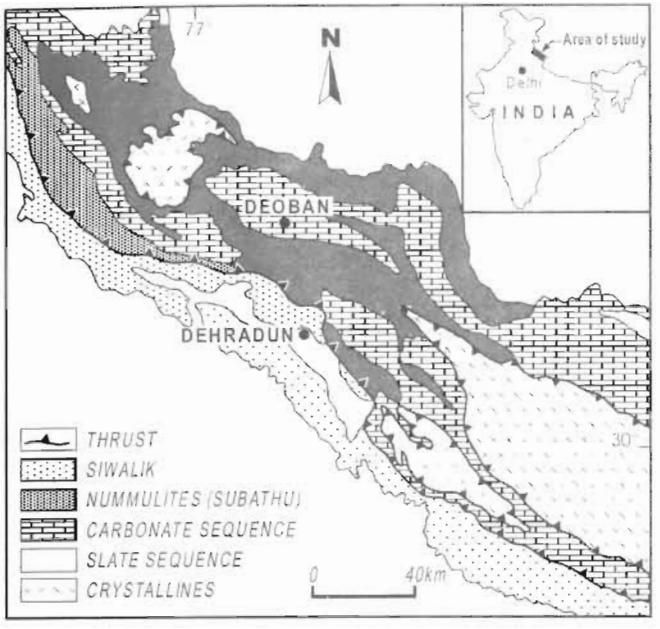


Fig. 1—Location and geological map of the Garhwal region, Lesser Himalaya, Uttaranchal Siwalik (Pliocene-Pleistocene, Subathu (Eocene), Carbonate sequence (Meso-Neoproterozoic), Slate sequence (Meso-Neoproterozoic), Crystallines (Palaeoproterozoic). Simplified after Gansser (1964).

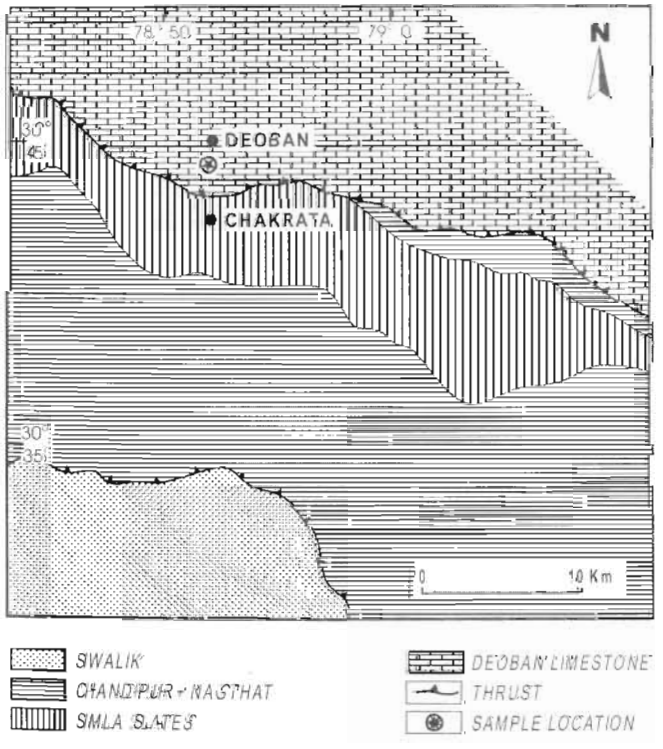


Fig. 2—Geological map showing stratigraphic units in the Chakrata area, Garhwal Himalaya, India and location of the fossiliferous chert-bearing horizon (After Sinha & Raaben, 1981).

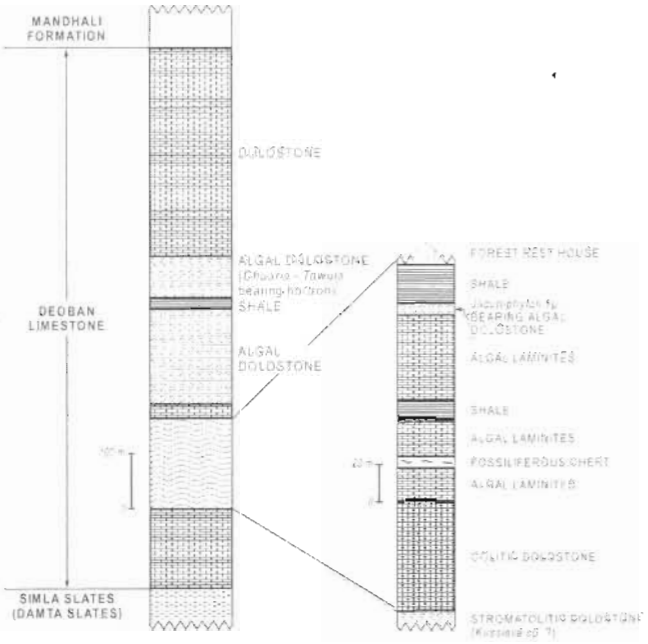


Fig. 3—Litho-column of the Deoban Limestone showing the position of the fossiliferous chert-bearing horizon (Simplified after Tewari, 1998; Kumar & Srivastava, 1992).

genera and also described two forms of uncertain affinity. The assemblage is made up of both coccoid and filamentous forms, dominated by forms of cyanobacterial affinity. Srivastava and Kumar (1997) described two forms of possible animal affinity (annelida and nematoda) and one form they interpreted as a back filled burrow. In the light of this a more detailed study of the Deoban Chert was undertaken. A fresh collection of chert samples was made in Chakrata area, Dehradun District, Uttaranchal. Fifty new thin sections were prepared and studied in detail for microfossil assemblage. All available slides referred in Kumar and Srivastava (1992) which were deposited in the museum of the Department of Geology, University of Lucknow, are also restudied for present paper. The paper incorporates a detailed account of the additional taxa from the Deoban Limestone.

GEOLOGICAL SETTING

The Deoban Limestone named after ca. 3000 m high Deoban peak constitutes an important Proterozoic carbonate litho-unit of the Garhwal Lesser Himalaya (Fig. 1) and is best developed near Chakrata town ship. The terrain is marked by rugged high peaks and deep gorges. The Deoban Limestone unconformably overlies the Simla Slates and underlain by the Mandhali Formation (Fig. 2). The succession is highly deformed and several generations of folding and faulting have made the lithostratigraphy of the area and measurements of true thickness quite complicated. The dominant lithology is represented by dolomicrite, stromatolitic dolostone, oolitic and

intraclastic dolostone and subordinate shales. Good exposures can be seen on Chakrata-Jadi and Chakrata-Buchkoti motor road. The dolostones in general are recrystallized. The fossil bearing black-bedded chert (maximum thickness measured about 15 cm), occurs as lenses and thin bands within the dolostones (Fig. 3), which could be traced up to several metres. The chert is greyish black to black with flat fracture and fenestral fabric. The chert horizon is associated with algal laminites, which are made up of intraclastic dolomite, conglomerate and breccia and dolomicrite. Therefore supratidal to intertidal zone can be suggested for chert bearing horizon.

Very little data has been added, since the publication of earlier report by Kumar and Srivastava (1992). Recently, the thickness of the Deoban Limestone has been estimated by Tewari (1998) as ca 1000 m. The lithology given by Tewari (1998), has been simplified and approximate position of the chert bearing unit has been shown in Fig. 3. Tewari (1998) has also given carbon and oxygen isotope data for 25 carbonate samples representing the entire thickness of the Deoban Limestone exposed in the Chakrata area. According to him the data is very close to Meso-Proterozoic isotope data.

AGE

No radiometric dates are available for the Deoban Limestone. Kumar and Srivastava (1992) have discussed the age of the Deoban Limestone on the basis of the available data and considered it to be of Early to Middle Riphean. Srivastava and Kumar (1995) have reported *Obruchevella* from the Deoban assemblage and have suggested Upper Riphean (Neoproterozoic) age for the chert- bearing horizon.

Tewari (1996) has recorded the presence of *Chuaria circularis* from the Deoban Limestone. The published photographs of *Chuaria circularis* were of very poor quality and because of this the samples available with Dr VC Tewari in the laboratory of the Wadia Institute of Himalayan Geology, Dehradun were re-examined by one of us (SK) and it is concluded that reported *Chuaria circularis* is simply an abiotic depression. However, presence of *Chuaria-Tawuia* association has now been noted by us in the upper part of the Deoban Limestone (see Fig. 3; Pl. 1.1, 2, 3, 4). This association also suggests rather Meso-Neoproterozoic age to fossil bearing horizon. Thus, on the basis of the presence of carbonaceous megafossils like *Chuaria-Tawuia* assemblage, organosedimentary structures like stromatolites (Raaben *et al.*, 2001), a spirally coiled cyanobacterial filamentous form *Obruchevella*, absence of trace fossils and very rare occurrence of acanthomorphic acritarchs, the chert bearing horizon may be considered as Upper Riphean to Vendian in age. No age connotation can be given on the basis of isotope data as suggested by Tewari (1998).

METHODOLOGY AND REPOSITORY

The work is based on thin section study of black-bedded chert under Nikon opti-phot-pol, Leitz Orthoplan and Leica-Quantimat microscopes with the help of Agfa-copex Tri-13 films. All slides are deposited in the Museum of the Geology Department, University of Lucknow, Lucknow, Uttar Pradesh, India.

PRESERVATION OF DEOBAN MICROFOSSILS

The fossiliferous chert is greyish black to black in hand specimen, but appears brown in thin sections. Organic matter shows various degrees of preservation, which often shows clotting in the form of coalified lumps.

Microorganisms of Deoban Microfossil Assemblage lost their morphological details wherever the process of coalification took place. The internal structure is preserved only when it is not severe. In thin sections of chert the microfossils are seen preserved within the laminae, and also within the clasts. The clasts give a brecciated appearance to the chert when observed under the microscope and degree of preservation and degradation differ from clast to clast.

The Deoban microfossil assemblage as well as other Proterozoic microbiotas are highly facies controlled. It appears that several combinations of microbial populations flourished in a low energy lagoon-intertidal environment and produced algal laminites. Under high-energy conditions and/or under dry conditions, the algal mat was destroyed and algal clasts were produced. In favourable conditions, these clasts were again cemented by the second generation of microbial population dominated by filamentous communities.

One sample of black chert and one sample of associated dolomite were analysed for δ^{13}Corg and δ^{13}Ccarb. δ^{13}Corg values for chert and dolomite are -24.5‰ and -19.8‰ (PDB) respectively. δ^{13}Ccarb for dolomite is 3.2 ‰ (PDB) and δ^{18}O is -11.9‰ (PDB). The data suggests some enrichment in ^{13}C possibly due to somewhat evaporatic conditions.

DEOBAN MICROFOSSIL ASSEMBLAGE

Kumar and Singh (1979) discovered the microbiota from the petrographic thin sections of the black-bedded chert belonging to the Deoban Limestone. Later on Shukla *et al.* (1987) and Kumar and Srivastava (1992) described detailed account of microfossils. The reported assemblage is as follows:

Coccoid forms—*Myxococcoides minor, M. inornata, Eosynechococcus isolatus, Glenobotrydion aenigmatis, G. majorinum, Melasmatosphaera parva, M. media, Tetraphycus*

Fig. 4—Additional coccoid morphotaxa, their size distribution, relative abundance and affinity.

			R.A.						Size range in microns (average)
	Phylum - Cyanobacteria								
	Class - Coccogoneae								
	Order - Pleurocapsales								
	Family - Pleurocapsaceae						P		
	Order - Chroococcales								
	Family - Chroococcaceae					C			
	Class - Hormogoneae								
	Order - Nostocales								
	Family - Nostocaceae				N				
	Ineertae sedis			I					
	Group - Acritarcha		A						
1	*Palaeopleurocapsa* sp.		R					P	2-4 (2.5)
2	*Scissilisphaera gradata*		R					P	6-35 (9.5)
3	*Scissilisphaera* sp.		R					P	6-8
4	*Coniunctiophycus gaoyuzhuangense*		C				C		1.5-4.5 (3.6)
5	*Archaeophycus* sp.		R				C		5-9 (7.5)
6	*Gloeodiniopsis lamellosa*		C				C		8-18 (14)
7	*Myxococcoides chlorelloidea*		C				C		15-35 (22)
8	*Myxococcoides stragulescens*		R				C		10-17 (12)
9	*palaeomerismopedia misrai* n. gen.& sp. nov.		R				C		2-3 (2.5)
10	*Arehaeoellipsoides minor*		R			N			18-26 (20)
11	*Arehaeoellipsoides major*		R			N			20-65 (30)
12	*Palaeosphaeridium zonale*		C		I				8-10 (8.5)
13	*Germinosphaera* sp.		R		I				8-15 (12.5)
14	*Palaeococcus indicus* n. gen. & sp. nov.		R		I				.5-1
15	*Dumbellina deobanensis* n. gen. & sp. nov.		R		I				10.20
16	*Maithea indica* new gen. & sp. nov.		R		I				9-13 (11)
17	Form 'A'		R		I				22-26 (24)
18	cf. *Cymatiosphaeroides* sp.		R	A					105-265
19	*Micrhystridium* sp.		R	A					23
20	*Favosphaeridium favosum*		R	A					26-36 (30)
21	*Trachysphaeridium* sp.		R	A					60-105
22	*Leiosphaeridia crassa*		R	A					30-70 (40)
23	*Leiosphaeridia jacutica*		R	A					75-240
24	*Caudosphaera* sp.		R	A					18
25	cf. *Ovulum saccatum*		R	A					24

major, T. cunjunctum, Globophycus rugosum, Huroniospora psilata, H. microreticulata, Caryosphaeroides pristine, Eoentophysalis magna, E. cumulus, E. belcherensis, Glooeodiniopsis lamellosa, G. gregaria, G. sp., *Sphaerophycus parvum,* Form 'A' and Form 'B'.

Filamentous forms—*Gunflintia minuta, G. grandis, Biocatenoides* sp., *Eomycetopsis siberiensis, E. robusta, E. filiformis, Siphonophycus kestron* and *Oscillatoriopsis* sp.

In present paper fortyfive additional forms are being described from the Deoban Chert. There are 44 species belonging to 33 genera and one form has been informally described as Form 'A'. Out of these, five taxa belong to new genera. The additional forms are as follows:

Cyanobacteria—*Archaeoellipsoides minor, A. major, Palaeopleurocapsa* sp., *Scissilisphaera gradata, Scissilisphaera* sp., *Coniunctiophycus gaoyuzhuangense, Archaeophycus* sp., *Gloeodiniopsis lamellosa, Palaeomerismopedia misrai* gen. & sp. nov. *Siphonophycus septatum, S. robustum, S. solidum, S. typicum, Polytrichoides lineatus, Oscillatoriopsis amadeus, O. obtusa, O. breviconvexa, Rhicnonema antiquum, Nostocomorpha* sp., *Eomicrocoleus crassus, Cyanonema* sp., *Palaeolyngbya catanata, Circumvaginalis* sp., *Obruchevella parva, O. valdaica, O. minor* and *Glomovertella glomerata.*

Incertae sedis—*Paleosphaeridium zonale, Germinosphaera* sp., *Myxococcoides chlorelloides, Myxococcoides stragulescence, Palaeococcus indicus* gen. & sp. nov., *Dumbellina deobanensis* gen. & sp. nov., *Maithea indica* gen. & sp. nov., *Eophycomyces herkoides, Bulgenias septata* gen. & sp. nov. and Form 'A'.

Acritarchs—cf. *Cymatiosphaeroides* sp., *Micrhystridium* sp., *Favosphaeridium favosum, Trachysphaeridium* sp., *Leiosphaeridia crassa, L. jacutica, Caudosphaera* sp. and cf. *Ovulum saccatum.*

SYSTEMATICS

Kingdom—EUBACTERIA

Phylum—CYANOBACTERIA

Class—COCCOGONAE

Order—PLEUROCAPSALES

Family—PLEUROCAPSACAE

Genus—PALAEOPLEUROCAPSA Knoll *et al.*, 1975

Type species—PALAEOPLEUROCAPSA WOPFNERII Knoll *et al.*, 1975

Species—PALAEOPLEUROCAPSA sp.

(Pl. 3·1, 2)

Description—Colonial cells, subcylindrical in shape, arranged in rows of 3-4 cells in pseudoparenchymatous pattern. Terminal cell is hemispheroidal. Long axis of median cells ranges between 2-4 μm (2.5 μm average) and short axis ranges between 1·5-3 μm, 2 μm average (12 cells measured).

