Late Proterozoic organic-walled microfossils from the Infrakrol of Solan, Himachal Lesser Himalaya : An additional age constraint in the Krol Belt succession

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The cherty nodules of the Infrakrol Formation, exposed at Anjighat near Solan, Himachal Pradesh, contain a diverse and abundant microbiota of organic-walled microfossils (OWMs). These include cyanobacterial filaments, coccoids, large acritarchs and vase-shaped microfossils (VSMs). The forms identified in the organic-walled microfossils assemblage are: *Eomycetopsis robusta, Siphonophycus kestron, Eomicrocoleus crassus, Oscillatoriopsis media, Obruchevella* aff. *parva, Diplococcus*-shaped structures, *Huroniospora psilata, Palaeoanacystis vulgaris, Sphaerophycus parvum, Leiospheridia* sp., 'Form A' and 'Form B' (large acanthomorphic acritarch) and vase-shaped microfossils. Based on these organic-walled microfossils and considering the recently proposed Precambrian (Vendian) and Early Cambrian ages for the overlying Krol and Tal formations respectively, a Late Proterozoic (possibly Early Vendian) age is concluded for the Infrakrol Formation.

Key-words—Organic-walled microfossils, Acritarchs, Cyanobacteria, Upper Proterozoic, Infrakrol (India)

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सारांश

हिमाचल लघुहिमालय में सोलन के अधःक्रोल से अनंतिम प्रोटीरोजीवी कार्बनिक-भित्तिदार सूक्ष्मजीवाश्म : क्रोल पट्टी अनुक्रम की आयु का एक और प्रमाण

मीरा तिवारी एवं आर० जे० आज़मी

हिमाचल प्रदेश में सोलन के समीप अन्जीघाट पर अनावरित अधःक्रोल शैल-समूह की रामसैकाश्मी ग्रंथियों में कार्बनिक-भित्तिदार सूक्ष्मजीवाश्मों वाला विभिन्नता से परिपूर्ण सूक्ष्मजीविता प्राप्त हुआ है। इस सूक्ष्मजीविता में सियनोजीवाणविक सूत्र, कोकॉयड्स, बड़े एक्रीटार्क एवं बर्तनाकार सूक्ष्मजीवाश्म विद्यमान हैं। जिनमें **ईओमाइसिटॉप्सिस रोबस्टा, साइफ़ोनोफ़ाइकस केस्ट्रॉन, ईओमाइक्रोसीलस क्रेसस, ओसिलेटोरिऑप्सिस मीडिआ, ऑब्रूचेवेला** सजातीय **पार्वा, डिप्लोकॉकस**-सदृश संरचनायें, **ह्यूरोनिओस्पोरा साइलेटा, पेलियोऐनासिस्टिस वुल्गेरिस, स्फ़ेयरोफ़ाइकस पार्वम्, लिओस्फ़ेयरीडिआ** जाति, प्ररूप- अ', प्ररूप ब' एवं बर्तनाकार सूक्ष्मजीवाश्मों का अभिनिर्धारण किया गया है। इन कार्बनिक-भित्तिदार सूक्ष्मजीवाश्मों तथा क्रमशः उपरिशायी क्रोल एवं ताल शैल-समूहों हेतु प्रस्तावित कैम्ब्रिय-पूर्व (वेंडियन) एवं प्रारम्भिक कैम्ब्रिय आयु के आधार पर अधःक्रोल शैल-समूह की अनंतिम प्रोटीरोजीवी (सम्भवतया प्रारम्भिक वेन्डियन) आयु आकलित की गई है।

THE recent fossil discoveries from the Tal Formation of the Lesser Himalaya (Azmi *et al.*, 1981; Azmi, 1983, Bhatt *et al.*, 1983, 1985; Tewari, 1984; Tripathi *et al.*, 1984; Kumar *et al.*, 1983, 1987) have put at rest the century old age controversy of the Blaini-Infrakrol-Krol-Tal succession whose age otherwise has been oscillating somewhere between the Precambrian and Mesozoic. At present the basalmost Chert-Phosphorite Member of the Tal Formation yielding rich small shelly fossils of precisely Precambrian-Cambrian boundary is an important datum marker in the Lesser Himalaya and this level has been found potential for global correlation as well. Accordingly, formations such as Krol, Infrakrol and Blaini successively lying stratigraphically below the Tal Formation, in descending order, are considered as latest Precambrian (terminal Proterozoic/Vendian). It is, therefore, necessary to develop a better resolution on terminal Proterozoic correlations for which the biostratigraphic data is still very meagre. While a few biostratigraphic studies on the Blaini, Infra Krol and Krol formations tentatively indicated a Late Precambrian age (Gundu Rao, 1970; Singh, 1983) to these formations; the most recent contributions on the microbiota from Blaini of Mussoorie area by Dhaundiyal and Moitra (1987) and Joshi *et al.* (1988) and from Infrakrol of Nainital area by Acharyya *et al.* (1989) and Venkatachala *et al.* (1990) are relevant as the present paper mainly deals with an additional good assemblage of organic-walled microfossils from a new locality near Solan, Himachal Pradesh.

GEOLOGICAL BACKGROUND AND LOCALITY

Geology of Himachal Lesser Himalaya has been extensively worked out by Medlicott (1864), Pilgrim and West (1928), Auden (1934) and Bhargava (1976). The Krol Belt lies in the southern part of the Lesser Himalaya which stretches for about 350 km from Kunihar in Himachal Pradesh to Nainital in Uttar Pradesh. The Blaini-Infra Krol-Krol-Tal succession, about 4,000 meters thick, is quite persistent in the Krol Belt stratigraphy which mainly comprises dolomites, limestone, shales, slates and quartzite with occasional chert and phosphorite beds and lenticles. This sequence is exposed in the form of several east-west trending synclines such as Pachmunda, Krol, Saindhar, Nigalidhar, Korgai, Mussoorie, Garhwal and Nainital syncline. The cherty nodules yielding the organic-walled microfossils were collected from dark carbonaceous Infrakrol shales exposed in the southeastern part of the Pachmunda Syncline (westernmost syncline of the Krol Belt) on Solan-Kumarhatti road near Anjighat milestone, 2.5 km southwest of Solan township (30° 53′ 47″ N : 77° 5′