Discussion—General morphology and dimensions of Deoban forms are comparable to *Pleurocapsa* (?) sp. described by Hofmann (1976) from the Belcher Islands. This is a rare form of Deoban assemblage. Parenchymatous cells and endosporulation stages are not very well preserved, hence identification only up to generic level is possible. Arrangement of cells in chain like manner in *Palaeopleurocapsa* is comparable to *Eosynechococcus mooreii* Hofmann (1976). But the cells are joined together through their long axis in *Palaeopleurocapsa* and by their short axis in *E. mooreii*. From India *Palaeopleurocapsa* has been reported from the Fawn Limestone Member of the Kheinjua Formation (Newari locality of the Semri Group, Lower Vindhyan) by Kumar and Srivastava (1995). The genera has also been reported by Green *et al.* (1988) from the Eleonore Bay Group, East Greenland, by Knoll *et al.* (1989) from the Backlundtoppen Formation, Spitsbergen and from many other localities.

Genus—SCISSILISPHAERA Knoll & Calder, 1983

Type species—SCISSILISPHAERA REGULARIS Knoll & Calder, 1983

Species—SCISSILISPHAERA GRADATA Knoll & Calder, 1983 emend. Green *et al.*, 1989

(Pl. 2·6, 7; Pl. 6·7, 10)

Description—Spheroidal to ellipsoidal cell like units range in diameter between 6 to 35 μm, 9·5 μm average (20 cells measured). Occurring as solitary cells in clusters or as an irregular aggregates of 4-10 individuals, either with or without encompassing envelope. Intracellular mass may or may not be present.

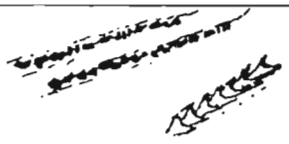
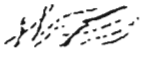
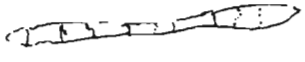
Discussion—*Scissilisphaera gradata* differs from *Scissilisphaera regularis* by a wide diameter range exhibited by former species. The form differs from *Gloeodiniopsis lamellosa* by a wide range of diameter where very small and quite large aggregates occur together. Smaller units are intrepreted as baeocytes (a characteristic feature of Pleurocapsalean affinity). A genus *Kheinjuasphaera* erected by McMenamin *et al.* (1983) from the Kheinjua Formation of India, also shows some resemblance with *Scissilisphaera gradata* in having wide diameter range, but the difference lies in multilamellate enveloping structure of latter taxa. Diameter range in Deoban form is narrow in comparison to the Greenland specimen described by Green *et al.* (1989). This is a rare form of the Deoban Assemblage.

→

Fig. 5—Additional filamentous morphotaxa, their size distribution, relative abundance and affinity.

RA = Relative abundance
C = Common
A = Abundant
R = Rare

Phylum - Cyanobacteria
Class - Hormogoneae
Order - Nostocales
Family - Nostocaceae — N
Order - Oscillatoriales
Family - Oscillatoriaceae — O
Incertae sedis — I

			R.A.				Size range in microns (average)
1	*Nostocomorpha* sp.		C			N	1.5-8 (5.5)
2	cf. *Circumvaginalis* sp.		R			N	10-11 (10.5)
3	*Siphonophycus septatum*		A		O		1-1.5
4	*Siphonophycus robustum*		A		O		3-12 (6)
5	*Siphonophycus solidum*		R		O		19-25 (21)
6	*Siphonophycus typicum*		C		O		3-10 (4.5)
7	*Polytrichoides lineatus*		R		O		2.5-4 (3)
8	*Oscillatoriopsis amadeus*		R		O		10-18 (13.5)
9	*Oscillatoriopsis obtusa*		R		O		4.5
10	*Oscillatoriopsis breviconvexa*		R		O		6-8µm (7)
11	*Rhicnonema antiquum*		C		O		6-9 (7.2)
12	*Eomicrocoleus crassus*		R		O		1.5-3 (2)
13	*Cyanonema* sp.		R		O		3-6 (4.5)
14	*Palaeolyngbya catenata*		R		O		8-16 (13)
15	*Obruchevella* aff. *parva*		R		O		5-6
16	*Obruchevella valdaica*		R		O		6
17	*Obruchevella minor*		R		O		2.5-3
18	*Glomovertella glomerata*		R		O		1.5-4.5
19	*Bulginia septata* new gen. & sp. nov.		R	I			3-15
20	cf. *Eophycomyces herkoides*		R	I			12-48

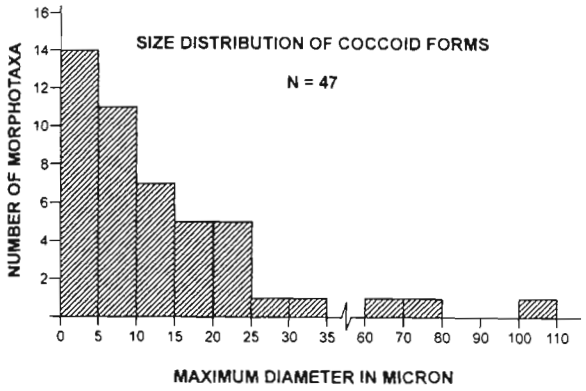


Fig. 6—Histogram for shorter diameter of coccoid forms including those, which have been described by Kumar and Srivastava (1992).

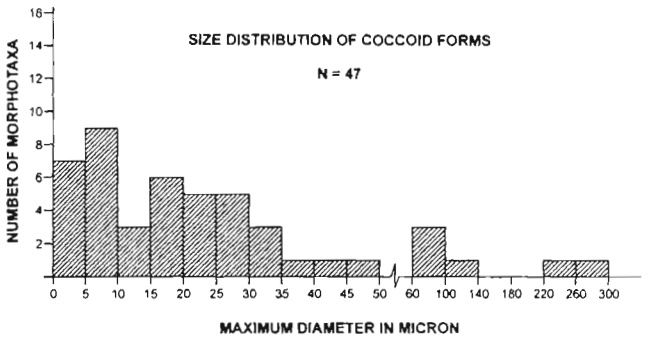


Fig. 7—Histogram for longer diameter of coccoid forms including those which have been described by Kumar and Srivastava (1992).

cf. **SCISSILISPHAERA** sp.

(Pl. 2·2)

Description—Spheroidal to polyhedral cells arranged in rosette like clusters. Cell diameter ranges from 6-8 μm, size of the cluster varies between 28-45 μm (45 cells measured). Intracellular mass may or may not present.

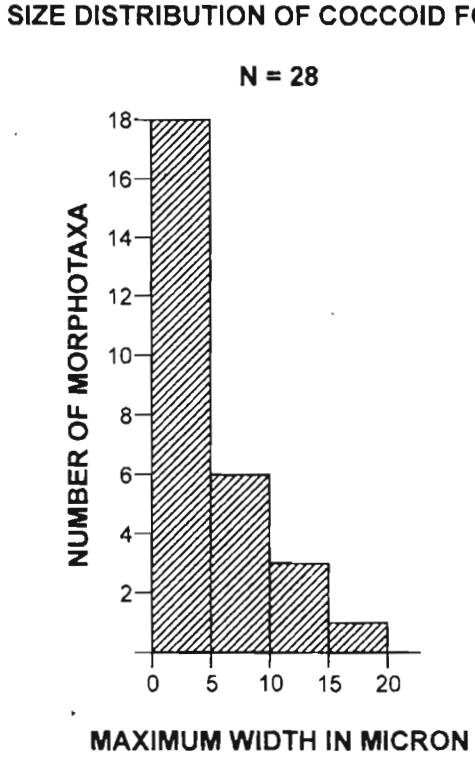


Fig. 8—Histogram for minimum width of filamentous forms including those which have been described by Kumar and Srivastava (1992).

Discussion—Specimens are cf. *Scissilisphaera* sp. belonging to family Pleurocapsaceae Schopf and Fairchild (1973) reported unnamed forms with few similar morphological features and are comparable to extant cyanobacterial form *Myxosacrcina*. Size of cells is smaller in comparison to specimens reported by Schopf and Fairchild (1973). Typical mode of occurrence in rosette or radially arranged cells is the diagnostic feature of this form and assignable to genus *Scissilisphaera*. Since present forms differ specifically from the established species of this genus, it is described as *Scissilisphaera* sp.

Order—CHROOCOCCALES

Family—CHROOCOCCACEAE

Genus—CONIUNCTIOPHYCUS Zhang, 1981

Type species—CONIUNCTIOPHYCUS GAOYUZHUANGENSE Zhang, 1981

Species—CONIUNCTIOPHYCUS GAOYUZHUANGENSE Zhang, 1981

(Pl. 3·3, 4)

Description—Cells small, spherical to ellipsoidal in shape. 1·5- 4·5 μm across, averaging 3·6 μm (80 cells measured), solitary or in cluster. Some times occur in pair with loosely dispersed aggregates. Few cells with dark inclusions are present.

Discussion—The genus was first described by Zhang (1981) from the Gaoyuzhuang Formation of China and compared it with living cyanobacteria *Microcystis*. Subsequently Golovenok and Belova (1984, 1986) described a genus *Eomicrocystis* as a fossil form of this extant counter part. Sergeev *et al.* (1995) considered the *Eomicrocystis* as a junior synonymn of *Coniunctiophycus*. In general morphology and appearance, the Deoban forms show close resemblance to the fossil forms *Coniunctiophycus gaoyuzhuangense* reported by Zhang (1981) from China.

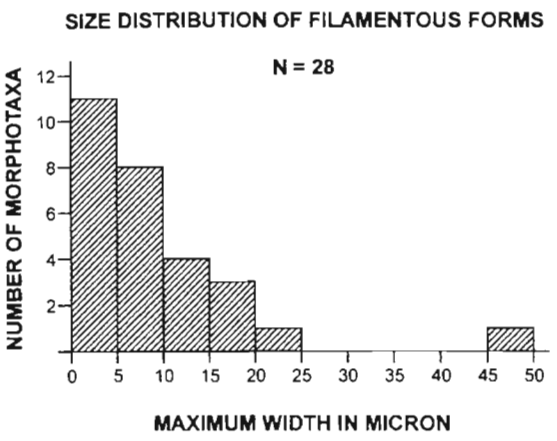


Fig. 9—Histogram for maximum width of filamentous forms including those, which have been described by Kumar and Srivastava (1992).

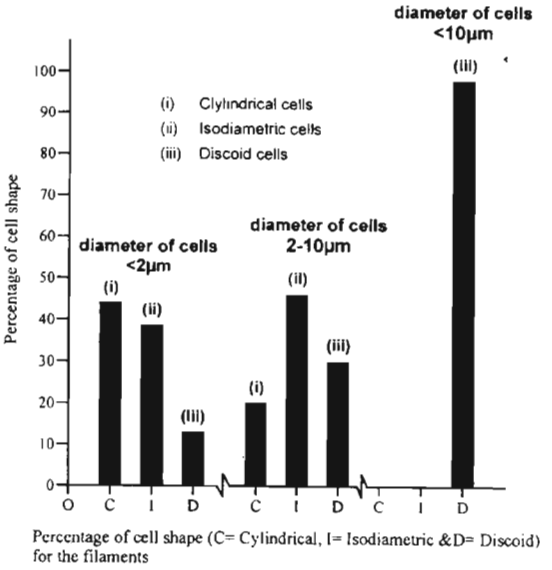


Fig. 10—Relationship between cell size and shape.

Genus—ARCHAEOPHYCUS Fuxing *et al.*, 1983

Type species—ARCHAEOPHYCUS VENUSTUS Fuxing *et al.*, 1983

Species—ARCHAEOPHYCUS sp. Fuxing *et al.*, 1983

(Pl. 1·7)

Description—Spheroidal to hemispheroidal or polyhedral, angular to irregular cell like units, range in diameter between 5-9 µm, 7·5 µm average. Occur in colonies composed of a few to tens of cells. Enclosing sheath is absent. Cell margins are sharp. Intracellular mass may or may not be present (15 units measured).

Discussion—Cell dimensions and absence of enclosing sheath and angularity in cells differentiate this genus from *Sphaerophycus* Schopf (1968). Morphologically the Deoban specimens are comparable to Jinning Yunnan's specimens (Fuxing *et al.*, 1983) except a comparatively narrow diameter range.

Genus—GLOEODINIOPSIS LAMELLOSA Schopf, emend. Knoll & Golubic, 1979

Type species—GLOEODINIOPSIS LAMELLOSA Schopf, emend. Knoll & Golubic, 1979

Species—GLOEODINIOPSIS LAMELLOSA

(Pl. 1·8, 9, 10, 12; Pl. 2·1; Pl. 3·9; Pl. 4·4)

Description—Spheroidal to hemispheroidal cell-like units, occurring in pairs, encompassed by a common organic sheath. Mesh of well arranged spheroids some times acquire hexagonal shape, in a net-like structure or some times arranged in a row. Very distinct and large intracellular mass and very faint cell walls are observed in cluster of spheroids with variable diameters. Vesicles with 2 to 3 intracellular spheroids are also present. Diameter of cells ranges from 8-18 µm, 14 µm average (50 cells measured). Diameter of intracellular mass ranges between 4-7 µm, 5 µm average (20 units measured).

Discussion—Two equal sized cell like units exhibited in Pl. 1.9, 10 are encompassed within a common sheath and are comparable to the specimens described by Schopf and Blacic (1971) as *Eozigion grande,* from the Bitter Springs Formation. They also have suggested chroococcalean (prokaryotic) affinity to this form, which was comparable with the two celled extant form *Chroococcus turgidus* or *Anacystis dimidiata*. Genus *Eozigion grande* is now merged with *Gloeodiniopsis lamellosa*. Cells distorted by mutual compressions are considered to be the result of cell division, producing two equal daughter cells. Cell walls acquired hexagonal to polyhedral shape due to mutual compression resulted in an entirely different look (Pl. 1.8, 12). Since specimens described here, deviate from the conventional appearance of the *G. lamellosa* and exhibit different morphological characters than the previously described specimens in 1992 paper, this form has been redescribed here.

Genus—MYXOCOCCOIDES Schopf, 1968

Type species—MYXOCOCCOIDES MINOR Schopf, 1968

Species—MYXOCOCCOIDES CHLORELLOIDEA Knoll *et al.*, 1991

(Pl. 2·3, 4, 5; Pl. 6·11)

Description—Thin, single walled, unicells comprising large spheroids in form of diads, tetrads and octads. Internal cell like units are well rounded to hemispherical and mostly attached to each other. Diameter of outer cell wall ranges between 15-35 μm, (22 μm average) and internal vesicle ranges between 6-12 μm, 10 μm average (20 specimens measured). Intracellular mass may or may not be present.

Discussion—Organisation of internal vesicles in diads, tetrads, octads within an encompassing sheath or outer vesicle like structure differentiate this species from the other species of *Myxococcoides* and lack of multiple lamellae differentiate it from *Gloeodiniopsis* species. In all respect it is identical to the Spitsbergen's specimens described by Knoll *et al.* (1991). It has been compared with the living green alga *Chlorella* (Knoll *et al.*, 1991).

Species—MYXOCOCCOIDES STRAGULESCENS Green *et al.*, 1989

(Pl. 6·9)

Description—Spheroidal cell like units have robust single walls, displaying functional tears lacking colonial mucilage and forming dense monospecific layers. Diameter of coccoids ranges between 10-17 μm, average 12 μm (27 cells measured).

Discussion—Functional tearing in cell walls has been taken as characteristic feature of *Myxococcoides stragulescense*, which favours its affinity towards protists. According to Green *et al.* (1989) it has been interpreted as an eukaryotic cyst. Among the comparable extant forms found today in physically similar tidal flat environments, cysts are made by *Dunaliella*, a green alga and *Paratetramitus*, an amoebo-flagellate protozoa (Green *et al.*, 1989). Deoban forms show almost similar morphology with Spitsbergen forms except narrow diameter range. Though forms exhibiting tearing are categorised as an individual species of *Myxococcoides*, but authors suggest that it should be merged with *Myxococcoides inornata* as it occurs in association with them and tearing may be a preservational feature, rather than a phylogenetic character.

Genus—PALAEOMERISMOPEDIA gen. nov.

Type species—PALAEOMERISMOPEDIA MISRAI gen. & sp. nov.

Etymology—Because of its similarity with modern form *Merismopedia*.

Diagnosis—Small spheroidal to ellipsoidal cell like units arranged bilineary or trilineary in a flat rectangular colonies.

Discussion—Schopf and Fairchild (1973) described from the Skillogalee Dolomite, South Australia an unnamed form, which was compared with the living cyanobacterial form *Merismopedia*. In dimensions, the Deoban microfossils fall in range of *Sphaerophycus parvum* (Schopf, 1968) but typical arrangement of cells in the form of rectangular colony is the differentiating feature of this genus. It is comparable to the living cyanobacterial form *Merismopedia tenneyssima* (Desikachary, 1959) in the size of the cell as well as in the rectangular arrangement. The Deoban form exhibits smaller aggregates in comparison to the Skillogalee specimens described by Schopf and Fairchild (1973).

Species—PALAEOMERISMOPEDIA MISRAI gen. & sp. nov.

(Pl. 3·5)

Type Locality—Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Slide no. Db_3-6, Coordinates 55.0/10.6 (Nikon).

Etymology—In honour of late Prof. R.C. Misra.

Diagnosis—Monospecific genus.

Description—Small colonies of 4-64 cell like units, spheroidal to ellipsoidal in shape where cells arranged in rectangular colonies, loosely packed and 2-3 μm (2.5 μm average) in diameter. Sharp margins with or without mucilagenous matrix are present (50 cells measured).

Class—HORMOGONAE

Order—NOSTOCALES Geitler, 1925

Family—NOSTOCACEAE

Genus—ARCHAEOELLIPSOIDES Horodyski & Donaldson, 1980 emend. Sergeev & Knoll, 1995

Type species—ARCHAEOELLIPSOIDES GRANDIS Horodyski & Donaldson, 1980

PLATE 1

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all photomicrographs except for 1, 2, 3 and 4 where it is equal to 2 mm. Name of the microscope used for photography is also given in the bracket)

1. *Tawuia dalensis*, Deoban Limestone, Chakrata area, Uttaranchal.
2. *Tawuia dalensis*, Deoban Limestone, Chakrata area, Uttaranchal.
3. *Chuaria circularis*, Deoban Limestone, Chakrata area, Uttaranchal.
4. *Chuaria circularis*, Deoban Limestone, Chakrata area, Uttaranchal.
5. *Archaeoellipsoides major*, Slide No. II/D/89-11, 50.2/22.6 (Nikon).
6. *Archaeoellipsoides minor*, Slide No. Db_1- 16, 76.8/5.9 (Leica).
7. *Archaeophycus* sp., Slide No. Db_2- 5, 139.1/19.4 (Olympus).
8. *Gloeodiniopsis lamellosa*, Slide No. Db_3- 6F, 48.5/15.5 (Nikon).
9. *Gloeodiniopsis lamellosa*, Slide No. Db_3- 6F, 57.9/12.9 (Nikon).
10. *Gloeodiniopsis lamellosa* Slide No. Db_3- 6F, 56.9/12.4 (Nikon).
11. Filament with akinite like structure, Slide No. Db_1- 11, 51.3/5.5 (Nikon).
12. *Gloeodiniopsis lamellosa*, Slide No. II/D/89, 60.7/0.4 (Leica).

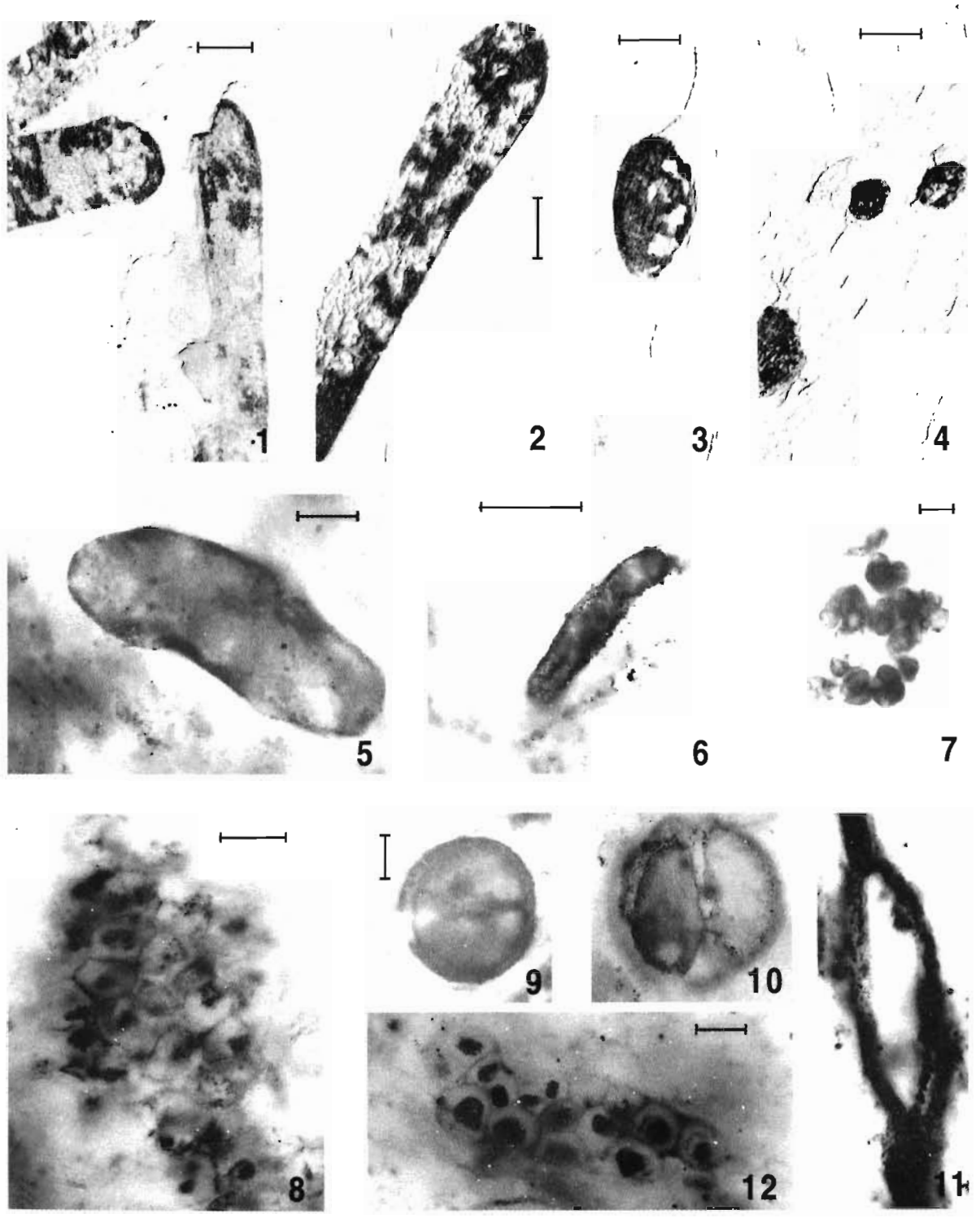


PLATE 1

Species—ARCHAEOELLIPSOIDES MINOR Sergeev & Knoll, 1995

(Pl. 1·6)

Description—Ellipsoidal cell-like units, solitary, with or without intracellular mass. Organic matrix may or may not be present. Ellipsoids show more or less smooth margins. Long axis ranges between 18-26 μm, average 20 μm. Short axis ranges between 6-9 μm, average 7 μm (5 specimens measured).

Discussion—Horodyski and Donaldson (1980) erected this genus for solitary occurring ellipsoidal structures. Zhang Yun (1985) also reported this form from the Wumishan Formation. This form has also been reported from the Fawn Limestone Member of the Kheinjua Formation, Lower Vindhyans, India by Kumar and Srivastava (1995). *Archaeoellipsoides* are considered as the akinites of nostocalean cyanobacteria. In Neoproterozoic microbial assemblages, these saussage like microfossils have been described as *Brevitrichoides* (see Jankauskas *et al.,* 1989), which occur rarely. Since Mesoproterozoic assemblages usually dominated by akinites or *Archaeoellipsoides*, Knoll and Sergeev (1995) considered them as evolutionary as well as environmental changes among microorganisms during Meso-Neoproterozoic periods. On comparing exceptionally well preserved microfossil assemblages from the Billyakh Group (Golovenok & Belova, 1984; Yakschin, 1991; Sergeev *et al.*, 1995), Kutungda and Debengda Formation of Northern Siberia (Yakschin, 1990; Sergeev *et al.*, 1994), the Jixian Group, Northern China (Zhang, 1981, 1985), Bangemall Group, Australia (Buick & Knoll, 1999), Dismal Lakes Group, Arctic Canada (Horodyski & Donaldson, 1980) and Kheinjua Formation, India (Kumar & Srivastava, 1995), it has been observed that marked decline in occurrence of akinite like structures or *Archaeoellipsoides* across the Meso-Neoproterozoic transition has taken place which is interpreted as a consequence of eukaryotic radiation during this period (Knoll & Sergeev, 1995).

Species—ARCHAEOELLIPSOIDES MAJOR Golovenok & Belova, 1984; Sergeev & Knoll, 1995

(Pl. 1·5)

Description—Single layered, solitary, straight or slightly curved sac like bodies, with rounded ends. Surface psilate to granular, obliterating the wall. Length varies between 20-65 μm, average 40 μm, width ranges between 6-12 μm, average 10 μm, (3 specimens measured).

Discussion—*Archaeoellipsoides minor* was originally described as *Eosynechoccus major* by Golovenok and Belova (1984). Dimensions of Deoban specimens are more in comparison to forms described by Amard and Sarfati (1997) from the Franceville Group, Gabon.

Genus—NOSTOCOMORPHA Xing & Liu, 1978; Hofmann & Jackson, 1994

Species—NOSTOCOMORPHA sp.

(Pl. 7·1, 3)

Description—Chain-like aggregates of spheroidal to polyhedral opaque grains of iron minerals arranged linearly within an unbranched sheath or without sheath, maximum length of entire structure measured is up to 220 μm. Width of filament is 1.5-8 μm, 5.5 μm average, unbranched. Sheath may or may not be present. Diameter of filaments varies from chain to chain (4 specimens measured).

Discussion—Morphology of these specimens is comparable to a number of Proterozoic microfossils. Hofmann and Jackson (1994) reported microfossils of identical morphologies as *Nostocomorpha* (excluding wider diameter range). Hofmann (1984) merged all taxa exhibiting opaque mineral replacement within a tubular sheath as *Siphonophycus* or *Eomycetopsis*. This form is a rare form of the Deoban Assemblage. These filaments inclining towards Oscillatoriacean affinity, but replacement by any mineral could give rise to such morphology.

Family—SCYTONEMATACEAE Rabenhorst, 1865

Genus—CIRCUMVAGINALIS Sergeev, 1993 emend. Sergeev & Knoll, 1995

Type species—CIRCUMVAGINALIS ELONGATUS Sergeev, 1993 emend. Sergeev & Knoll, 1995

Species—cf. CIRCUMVAGINALIS sp.

(Pl. 8·3)

Description—Tube-like structure composed of successively superimposed funnel-shaped units, which appear to be partly inserted into each other as cone in cone structure. Width of the individual unit ranges between 10-11 μm, 10·5 μm

PLATE 2 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Gloeodiniopsis lamellosa*, Slide No. I/D/89-3, 59.4/15.2 (Nikon).
2. *Scissilisphaera* sp., Slide No. Db_2- 6, 87.8/14.5 (Leica).
3. *Myxococcoides chlorelloidea*, I/D/89, 55.6/13.4 (Nikon).
4. *Myxococcoides chlorelloidea*, II/D/89, 59.7/11.9 (Nikon).
5. *Myxococcoides chlorelloidea*, Slide No. Db_1-9, 53.3/14.3 (Nikon).
6. *Scissilisphaera gradata*, I/D/89, 52.0/12.8 (Nikon).
7. *Scissilisphaera gradata*, Slide No. Db_3-6, 69.0/16.7(Nikon).

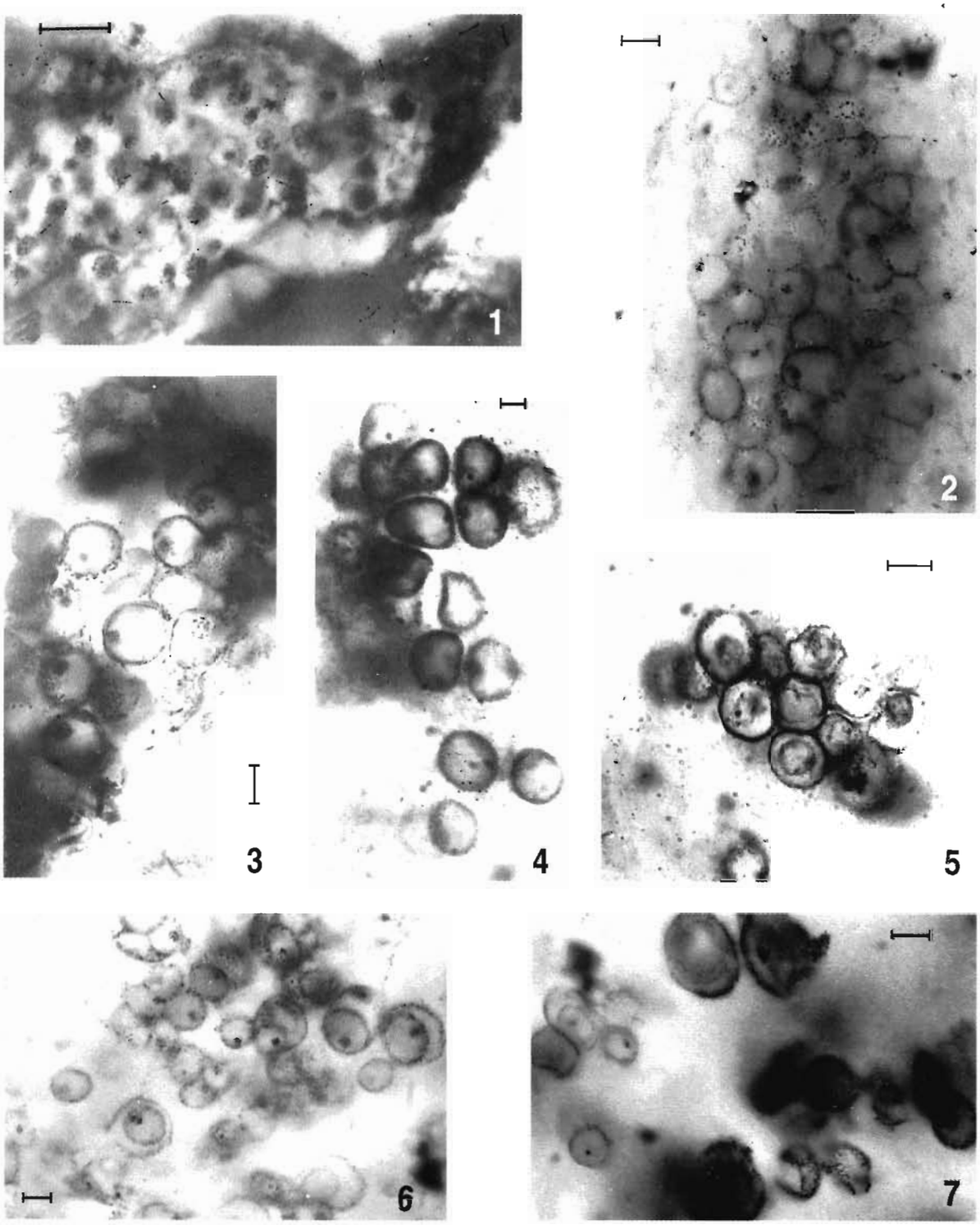


PLATE 2

average, which is almost uniform throughout the length. Length varies from 5-7 μm. Length of the entire structure is 105 μm. Granular organic matter is seen at the margins of funnel-shaped units (Single specimen).

Discussion—Different degradational stages of *Scytonema* particularly the last stage shown by Golubic and Barghoorn (1977) exhibited more or less the same features as seen in the present form. Therefore the Deoban microfossils may be interpreted as a degradational stage of *Scytonema*-like form. Width of Deoban's specimen is less than the forms described by Sergeev *et al.* (1995), but the morphology is comparable.

Order—OSCILLATORIALES

Family—OSCILLATORIACEAE

Genus—SIPHONOPHYCUS Schopf, 1968

Type species—SIPHONOPHYCUS KESTRON Schopf, 1968

Species—SIPHONOPHYCUS SEPTATUM Schopf, 1968; Butterfield in Butterfield *et al.*, 1994

(Pl. 10·9)

Description—Thin tubular filaments, which are unbranched, septate, straight or sinuous with granular texture. Diameter of tubes varies between 1-1·5 μm. Maximum length measured for these filaments exceeded up to 200 μm (15 filaments measured).

Discussion—Morphological features except the dimensions are almost same for forms assigned to *Archaeotrichion, Eomycetopsis* and *Siphonophycus*. Knoll *et al.* (1991) merged *Eomycetopsis* into *Siphonophycus*. Very thin tubular sheaths ranging in diameter from 1-1.5 μm have been assigned to *Archaeotrichion* and tubular sheaths with diameter of more than 2 μm to genus *Siphonophycus*. But Butterfield *et al.* (1994) described *A. contortum* as junior synonymy of *Siphonophycus septatum*. Here authors follow taxonomy recommended by Butterfield *et al.* (1994).

Species—SIPHONOPHYCUS ROBUSTUM Schopf, 1968 emend. Knoll & Golubic, 1979 comb. Knoll *et al.*, 1991

(Pl. 7·2; Pl. 10·10)

Description—Thin, tubular, nonseptate filaments which may be straight or sinuous. Walls smooth and cross sections are mostly circular. Diameter of filaments varies between 3-12 μm. Normally filaments acquire quite long length, up to 220 microns.

Discussion—This is one of the very common species of Proterozoic microfossils. As far as affinity of these forms is concerned they are considered as the empty sheaths of cyanobacterial trichomes. Deoban forms also exhibit normal basic features of this abundantly occurring taxa. This partricular species has already been reported in paper on Deoban Microfossil assemblage by Kumar and Srivastava, (1992), but then it was described as *Eomycetopsis robustum*.

Species—SIPHONOPHYCUS SOLIDUM Golub, 1979 emend. Butterfield in Butterfield *et al.*, 1994

(Pl. 7·6; Pl. 9·6)

Description—Unbranched, nonseptate filamentous sheaths acquiring ring-shaped morphology, occur solitary. Surface texture is psilate to granular. Width of filament ranges between 19-25 μm, (22 μm average). Septae-like structures are also present at a few places. Maximum length measured 180 μm. Filament is ruptured at few places. Thickness of wall ranges from 1·5-2 μm (2 specimens measured).

Discussion—Butterfield in Butterfield *et al.* (1994) emended the thick sheath acquiring ring-shape as *Siphonophycus solidum*. Width of the Deoban specimens is comparable to the forms reported from SW China by Fuxing *et al.* (1983) where filament acquired a ring-shaped structure and septae-like structures present. It was previously named as *Circulinema muirae*. Apparently there is no difference between *C. muirae* and *Siphonophycus solidum*. Pl. 7·6 shows comparatively smaller diameter (14-15 μm), but almost similar morphology except, sheath does not acquire ring-shape, it is sinuous structure. Hence categorised under *S. solidum*.

Species—SIPHONOPHYCUS TYPICUM Hermann, 1974 emend. Butterfield in Butterfield *et al.*, 1994

(Pl. 5·4; Pl. 9·8)

Description—Filamentous tubes of variable diameters are occurring together in different orientations. Tubes are straight to sinuous, without inclusions. Diameter varies from

PLATE 3 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Palaeopleurocapsa* sp., Slide No. Db_2-12, 139.0/16.2 (Olympus).
2. *Palaeopleurocapsa* sp., Slide No. Db_1-15, 144.8/12.3 (Olympus).
3. *Nannococcus vulgaris*, Slide No. Db_1-15, 46.9/10.2 (Nikon).
4. *Nannococcus vulgaris*, Slide No. Db_1-7, 55.3/17.1 (Nikon).
5. *Palaeomerismopedia misrai*, Slide No. Db_3- 6, 55.0/10.6 (Nikon).
6. *Palaeococcus indicus*, Slide No. Db_2-12, 49.8/20.5 (Nikon).
7. *Palaeococcus indicus*, Slide No. Db_2-12, 49.4/15.5 (Nikon).
8. *Palaeosphaeridium zonale*, Slide No. Db_1-6, 53.7/13.3 (Nikon).
9. *Gloeodiniopsis lamellosa*, Slide No. 11/D/89, 58.8/10.2 (Nikon).
10. Ascogenous hyphae like structure of Ascomycetes, Slide No. Db_1-12, 137.8/5.1(Olympus).
11. *Maithea indica* gen. and sp. nov., Slide No. Db_2-12, 50.6/20.8 (Nikon).
12. *Maithea indica*, Slide No. Db_2-12, 50.2/20.8 (Nikon).

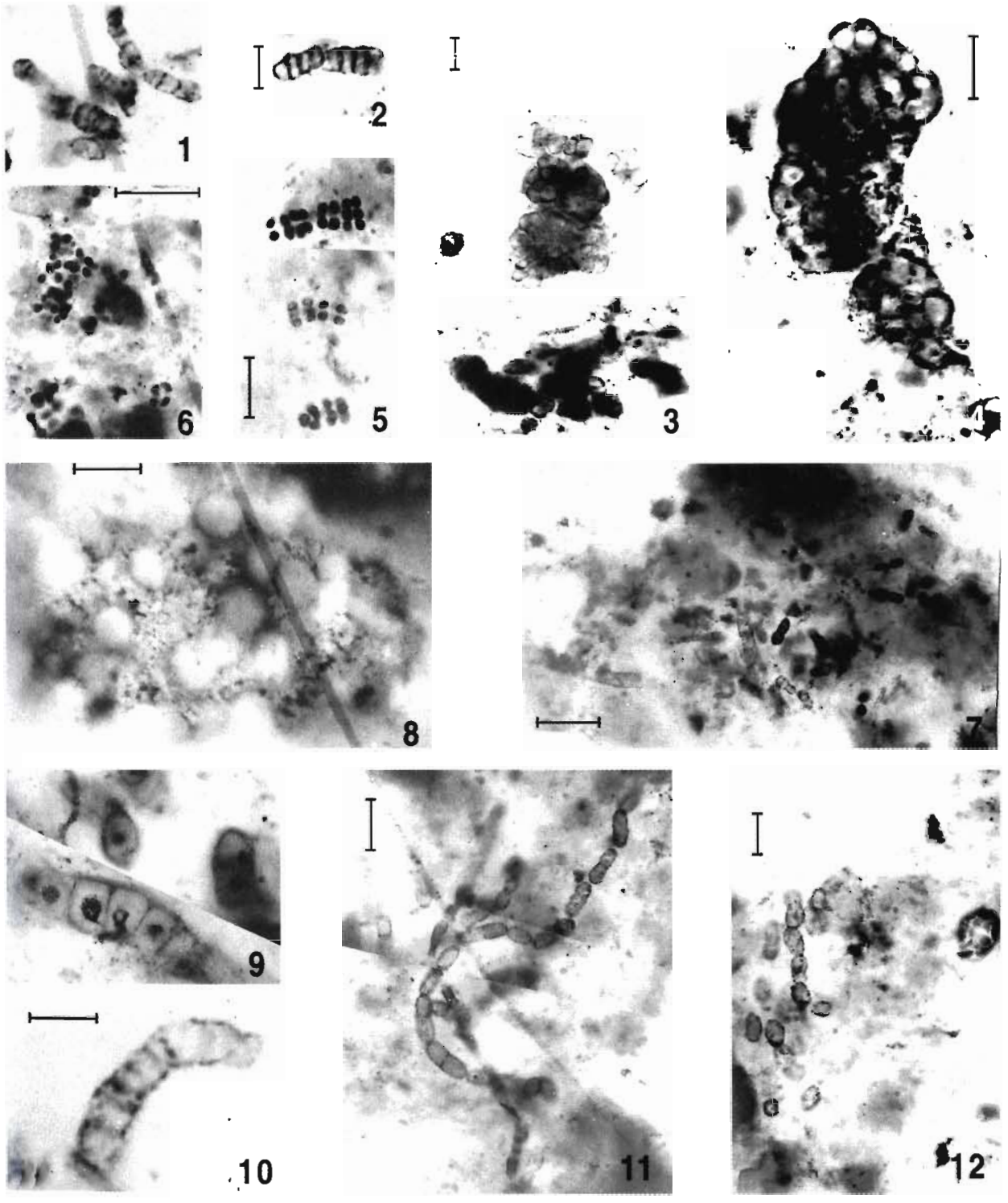


PLATE 3

3 to 10 μm, 4·5 μm average (15 tubes measured). Length of sheath ranges between 20-26 microns.

Discussion—According to revision suggested by Butterfield in Butterfield *et al.* (1994), the present forms are assignable to *S. typicum*.

Genus—POLYTRICHOIDES Hermann (1974) emend. Hermann, 1976 (in Timofeev & Hermann, 1976)

Type species—POLYTRICHOIDES LINEATUS Hermann (1974) emend. Hermann, 1976

Species—POLYTRICHOIDES LINEATUS Hermann (1974), emend. Hermann, 1976

(Pl. 8·7)

Description—Filamentous septate tubes arranged parallel and closed to each other within a common enclosing sheath. Filaments psilate to finely granular 5-6 tubes in a bundle (5 specimens measured). Each tube ranges in diameter from 2·5 to 4 μm (3 μm average). Diameter of a bundle ranges between 20-24 μm, 22 μm average (3 specimens measured).

Discussion—General morphology of *Polytrichoides* and *Microcoleus* is almost same except the presence of enclosing sheath in case of *Polytrichoides* and filaments exhibit presence of septae. The Deoban forms are comparable to the Chinese forms described by Zang and Walter (1992).

Genus—OSCILLATORIOPSIS Schopf, 1968

Type species—OSCILLATORIOPSIS OBTUSA Schopf, 1968

Species—OSCILLLATORIOPSIS AMADEUS Schopf, 1968 comb. Butterfield in Butterfield *et al.*, 1994

(Pl. 7·8)

Description—Multicellular, uniseriate, unbranched, trichomed filaments, 10-18 μm in width, 13·5 μm average (5 specimens measured). Transverse walls of cells are distinct, compressed cells contain numerous inclusions. Tapering in one end is well marked.

Discussion—Width range is comparable to *O.amadeus* reported by Butterfield *et al.* (1994) from the Svanbergjellet Formation of Spitsbergen.

Species—OSCILLATORIOPSIS OBTUSA Schopf, 1968 emend. Butterfield in Butterfield *et al.*, 1994

(Pl. 9·4)

Description—Multicellular, uniseriate, unbranched trichome, cross walls very faint, sheath absent. Filaments are solitary, straight up to 92 μm long. Diameter of the filament ranges from 4-5 μm (single specimen traced).

Discussion—Morphologically it is comparable to many species of extant oscillatoriacean filament. Deoban's specimen is comparable to the *O. obtusa* reported from the Bitter Springs Formation by Schopf and Blacic (1971).

Species—OSCILLATORIOPSIS BREVICONVEXA Schopf & Blacic, 1971

(Pl. 7·4, 10)

Description—Trichome multicellular, unbranched, uniseriate, slightly constricted at cross walls. Since both filaments assignable to *O. breviconvexa* are incomplete, nature of filaments towards ends is not known i.e., whether it is attenuated or dialated. Remnants of sheath are seen in one of the specimens. Filaments range in diameter from 6-8 μm. Maximum length measured is 102 μm.

Discussion—The Deoban specimens exhibit comparable morphology and size range as mentioned for the Bitter Springs' specimens.

Genus—RHICNONEMA Hofmann, 1976

Type species—RHICNONEMA ANTIQUUM Hofmann, 1976

Species—RHICNONEMA ANTIQUUM Hofmann, 1976

(Pl. 7·9; Pl. 8·6; Pl. 9·2)

Description—Unbranched multicellular uniseriate trichome surrounded by tubular sheath. Filament is straight or curved, septation in inner thin filament is apparently seen at few places. Width of inner filament ranges between 1·5-3 μm, 2 μm average, width of outer sheath ranges between 6-9 μm, 7·2 μm average (7 specimens measured).

Discussion—General morphology of forms assigned *to Rhicnonema antiquum* is similar to that described by Hofmann (1976) from the Belcher Islands except the helicoid nature of

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PLATE 4 →

(Photomicrographs of coccoid forms in thin sections of black bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs except for 'a', 'e' and 'j' where it is equal to 50 microns Name of the microscope used for photography is also given in bracket)

1. *Trachysphaeridium* sp., Slide No. I/D/89—8, 50.7/18.6 (Nikon).
2. *Trachysphaeridium* sp., Slide No. II/D/ 89—11, 49.2/20.5 (Nikon).
3. *Leiosphaeridia crassa*, (Spirally grooved), Slide No. Db-2 A, 56.1/ 12.8 (Nikon).
4. *Gloeodiniopsis lamellosa*, Slide No. Db_1-7, 56.8/2.0 (Leica).
5. *Trachysphaeridium* sp., Slide No. I/D/ 89—8, 57.1/12.3 (Nikon).
6. *Leiosphaeridia crassa*. Slide No. I/D/89-1, 55.4/8.4 (Nikon).
7. *Micrhystridium* sp., Slide No. Db_1-15, 46.7/9.3 (Nikon)
8, 11. *Favosphaeridium favosum*, Slide No. Db_2-1, 133.1/9.5 (Olympus).
9. *Leiosphaeridia crassa*, Slide No. I/D/89- 1, 55.4 /10.4 ((Nikon).
10. *Trachysphaeridium* sp., Slide No. Db_1-17, 50.9/17.8 (Nikon).

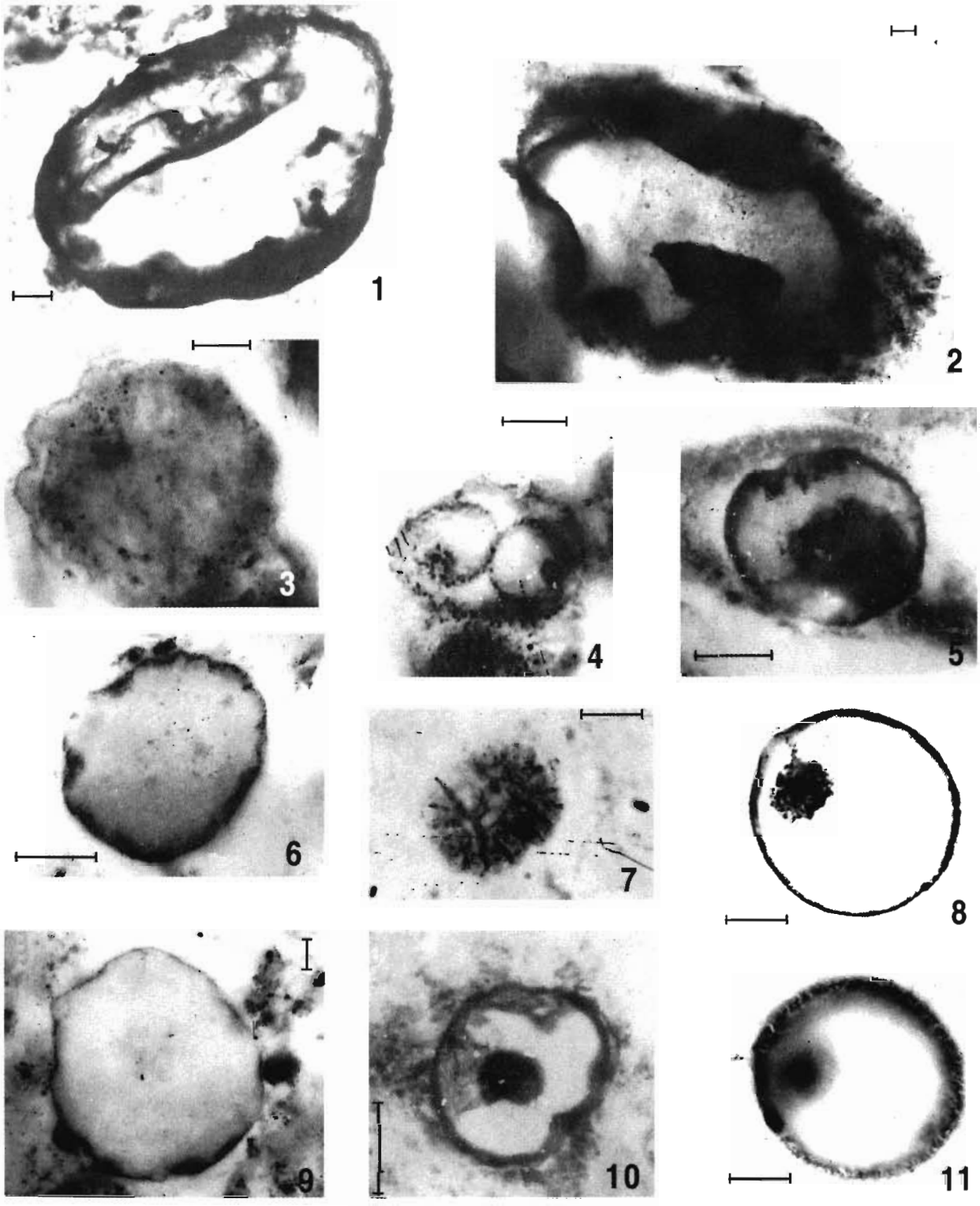


PLATE 4

the median filament as mentioned by him. Diameter range of median filament is almost same where as outer sheath like structure shows wide diameter range in comparison to the Belcher specimens. Fuxing *et al.* (1983) also reported specimens with similar morphology (including the helical structures of trichome) from China. Width of the median filaments in the Deoban assemblage is more than the forms reported by Zhang Yun (1985) from China, while outer sheath shows same diameter range. The taxa also show some resemblance with *Siphonophycus typicum.*

Genus—EOMICROCOLEUS Horodyski & Donaldson, 1980

Type species—EOMICROCOLEUS CRASSUS Horodyski & Donaldson, 1980

Species—EOMICROCOLEUS CRASSUS Horodyski & Donaldson, 1980

(Pl. 8·9; Pl. 9·9)

Description—Unbranched, thin filaments, laterally enclosed within a common cylindrical sheath up to 40 µm in width. Each sheath encompasses a bundle of closely arranged filamentous tubes with diameter 1·5-3 µm (2 µm average). Number of tubes vary in each sheath. Texture of filaments is granular, numerous inclusions present in these ensheathed filaments (4 specimens measured).

Discussion—Width of the Deoban specimens is little larger than the Dismal Lake's specimens described by Horodyski and Donaldson (1980), but overall morphology is same. The width is also larger in comparison to *Eomicrocoleus* sp. reported by Hofmann and Jackson (1994) and by Buick and Knoll (1999). It has a smaller dimension in comparison to cf. *E. crassus* reported from the Newari locality, Fawn Limestone Member of the Kheinjua Formation, India by Kumar and Srivastava (1995). This form is a rare component of Deoban Assemblage. Preservation of the filaments is rather poor and details of morphology are not clearly visible. In morphology, the Deoban form resembles with extant *Microcoleus lacustris* Desikachary (1959).

Genus—CYANONEMA Schopf, 1968

Type species—CYNONEMA ATTENUATUM Schopf, 1968

Species—CYANONEMA sp.

(Pl. 7·5, 7, 11; Pl. 9·3)

Description—Multicellular, uniseriate, unbranched, occasionally slightly constricted at septa, solitary filamentous forms without enclosing sheath. Cells elongate, slightly curved and occasionally break into segments from the septa. Length of cells 3-6 µm and width ranges between 2-5 µm (12 cells measured, 3 specimens found).

Discussion—Tendency of filaments to break into segments from the septa is identical to the species reported from Jinning Yunnan of SW China by Fuxing *et al.* (1983). Oehler (1977) also reported filaments with well-marked septa. The Deoban forms show close resemblance with *C. inflatum* but its internal feature is not well preserved. Thus, the form is identified up to generic level only. Dimensions and some features are comparable to *C. ligamen* reported by Zhang Yun (1981) from the Gaoyuzhuang Formation of China; the difference is the presence of cross walls only. *Cyanonema minor* is the species from Mc Arthur Group described by Oehler (1977), differentiable by its small dimensions. In Pl. 7·7 morphology resembles to some extent with extant cyanobacterial form *Gloeotrichia.*

Genus—PALAEOLYNGBYA Schopf, 1968

Type species—PALAEOLYNGBYA BARGHOORNIANA Schopf, 1968

Species—PALAEOLYNGBYA CATENATA Hermann, 1974 emend. Butterfield in Butterfield *et al.*, 1994

(Pl. 9·5, 7)

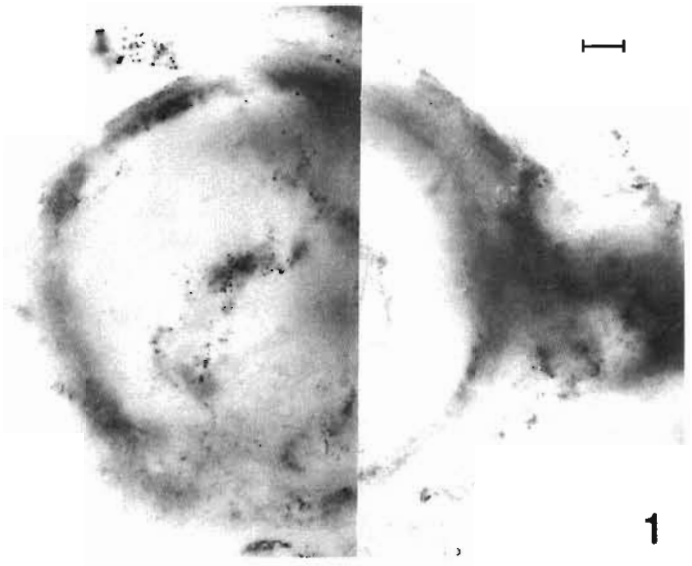
Description—Multicellular, uniseriate, filaments with enclosing sheaths. Trichomes solitary, straight to slightly curved, granular surface, prominent cross walls may or may not be present. Width of filaments ranges between 12-20 µm (14 µm average, inclusive of encompassing sheath), cells are disc-shaped with length 5-7 µm, 5·5 µm average and width of 8-16 µm, 13 µm average (23 cells measured). Maximum length is 180 µm (4 specimens measured).

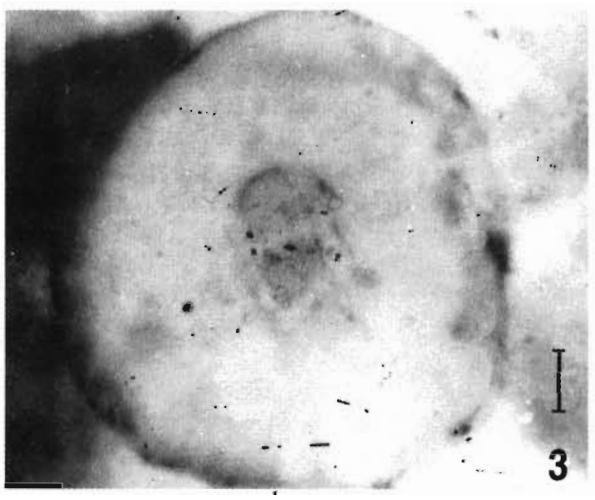
Discussion—According to Schopf (1968), septation is simply due to cell division, resulting in asexual reproduction. This genus is a rare member of the Deoban Assemblage. Width

PLATE 5 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. cf. *Cymatiosphaera* sp., Slide No. I/D/89-9, 62.0/10.6 (Nikon).
2. Septate filament with akinite like structures, Slide No. Db_2-12, 52.8/9.58 (Nikon).
3. *Leiosphaeridia jacutica*, Slide No. I/D/89-4, 54.1 /12.9 ((Nikon).
4. *Siphonophycus robustum*, Slide No. Db_1-15, 50.7/18.8 (Olympus).
5. *Caudosphaera* sp., Slide No. Db_2-7, 49.9/15.8 (Olympus).
6. cf *Ovulum saccatum*, Slide No. Db_1-2, 80.2/14.2 (Leitz).
7. Unusual form with aestrix mark seen within a vesicle, Slide No. Db_2-F. 142.2/3.6 (Olympus).
8. V-shaped engrovement in spheroid with prominent intracellular mass, Slide No. Db2-12, 49.8/ 9.9 (Nikon).





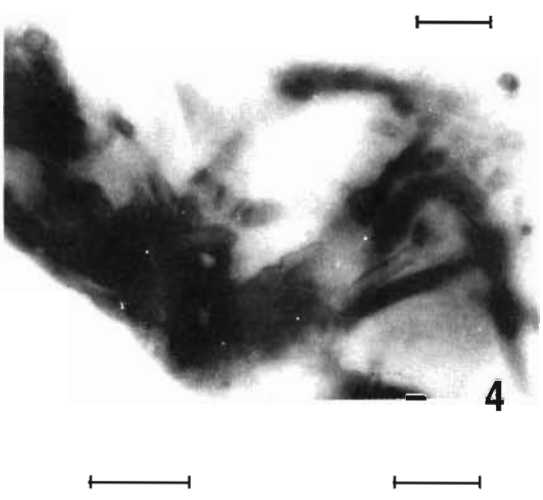


PLATE 5

of filaments is comparable to the *Palaeolyngbya maxima* described by Zhang Yunl (1981) from China, which was subsequently synonymised by Butterfield in Butterfield *et al.* (1994) to *Palaeolyngbya catenata.*

Genus—OBRUCHEVELLA Reitlinger, 1948, emend. Yakschin & Luchinina, 1981

Type species—OBRUCHEVELLA DELICATA Reitlinger, 1948

Species—OBRUCHEVELLA AFF. PARVA Reitlinger, 1959

(Pl. 10·3)

Description—Tightly to loosely coiled nonseptate tubular filaments are showing different modes of coiling. Sometimes they are single whirled and most of the times there are 4-6 whorls. Diameter of tubular filaments ranges from 5 to 6 µm (5 specimens measured). Diameter of helix ranges from 45 to 60 µm, 55 µm average.

Discussion—Filaments acquiring helically coiled morphology are observed in Deoban Assemblage, which are much thinner than the other reported forms. Range of the diameter of the Deoban specimens are comparatively less than the Chinese forms described by Song (1984) from the Jinning Yunnan.

Species—OBRUCHEVELLA VALDAICA Jankauskas in Jankauskas *et al.*, 1989

(Pl. 10·7)

Description—Tightly coiled, nonseptate, tubular filament with 4 to 5 whorls. Diameter of tube is uniform throughout, which is 6 µm (single specimen).

Discussion—Tight coiling with a round, empty central space is the feature exhibited by a single specimen in Deoban Assemblage. Morphology shows close resemblance with *O. valdaica* reported from the Thule Supergroup, Northwest Greenland by Samuelsson *et al.* (1999). Dimensions are also comparable to the Thule specimens.

Species—OBRUCHEVELLA MINOR Zhang Zhong Ying, 1984.

(Pl. 10·5, 6)

Description—Tubular, spring like, spirally coiled filaments of 2·5 to 3 µm diameter, helically coiled around an open centre. Helixes straight to slightly curved along its length. External diameter of helix is from 12 to 22 µm. Coiling is loose and adjacent coils do not touch each other. Transverse markings are not seen.

Discussion—*Obruchevella minor* is differentiable from the other species of the genus by its mode of coiling and diameter range of tubes. This species is supposed to be the smallest spirally coiled fossil filaments.

Genus—GLOMOVERTELLA Reitlinger, 1959

Type species—GLOMOVERTELLA GLOMERATA Reitlinger, 1959

Species—GLOMOVERTELLA GLOMERATA Reitlinger, 1959

(Pl. 10·8)

Description—Tightly to loosely coiled nonseptate tubular filaments are exhibiting different modes of coiling. Sometimes they are single whorled and most of the times there are 4 to 6 whorls. Diameter of tubes ranges between 1·5 to 4·5 µm (5 specimens measured). Diameter of helix ranges from 15 to 35 µm, 24 µm average.

Discussion—Haphazardly oriented loosely coiled filaments are easily differentiable from the helically coiled filamentous form *Obruchevella.*

INCERTAE SEDIS

Coccoid forms

Genus—PALEOSPHAERIDIUM Yin Chongyu, 1985

Type species—PALEOSPHAERIDIUM ZONALE Yin Chongyu (1985) emended Zang & Walter, 1992

Species—PALEOSPHAERIDIUM ZONALE Zang & Walter, 1992

(Pl. 3·8)

PLATE 6 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Germinosphaera* sp., Slide No. Db_1-15, 51.6/17.7 (Nikon).
2-$_1$, 2-$_2$. Budding-like structure in a filamentous form, Slide No. Db_2-F, 142.5/2.6 (Olympus).
3. *Leiosphaeridia crassa*, Slide No. Db_3-9, 46.8/10.2 (Nikon).
4. Budding-like structure in coccoid form, Slide No. Db_2-G, 53.8/ 6.0 (Leica).
5. *Dumbellina deobanensis*, gen. and sp. nov. Slide No. II/D/89-6, 57.8/16.5 (Nikon).
6. *Dumbellina deobanensis*, gen. and sp. nov, holotype, Slide No. II/D/89-6, 42.0/24.2 (Nikon).
7. *Scissilisphaera gradata*, Slide No. Db_3-6, 69.5/17.3 (Leica).
8. *Trachysphaeridium* sp., Slide No. Db2-7.57.8/ 12.0 (Nikon).
9. *Myxococcoides stragulescense*, Slide No. Db_3-9, 74.6/14.2 (Nikon).
10. *Scissilisphaera gradata*, Slide No. Db_3-6, 69.6/17.3 (Leica).
11. *Myxococcoides chlorelloides*, Slide No. Db_3-6, 80.0/12.7 (Nikon).

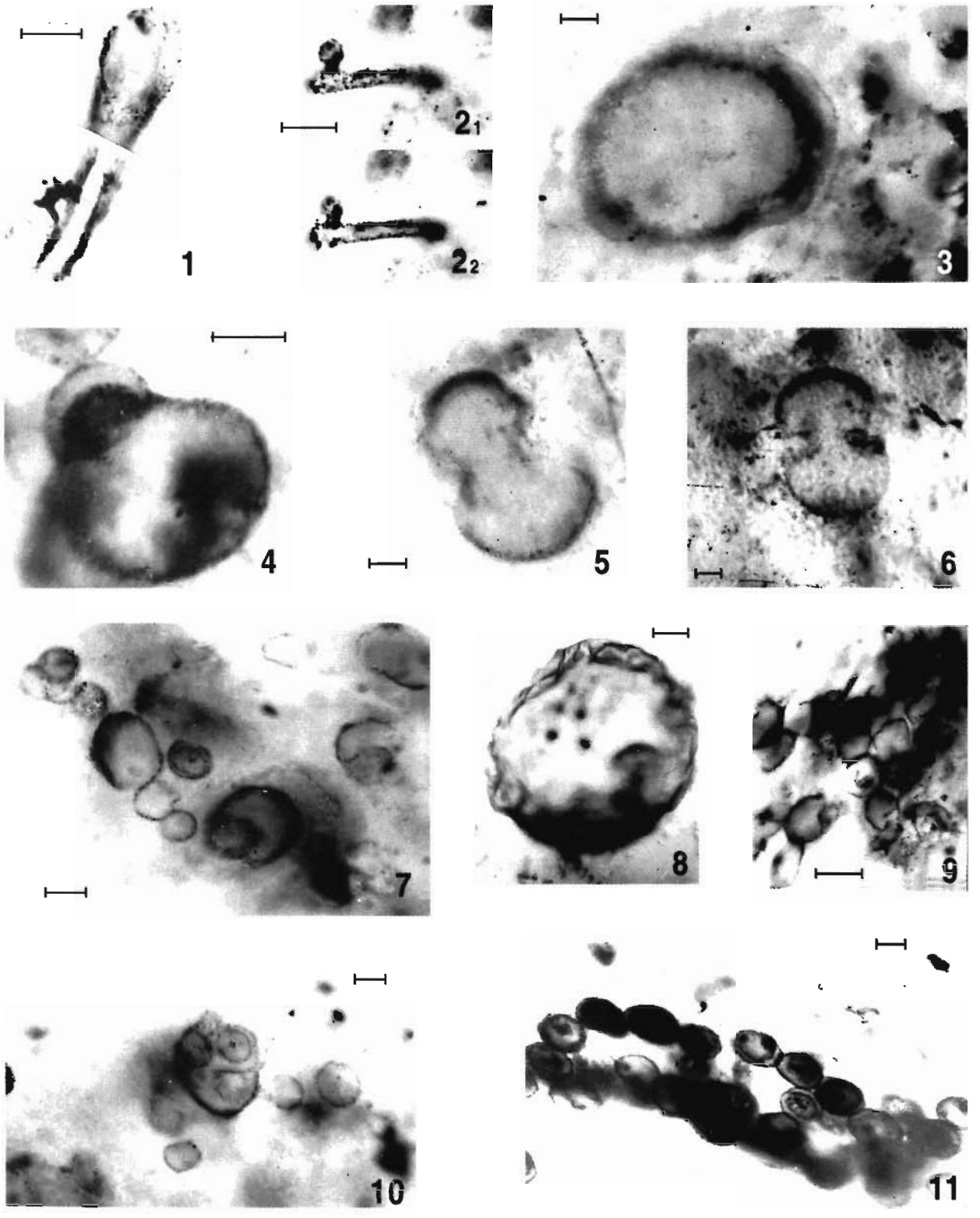


PLATE 6

Description—Colonies of group of spheroidal vesicles, joined together by a sheath like structure. Vesicles are psilate to granular in texture. Cell walls form a thickened ring like structure around each vesicle. Vesicle diameter ranges between 8-10 μm, (8·5 μm average) (22 specimens measured).

Discussion—Solitary vesicles of *Palaeosphaeridium* resemble with *Leiosphaeridia asperata,* except the thick walls, size and granular texture. Diameter of vesicle is smaller in comparison to Anhui and Jiangsu specimens from China described by Zang and Walter (1992).

Genus—GERMINOSPHAERA Mikhailova, 1986

Type species—GERMINOSPHAERA UNISPINOSA Mikhailova 1986; Amard & Sarfati, 1997

Species—GERMINOSPHAERA sp.

(Pl. 6·1)

Description—Spheroidal to ellipsoidal psilate vesicle with a tube extending outward from the vesicle. Diameter of the vesicle ranges from 8-15 μm, 12·5 μm average, tube 9-22 μm long and 3-5 μm wide (4 specimens measured). In one of the specimen, extant end of the tube is opened whereas in rest of the specimens extending tube is closed.

Discussion—This form is comparable to *Germinosphaera* sp. described by Amard and Sarfati (1997) from the Franceville Group of Gabon. Dimensions of the Deoban forms are comparatively larger than the Franceville forms and smaller than the type specimens described from the Upper Riphean Dashkin Formation, Siberia by Mikhailova (1986). Affinity of this form is not clearly established. It has been compared with the germinating zoospores of modern Xanthophycean algae, *Vaucheria* (Butterfield *et al.*, 1988, 1994).

Genus—PALAEOCOCCUS gen. nov.

Type species—PALAEOCOCCUS INDICUS gen. & sp. nov.

Diagnosis—Spheroidal to ellipsoidal and some times sickle-shaped cell like units, mostly less than one micron in dimensions.

Discussion—Small size and shape of these forms differentiate them from *Eosynechoccus amadeus* described by Knoll and Golubic (1979). Shape and mode of occurrence of some of these forms are comparable to *Sphaerophycus parvum* and *Eosynechococcus* but, size of these tiny spheroids is differentiable from any other cyanobacterial form and support their bacterial affinity. Yuan and Hofmann (1998) described bacterial form among problematica and reported them as Rod-bacteria like type 'B' from the Neoproterozoic Doushantou Formation of China.

Species—PALAEOCOCCUS INDICUS gen. & sp. nov.

(Pl. 3·6, 7)

Type Locality—Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Slide no. Db_2-12, Coordinates 49·8/20·5 (Nikon).

Etymology—With reference to its occurrence in India.

Diagnosis—Monospecific genus.

Description—Very small micron sized spheroids, ellipsoids or sickle-shaped structures occur isolated, diads or in small clusters, granular texture, margins smooth or granular. Diameter 0·5-1 μm (50 specimens measured). Intracellular mass may or may not be present.

Discussion—Exceptionally small size of this form is characteristic feature and differentiate it from any other cyanobacterial form. Mode of occurrence and dimensions are comparable to extant bacterial forms. When it occurs as solitary individuals then it can be comparable to *Micrococcus* and when it occurs as diads then it is comparable to *Diplococcus.* And when it occurs in chains, it is called *Streptococcus* as seen in Pl. 3·7. Elliptical forms can be compared with *Bacillus* and *Diplobacillus*. Though the morphology is also comparable to *Eosynechococcus* and *Sphaerophycus* but its small dimensions disfavour the *Eosynechococcus* affinity. Some of these specimens are comparable to Chinese Rod-bacteria like type reported from the Neoproterozoic Doushantou Formation by Yuan and Hofmann (1998). Deoban Forms cannot be considered as the degraded cyanobacterial cells because preservation of these forms is very good.

Genus—DUMBELLINA gen. nov.

Type species—DUMBELLINA DEOBANENSIS

PLATE 7 ⟶

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Nostocomorpha* sp., Slide No. Db_2-D-9, 50.3/21.5 (Nikon).
2. *Siphonophycus robustum,* Slide No. Db_3-6, 49.1/19.6 (Nikon).
3. *Nostocomorpha* sp., Slide No. Db_3-9, 79.2/18.7 (Leica).
4. *Oscillatoriopsis breviconvexa*, Db2-9, 50.3/ 21.5 (Nikon).
5. *Cynonema* sp., Slide No. Db_3-9, 70.8/10.4 (Leica).
6. *Siphonophycus solidum,* Slide No. II/D/89, 54.6/1.4 (Leitz).
7. *Cyanonema,* morphology comparable also to extant Cyanobacterial taxa *Gloeotrichia,* Slide No. Db1-19, 52.7/ 7.8 (Nikon).
8. *Oscillatoriopsis amadeus,* Slide No. Db_2-16, 63.9/13.54.6/1.4 (Nikon).
9. *Rhicnonema antiquum,* Slide No. Db_2-6, 51.1/11.9 (Nikon).
10. *Oscillatoriopsis breviconvexa,* Slide No. Db_1-26, 139.7/14.2 (Olympus).
11. *Cynonema* sp., Slide No. Db_3-6, 53.9/10.8 (Nikon).

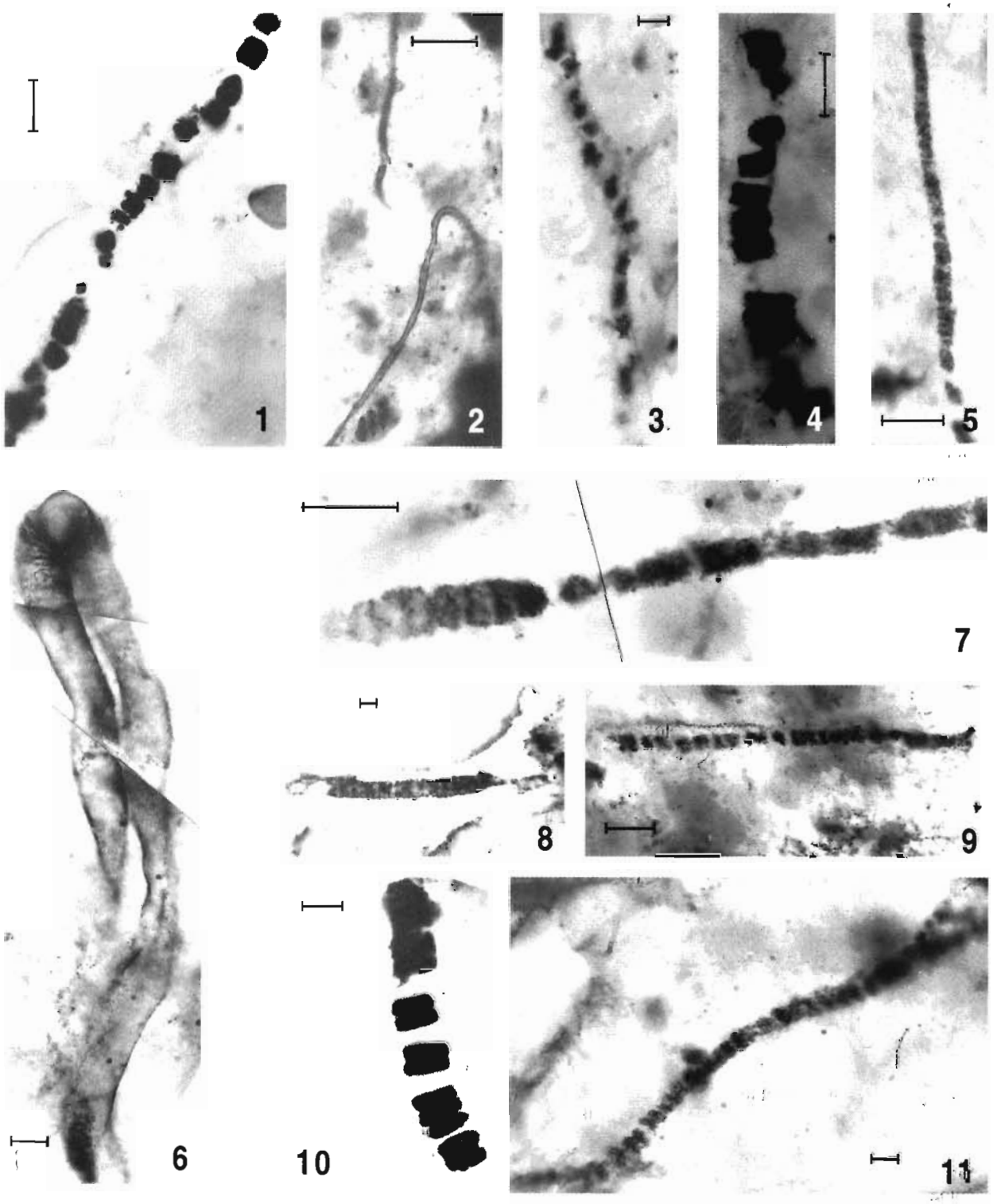


PLATE 7

Etymology—Because of its dumbbell-shaped morphology.

Diagnosis—A dumbbell-shaped body with marked constriction in median part.

Discussion—The form is differentiable from the chroococcacean cyanobacteria by typical dumbbell-shaped morphology, which is comparable to extant chlorophycean form. The form shows a possible division stage of a Chlorophycean aggregate or may be an individual entity. Tewari (1992, 1996) reported a form of comparable morphology without any description and taxonomic affinity. He simply mentioned it as a division stage. Zang and Walter (1992) described an acritarchean form *Leiosphaeridia timofeevi* as a paired cell exhibiting vegetative cell division. Dimensions and shape of Deoban specimens are easily differentiable from the other acritarchean forms from China.

Species—DUMBELLINA DEOBANENSIS gen. & sp. nov.

(Pl. 6·5, 6)

Type Locality—Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Slide no. II/D/89-6, Coordinate 42·0/24·2 (Nikon).

Etymology—Because of its occurrence in the Deoban Limestone.

Diagnosis—Monospecific genus.

Description—Dumbbell-shaped cellular body is markedly constricted centrally, resulting into two perfectly symmetrical halves. Diameter of constricted part is 10-20 μm. Maximum diameter measured is 42 μm, length of entire structure is 60-85 μm, 72 μm average (3 specimens measured).

Discussion—Consistency in morphological features in three different specimens supports their original entity in place of degradational variant of any other genera or species. Internal structures are absent.

Genus—MAITHEA gen. nov.

Type species—MAITHEA INDICA new gen. & sp. nov.

Etymology—In honour of Dr PK Maithy.

Diagnosis—In association with elongated or rod-shaped cell like units arranged in chains, presence of segmented or broken filaments, where segments (as reported in Cyanonema) arranged linearly.

Discussion—Small size of these forms differentiate them from the other known Proterozoic microfossils occurring as akinites in chains like *Archaeoellipsoides conjunctivus*, Zhang (1981). In extant chlorophycean form *Hormidium*, plant body tends to break into many fragments and each fragment subsequently forms an individual plant. Specific mode of occurrence (small rod-shaped cells arranged in chains) and in association with these chains or diads, presence of fragmented/segmented filamentous or tubular structures of almost same diameter range, favour the assignment of present forms with *Hormidium,* an extant chlorophycean form. There is also a possibility that these forms represent the variables of *Eosynechococcus* like structures. Smaller size and horizontal division line is the feature differentiating it from the *Archaeo ellipsoides.*

Species—MAITHEA INDICA new gen. & sp. nov.

(Pl. 3·11, 12)

Type Locality—Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Db_2-12, coordinates 50·6/20·8 (Nikon).

Etymology—Because of its occurrence in India.

Diagnosis—Monospecific genus.

Description—Small rod-shaped cell like units with marked constriction in the middle part across the length. Margins very sharp and at places cells arranged in pairs or in chains, which are straight or highly sinuous. The ellipsoidal units attached each other from the short axis. Cell diameter or long axis ranges between 9-13 μm, 11 μm average, while short axis ranges between 3-5 μm, 4 μm average (15 cells measured).

Discussion—Chain of elongated cells as in *Eosynechococcus mooreii* (McMenamin *et al.*, 1983) and in association with these cells, presence of thin filaments (nonseptate) broken into segments, arranged in linear manner and spheroids with intracellular mass and ruptured or cracked surface, to some extent support chlorophycean affinity as seen in extant chlorophycean form *Hormidium.*

Form 'A'

(Pl. 8·4, 5)

PLATE 8 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Bulgenia septata*, gen. & sp. nov., Slide No. Db_1-26, 59.3/6.2 (Nikon). A bud-like structure is seen in the lower part of the photomicrograph.
2. *Leiosphaeridia jacutica*, Slide No. Db_3-9, 53.7/14.5 (Nikon).
3. *Circumvaginalis*, Slide No. I/D/89, 55.3/9.3 (Nikon).
4. Form *'A'*, Slide No. Db_3-9, 73.6/16.9 (Leica).
5. Form 'A'. Slide No. Db_3- 9, 80.2/15.1 (Leica).
6. *Rhicnonema antiquum*, Slide No. Db_1-15, 53.0/11.5 (Nikon).
7. *Siphonophycus typicum*, Slide No. II/D/89-G, 79.1/ 36.9 (Leitz).
8. *Bulgenia septata*, gen. & sp. nov., Slide No. Db_1-26, 59.3/6.2 (Nikon).
9. *Eomicrocoleus crassus*, Slide No. Db_2-12, 49.4/20.8 (Nikon).

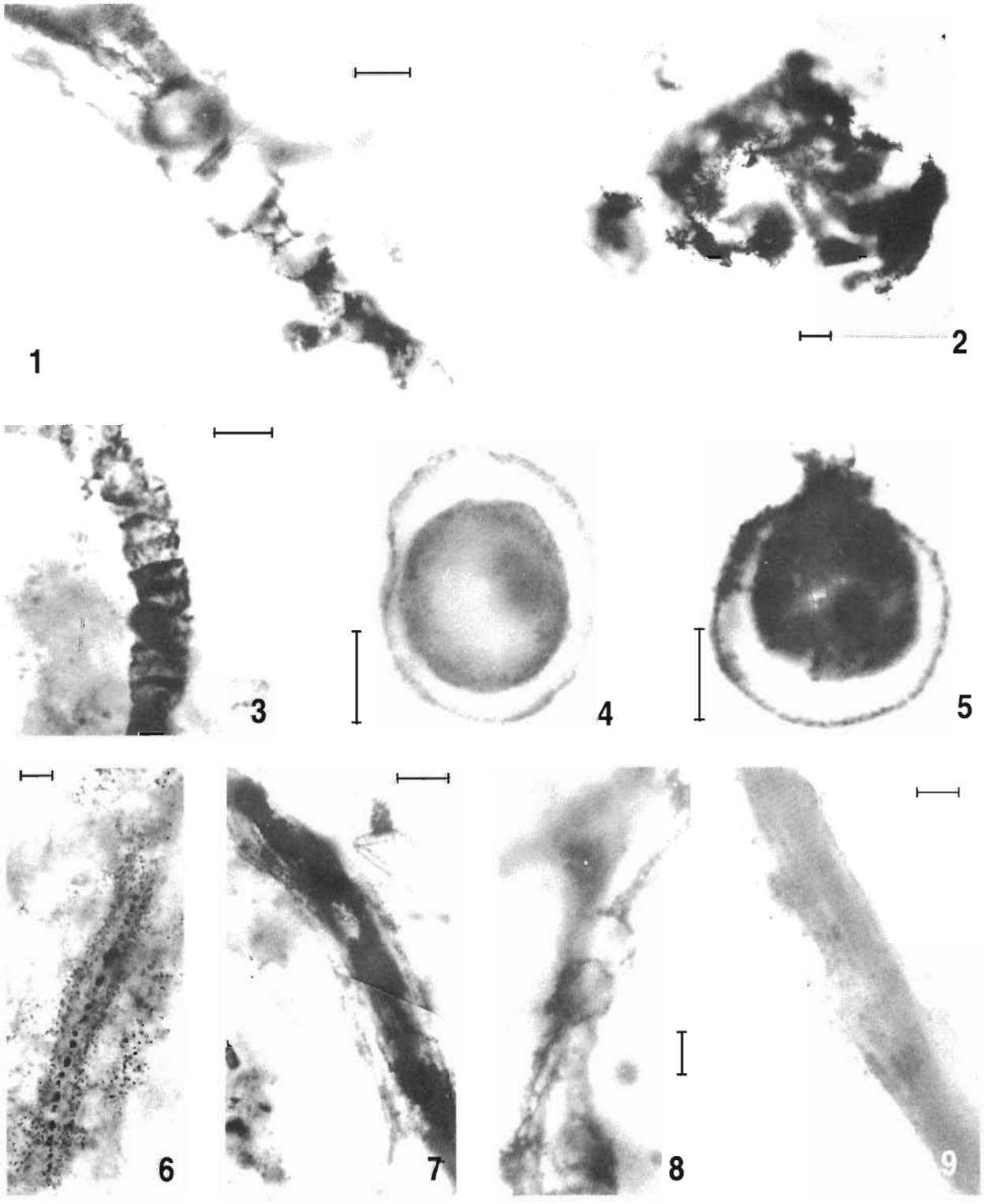


PLATE 8

Description—Two spheroids slightly of different size, one encapsulating the other, outer spheroid light coloured, thick walled ranging in diameter from 22-26 μm, inner spheroid darker and thicker walled ranging in diameter from 16-18 μm. Inner spheroid both detached as well as contiguous. In one specimen intracellular mass appears to be coming out from the inner spheroid (2 specimens traced).

Discussion—The Deoban specimens show some resemblance with *Globophycus rugosum* described from the Bitter Springs Formation by Schopf (1968). However in Deoban forms the wall is very thick, the inner spheroid is also contiguous and in one specimen the intracellular mass is oozing out. It is also not clear whether the inner spheroid is a separate spheroid or is the condensed intracellular mass.

FILAMENTOUS FORMS

Genus—BULGINIA gen. nov.

Type Species—BULGINIA SEPTATA gen. & sp. nov.

Type Specimen—Sample No. Db-1-26, Coordinates 59·3/ 6·2 (Nikon).

Etymology—With reference to repetitive bulging in cells.

Diagnosis—Tubular septate filaments with sac-like bulging at regular intervals and with lateral branching forming a bud-like structure.

Discussion—Branching among Proterozoic filaments is already recorded in forms like *Ulophyton* and *Proterocladus,* but repeated bulging in tubular septate filament resulted in sac-like structure and a bud-like feature differentiate it from the rest of the Proterozoic branched filamentous forms. Consistency and repetitive occurrence of bulging rule out the possibility of secondary origin of these structures

Species—BULGENIA SEPTATA gen. & sp. nov.

(Pl. 8·1, 8)

Type Locality—Black Bedded chert, Deoban Limestone, Chakrata area, Dehradun District, Uttaranchal.

Type Specimen—Db-1-26, Coordinates- 59.3/6.2 (Nikon).

Diagnosis—monospecific genus.

Etymology—with reference to its septate filamentous structure.

Description—Thick walled, granular, septate filaments with uneven margins and variable width. Sudden bulging resulted in an empty sac-like structures without much internal details. Bulging is repeated and at a few places in between two bulged structures a common neck-like joining is seen. Diameter of the connecting tube varies between 3-4.5 μm (3.5 μm average). Maximum diameter of these bulged structures is 15 μm. Maximum length measured 160 μm (4 specimens measured). An outgrowth or a bud-like structure is seen in (Pl. 8.1) where diameter of bud is 3 μm, length is measured as 9 μm.

Discussion—Sudden bulging and septation in filamentous part, and bud-like structure are the characteristic features of this form. Edhorn (1973) reported terminal and intercalated heterocysts like features in forms of the *Animikia* from the Thunder Bay, Ontario, however her illustrations are not convincing. Amard and Sarfati (1997) reported specimens of almost similar morphologies and described them as budding bacteria, however dimensions of Deoban specimens are comparatively much larger. Barghoorn and Tyler (1965) also described *Animikea septata* with identical morphology. For similar structures phylogenetic affinities with green algae Voucheriaceae were earlier suggested by Barghoorn and Tyler (1965). Awramik and Barghoorn (1977) interpreted almost similar morphologies as budding bacteria. Amard and Sarfati (1997) suggested it rather yeast type budding. A living green algal genus *Oedogonia* represents morphological similarity with Deoban forms. Akinite like structures or bulged portions of septate filaments can also be interpreted as Oogonium, in which formation of oospores occur. Budding structure may be a dwarf male plant called *Nannandrea* as in *Oedogonium concatenatum* (see Vashistha, 1977). There is one more possibility that these bulged portions of septate filaments can be akinites produced by nostocalean cyanobacteria.

Genus—EOPHYCOMYCES Allison and Awramik, 1989

Type species—EOPHYCOMYCES HERKOIDES Allison and Awramik, 1989

Species—cf. EOPHYCOMYCES HERKOIDES

(Pl. 9·1; Pl.10·4)

Description—Tubular cylindrical filaments of variable diameter, exhibiting branching are present. These are gently to strongly curved structures. Filaments have prominent walls, at places compressed or collapsed, granular to psilate texture. Bulbous and thumb-like protrusions are the characteristic features of this form. Diameter of filament ranges between 12-48 μm (2 specimens measured).

PLATE 9 →

(Photomicrographs of coccoid forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1. *Eophycomyces herkoides*, Slide No. Db_2-E, 51.3/ 21.5 (Nikon).
2. *Rhicnonema antiquum*, Slide No. Db_1-15, 53.0/ 11.5 (Nikon).
3. *Cyanonema antiquum*, Slide No. Db2-1, 57.4/ 6.6 (Nikon).
4. *Oscillatoriopsis obtusa*, Slide No. Db_1-26, 57.6/ 21.6 (Nikon).
5. *Palaeolyngbya catenata*, Slide No. Db_1-7, 53.8/ 18.6 (Nikon).
6. *Siphonophycus solidum*, Slide No. Db_1-15, 52.4/ 24.5 (Nikon).
7. *Paleolyngbya catenata*, Slide No. Db_1-11, 51.3/ 5.5 (Nikon).
8. *Siphonophycus typicum*, Slide No. Db_2-12, 54.0/ 14.3 (Nikon).
9. *Eomicrocoleus crassus*, Slide No. II/D/89-6, 82.5/ 29.4 (Leica).

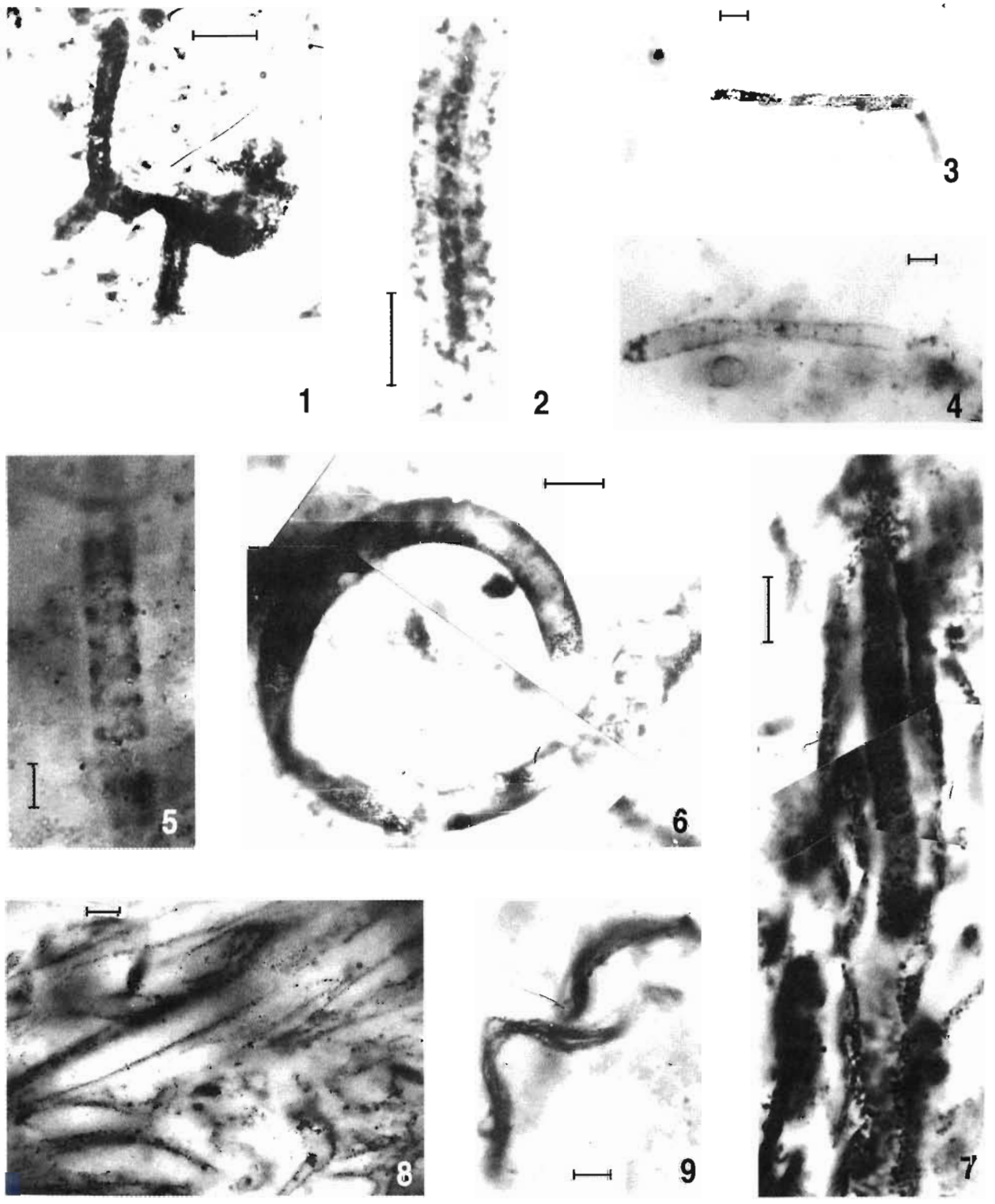


PLATE 9

Discussion—Bulbous protrusions, branching and thumb-like structures favour fungal affinity (more closely towards *Allomyces;* Allison & Awramik, 1989). Barghoorn and Tyler (1965) and Awramik and Barghoorn (1977) also described, a nonseptate, branched, tubular filaments as *Archaeorestis*, and Licari (1978) described branched tubular structures as *Palaeosiphonella.* Branching can also be false in nature. General morphology of the Deoban form is comparable to the *Eophycomyces* described by Allison and Awramik (1989) from the Tindir Group, Canada.

Group—ACRITARCHA

Domain—EUCARYA

Genus—CYMATIOSPHAEROIDES Knoll, 1984

Type species—CYMATIOSPHAEROIDES KULINGII Knoll, 1984 emend. Knoll *et al.*, 1991

Species—cf. CYMATIOSPHAEROIDES sp.

(Pl. 5·1)

Description—Large, spheroidal to subspheroidal vesicle-like structure with prominent enclosing sheath. Diameter of the vesicle ranges from 100-250 µm, diameter of the outer sheath ranges between 105-265 µm (3 specimens measured). Process like structures are invisible.

Discussion—Presence of outer sheath encompassing the spheroidal vesicle-like structures is the distinguishing feature of this genus. Deoban specimens exhibit all mentioned features except hairy processes, therefore the form has only been reported as cf. *Cymatiosphaeroides.*

Genus—MICRHYSTRIDIUM Deflandre (1955) emend. Downie and Sarjeant, 1963

Type species—MICRHYSTRIDIUM DISSIMILARE Volkova, 1969

Species—MICRHYSTRIDIUM sp.

(Pl. 4·7)

Description—Spheroidal vesicle-like structure with a number of thin or slender, almost equally placed processes around it. Vesicle diameter 23 µm. Length of process like structures varies between 5-7 µm, diameter of processes up to 1.5 µm. At the surface, pentagonal and hexagonal chambers or a reticulate pattern acquiring honey- comb like feature is visible. Single specimen is traced.

Discussion—Diameter of Deoban form is more than the range given by Knoll and Swett (1987) from Spitsbergen. Generally, species of genus *Micrhystridium* are less than 20 µm in diameter. Details of thin processes whether they widened or tapered at the base or tapered at distal parts, are not clear. However, the general appearance of Deoban specimen is comparable to *Micrhystridium*, reported by Knoll and Swett (1987) from Spitsbergen.

Genus—FAVOSPHAERIDIUM (Timofeev) Timofeev, 1966

Type species—FAVOSPHAERIDIUM SCANDICUM Timofeev, 1966

Species—FAVOSPHAERIDIUM FAVOSUM Vidal, 1976

(Pl. 4·8, 11)

Description—Spheroidal to ellipsoidal solitary vesicles with honey-comb like surface ornamentation. Walls moderately thick. Diameter ranges between 26-36 µm, 30 µm average. Intracellular mass may or may not be present (6 specimens measured).

Discussion—The Deoban specimens described here are similar to the forms described by Vidal (1976). Zang and Walter (1992) described a form comparable to *Favosphaeridium* sp. from China in which presence of an opening has also been mentioned. This particular feature is not visible in the Deoban forms.

Genus—TRACHYSPHAERIDIUM Timofeev (1959), 1969

Type species—TRACHYSPHAERIDIUM ATTENUATUM Timofeev 1959 emend. Knoll & Calder, 1983

Species—TRACHYSPHAERIDIUM sp.

(Pl. 4·1, 2, 5, 10)

Description—Spheroidal vesicles are thick walled, robust, psilate to finely granular or reticulate surface texture. Inside each vesicle there is large and prominent intracellular mass, which is dense and almost round in shape and eccentric in position. Diameter ranges from 60-105 µm (75 µm average). Diameter of intracellular mass ranges between 12-23 µm (4 specimens measured).

PLATE 10 →

(Photomicrographs of filamentous forms in thin sections of black-bedded chert. Co-ordinates in mm, scale bar = 10 microns for all the photomicrographs. Name of the microscope used for photography is also given in bracket)

1 Branching in filamentous form, Slide No. Db2-16, 83.7/17.8 (Leica).
2. Branching in filamentous form, Slide No. Db2-16, 69.8/14.4 (Leica).
3 *Obruchevella parva*, Slide No. Db1-26, 56.0/17.9 (Leica).
4. *Eophycomyces herkoides*, Slide No. Db2-19, 78.3/16.3 (Leica).
5, 6. *Obruchevella minor*, Slide No. Db2-12, 54.9/12.5 (Nikon).
7 *Obruchevella valdaica*, Slide No. Db2-12, 47.8/18.2 (Nikon).
8. *Glomovertella glomerata*, Slide No. Db2-12, 47.8/18.2 (Nikon).
9. *Siphonophycus septatum*, Slide No. Db2-1, 55.2/6.8 (Nikon).
10. *Siphonophycus robustum*, Slide No. Db2-12, 49.4/20.8 (Nikon).

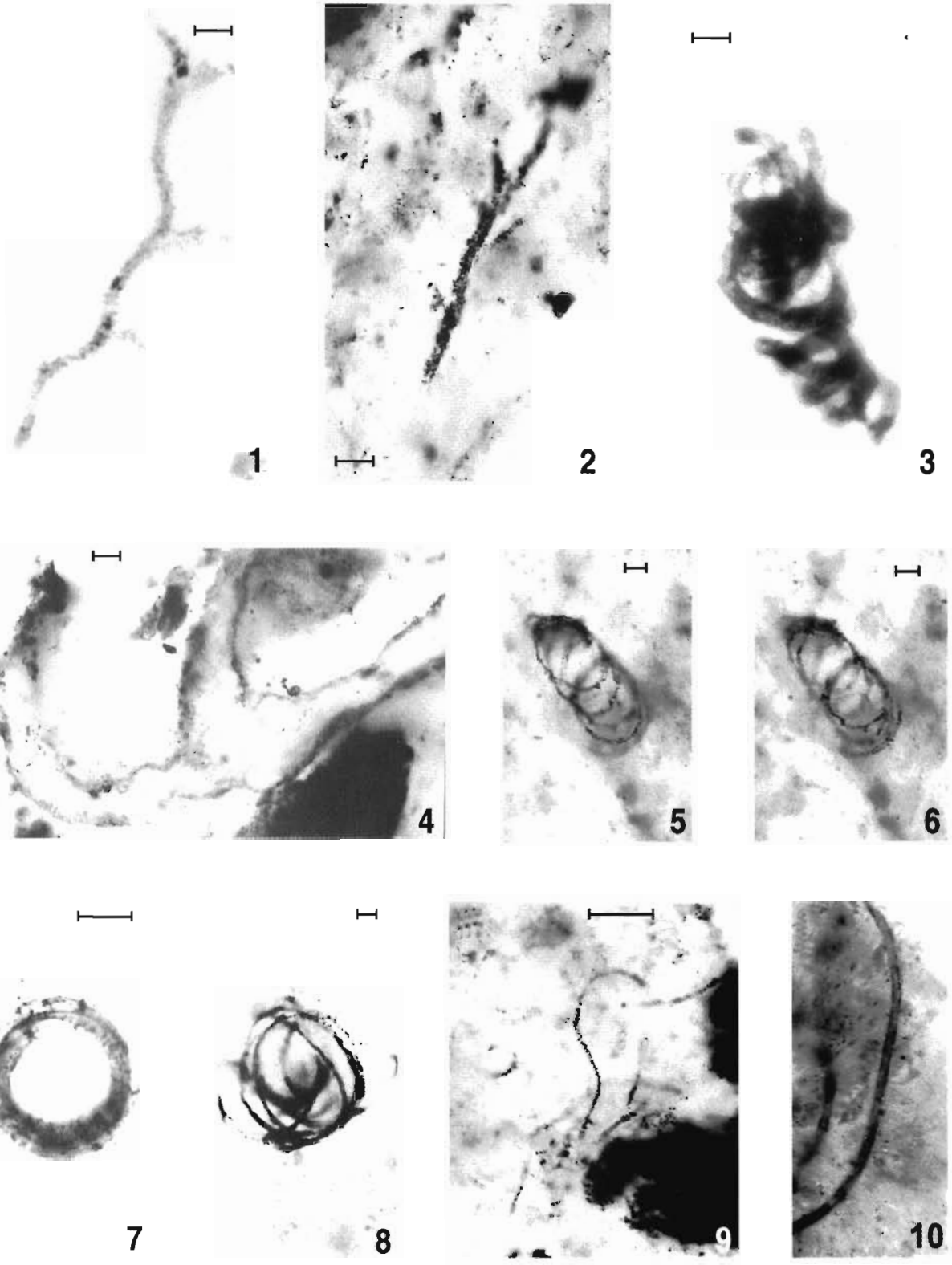


PLATE 10

Discussion—Unusual large size and thick, robust wall with prominence of intracellular mass, are the characters of *Trachysphaeridium*. However, numerous hollow processes, mentioned by Knoll and Calder (1983) on the inner walls of vesicle are not observed in present form. Diameter range is more in comparison to specimens from the Spitsbergen by Knoll and Swett (1987). Dimensions and general morphology is comparable to Kheinjua specimens described from Newari locality of the Vindhyan Supergroup, India (Kumar & Srivastava, 1995).

Genus—LEIOSPHAERIDIA Eisenack, 1958 emend. Downie & Sarjeant, 1963

Type species—LEIOSPHAERIDIA BALTICA Eisenack, 1958

Species—LEIOSPHAERIDIA CRASSA (Naumova, 1949) comb. Jankauskas *et al.*, 1989

(Pl. 4·3, 6, 9; Pl. 6·3, 8)

Description—Unornamented sphaeromorph ranging in diameter from 30 to 70 μm (40 μm average), occur sporadically as isolated aggregates, trapped within algal mats. Walls are thin and generally smooth (8 specimens measured). Cell wall 1·5 to 2 μm thick and shows crenulation or folding in a few specimens.

Discussion—Morphologically there is no difference between sphaeromorphs assignable to *Leiosphaeridia crassa* and *Leiosphaeridia jacutica* except the diameter. Considering the recent revision of Leiosphaerids proposed by Jankauskas and Mikhailova in Jankauskas *et al.* (1989) forms ranging in diameter from 70 μm up to 800 μm are assigned to *L. jacutica*, where as forms with diameter less than 70 μm are assigned to *L. crassa*. Deoban forms show resemblance with the Spitsbergen specimens described as *L.crassa* by Knoll *et al.* (1991).

Species—LEIOSPHAERIDIA JACUTICA Timofeev (1966) emend. Mikhailova, 1986; Jankauskas; in Jankauskas *et al.* 1989

(Pl. 5·3; Pl. 8·2)

Description—Large, thin and smooth walled unornamented sphaeromorphs exhibiting wall thickness between 2-4 μm and diameter 75-240 μm (98 μm average), occur solitary or colonial aggregates (9 specimens measured).

Discussion—Morphology is comparable to the forms described from the Spitsbergen by Knoll and Swett (1987).

Genus—CAUDOSPHAERA Hermann & Timofeev in Jankauskas *et al.*, 1989

Type species—CAUDOSPHAERA EXPANSA Hermann & Timofeev 1989 in Jankauskas *et al.*, 1989

Species—CAUDOSPHAERA sp.

(Pl. 5·5)

Description—A globular or balloon-shaped structure truncated longitudinally in a thin tail like extension. Maximum diameter of cellular unit is 18 μm, with psilate to granular texture. Length of entire unit is 26 μm (Single specimen traced).

Discussion—*Caudosphaera expansa* described by Hermann and Timofeev in Jankauskas *et al.* (1989) is comparatively much larger in size than the Deoban specimen. Russian specimen has diameter up to 440 μm. Thus, except dimensions, other morphological features are comparable, suggesting only generic assignment to the present specimen.

Genus—OVULUM ACRITARCHA Jankauskas, 1975

Type species—OVULUM ACRITARCHA Jankauskas 1975 Zang & Walter, 1992

Species—cf. OVULUM SACCATUM (?)

(Pl. 5·6)

Description—Vesicle is unornamented with granular surface texture, wall apparently folded. Vesicle rounded at one end and seems opened and tapered at the other end. Opening, at places seems to be double walled. Long axis 24 μm, short axis 8·5 μm, opening like structure is present on long axis (single specimen).

Discussion—Jankauskas (1975) has first erected this genus, but described in detail by Volkova *et al.* (1979). Genus is differentiable from the Chitinozoan forms in lacking the neck like feature and smaller dimensions. This particular specimen can also represent an oogonium like structure during oospore formation specially reminds a stage in the life cycle of *Oedogonium* (Chlorophycean affinity) where oogonium acquires identical morphology. Since present specimen is fairly degraded, it is not clear whether the opening mentioned in Deoban form is of primary origin or not.

DISCUSSION AND CONCLUSIONS

1. The over all Deoban microfossil assemblage is comprised of 75 forms and now represents as one of the most diversified microbial assemblages of the world. Twentyfive taxa among coccoid forms vary from less than one micron to 265 microns in diameter. Relative abundance, affinity, general morphology and size distribution of coccoid forms is given in (Fig. 4) and for filamentous forms, diameter ranges from less than one micron to 48 microns in width, their general morphology, relative abundance, affinity and size distribution is given in (Fig. 5). Size distribution, for both shorter and longer diameter for coccoids are unimodal (Figs 6 & 7). Only 6% coccoids exhibit diameter more than 60 microns. Thus, very small sized coccoid are the most dominating

community. Size distribution for the filamentous forms (Figs 8 & 9) exhibit minimum width with mode at 2.5 microns (Fig. 8) and 64 % filamentous forms are having less (minimum) width than 5 microns and only 4% filaments are having width of more than 15 microns. The most dominant forms are very small sized coccoids and filaments of less than 5 microns.

2. Fairchild (1985) has used size of the microfossils as one of the most important criterion for distinguishing probable eukaryotic unicell in silicified Precambrian microfloras. He has suggested that, coccoids with more than 55 μm diameter tends to be of eukaryotic affinity. In contrast, Sun (1987), Sergeev (1994) and Steiner (1996) represented that empty colonies of prokaryotes may go up to a few millimeters. In Deoban assemblage, many forms with less than 55 microns in diameter have been assigned eukaryotic affinity. Therefore in addition to size, we mainly related microfossil morphology as distinguishing feature for identification of eukaryotes. For instance, forms displaying budding structure illustrated in Pl. 6.2-$_1$, 2-$_2$. 4, where the dimensions are generally typical of prokaryotes, have been considered showing possible chlorophycean, acritarchean and fungal affinities. Hence, it is very difficult to draw any demarcating line for distinction between prokaryotes and eukaryotes considering the size of the microfossils as the only parameter. Complete morphology should be considered in assigning the taxonomic position of any specimen.

3. Demoulin and Janssen (1981) observed that filamentous blue green algae of average size tend to have isodiametric cells. Very thin filamentous forms often have cylindrical cells and forms with larger width (> 10 μm) have only discoidal cells. This change in cell dimensions appears to be due to difficulties faced by the cell in building and regulating cytoplasmic structures for the synthesis of heavy hydrophobic proteins, because of the distance from the nucleoplasm. This problem among large sized cells could be solved by flattenning the cells and decreasing the distance between the nucleoplasm and the cell periphery. In Deoban assemblage, the cyanobacterial population of average size of about 5 μm in diameter have tendency to have isodiameteric cells, while very narrow filamentous forms have mostly cylindrical cells. Discoid cells are common among broad filaments of > 10 μm in diameter (Fig. 10) as also described by Demoulin and Janssen (1981).

4. Extensive diversity represented by different morphologies assignable to a wide range of taxonomic affinities is an important aspect of the Deoban assemblage. Affinity varies from simple cyanophycean filaments and coccoids to forms exhibiting some resemblance with chlorophycean, xanthophycean (?), chlorococcalean, fungal, bacterial and forms of uncertain affinity placed among acritarchean forms. There are still few forms, which could not be identified and have not been assigned any taxonomic position, hence are placed among incertae sedis. One of these forms has informally been described as Form 'A'.

5. In modern peritidal environments, where microbial mats occur, community composition and diversity vary strongly as a function of environments (Logan *et al.*, 1974; Golubic,1976, 1985). It has been noticed that the diversity is lowest in harshest environments, such as hypersaline pools (Bauld, 1984; Golubic, 1985). The diversity in the Deoban assemblage represents an environmental setting which was very conducive for the growth of life, where a complex ecosystem flourished probably in a tidal zone.

6. The assemblage represents an ecosystem, which was comprised of plant life dominated by cyanobacterial population. However, the presence of forms inclined possibly towards animal affinities described by Srivastava and Kumar (1997) needs additional support.

7. Considering the spatial distribution, microfossils can be categorized as mat builders, mat dwellers and allocthonous forms. They occur in clusters as well as in isolation. *Siphonophycus* among the filaments and *Eoentophysalis* among coccoids (both of cyanobacterial affinity) are the most dominating communities of this assemblage and both occur as mat builders. A number of forms especially large population of *Myxococcoides* and isolated filaments of *Siphonophycus* or Oscillatoriacean filaments occur in between algal clasts. Acritarchs occur as allocthonous aggregates representing planktic mode of occurrence. In recent/ modern microbial mats domination of *Entophysalis, Microcoleus* and *Phormidium* is well recorded in Andros Islands, Shark Bay and Bahamas Islands (Monty, 1965) and abundance of similar looking benthic community of the Deoban Assemblage suggests extreme conservatism in algal mat building community. In all these modern analogous cases, the *Entophysalis, Phormidium* and *Microcoleus* population dominates in the warm, shallow, hypersaline bodies of quite water in the intertidal zones or in coastal ponds that have very limited access to the open ocean (Knoll & Golubic, 1979). It supports the observations of Schopf and Klein (1992) that the microbial communities in modern coastal environments such as the Bahamas, Persian Gulf, Shark Bay of Australia and parts of lagoon in Baja- California, represent the fossilised communities, documenting the persistance of specific microbial taxa and groups of taxa in particular/specific environments.

8. Several types of division patterns are marked which help in assigning taxonomic position. These are as follows:

a. Budding like features in a few spheroids may represent a stage of vegetative reproduction and may have given rise to a new individual (Pl. 6.4). There is also a possibility that it can be a result of degradation.

b. Specimens exhibiting a dumbbell-shaped body (*Dumbellina deobanensis,* gen. nov. & sp. nov.) are distinctly constricted in the centre (Pl. 6.5, 6). It can be a desmid-like structure (of Conjugalean affinity) or it can also be a division stage of a large chroococcacean cyanobacterial coccoid representing the intracellular mass, where envelope was destroyed or detached from the central mass. It represents a single unit, which has lost any other details due to degradation (Pl. 6.5, 6).

c. The branching in filaments is recorded in a few specimens but it is not clear whether it is true or false branching (Pl. 10.1, 2, 4).

d. A bud-like structure is recorded in *Bulgenia septata,* which is comparable to recent Chlorophycean form *Oedogonium* and mode of occurrence comparable with *Anabaena,* represents a vegetative mode of reproduction (Pl. 8.1).

e. Hexagonal cell like structures are of quite small size with plasmolysed inner wall and prominent intracellular mass. Typical arrangement of cells and morphology of this form is incomparable to any known fossil form. However, it shows some resemblance with extant chlorococcalean form *Scenedesmus platydiscus* as well as with chroococcacean form *Aphanocapsa.* Present morphology can also be a result of mutual compression of cells, where muitilamellate cell like units of *Gloeodiniopsis lamellosa* exhibit such morphology (Pl. 1.12; Pl. 3.9). However, uniformity in cell structure acquiring hexagonal shape suggested to be their original morphological character. It can also represent a typical division pattern or a mode of occurrence comparable to extant Chlorophycean form belonging to *Chetophorales* (?) or *Coleochaete* affinity (Pl. 1.12; Pl. 3.9).

f. Budding as occurs in extant Xanthophycean algae (Yellow-Green algae) *Vaucheria* has also been marked in one specimen (Pl. 6.2-$_1$, 2-$_2$). By changing the focus attachment point of bud-like structure with adjacent elongated unit is clearly visible which rules out the possibility of superimposition of two units.

9. The Deoban microfossil assemblage is marked by a number of forms, which can be grouped as eukaryotes, represented by forms comparable to some extent to chlorophycean, xanthophycean and fungal forms. A few forms have been assigned to acritarchs, which are considered as microfossils of uncertain affinity. Presence of forms of animal-affinity, however could not be conclusively proved (Srivastava & Kumar, 1997).

10. Since Mesoproterozoic assemblages are mostly devoid of cellularly preserved green algae or vase-shaped protists, *Ovulum* like microfossils (Pl. 5.6) and acanthomorphic (process bearing) acritarchs (Pl. 4.7) in the Deoban Assemblage support Neoproterozoic age for the fossil bearing horizon.

11. Presence of helically coiled filamentous form assignable to *Obruchevella* can also be considered as an age marker. Its occurrence has been recorded from the Neoproterozoic and younger sequences (Pl. 10.3, 5, 6, 7, 8).

12. Spinose acritarchs are rare before the latest Proterozoic. Volkova (1969) and Lo (1980) reported rare occurrence of *Micrhystridium* in the late Proterozoic of Russian Platform and Yudoma Group. However, abundance of acanthomorphs in the Vendian assemblages is well recorded. It sharply diversified further in Lower Cambrian assemblages. Rare presence of *Micrhystridium* (Pl. 4.7) and a form, which is spirally engrooved (may be an initiation of spines, Pl. 4.3) in the Deoban assemblage supports the Neoproterozoic or a pre-Vendian age for the Deoban Formation.

13. Abundance of *Leiosphaerids* is a characteristic feature of the Vendian assemblages, particularly in shallow marine environments. Since Deoban assemblage shows rare occurrence of these acritarchs, which also suggests a pre-Vendian age or it can also be a function of environments as well.

14. Presence of akinite like bodies in the filamentous forms confirm the ability of cyanobacterial forms to fix nitrogen (Pl. 1·11; Pl. 5·2; Pl. 8·1, 8). It should be mentioned here that true heterocysts in Proterozoic cyanobacteria have not yet been recorded (Willmotte & Golubic, 1991; Golubic *et al.,* 1995). Most enlarged cells on fossilised filaments of cyanobacteria are interpreted as a result of degradation (Golubic & Barghoorn, 1977; Gerasimenko & Krylov, 1983).

15. Because of very small size, recognition of bacteria is very difficult in thin section studies. Its presence in Deoban assemblage (Pl. 3.6, 7) suggests an ideal condition for preservation of biota and also its role in algal mat building activity during Precambrian.

16. There is a single specimen, which shows a prominent aestrix mark within an ellipsoidal vesicle with granular surface texture (Pl. 5.7). Long axis is 26 μm and short axis measured is 16 μm. The asetrix mark may be an original feature or it may be due to degradation. The morphology could not be interpreted.

17. There are specimens in which discoid cell like units arranged linearly and give appearance of a diffused septation (Pl. 3·10). Diameter ranges between 7-9 μm, length varies from 28-32 μm. There are five specimens. The form shows close resemblance with *Ascogenous* hyphae or ascospores belonging to higher fungi

Ascomycetes. There is a remote possibility that present morphology is a result of degradation.

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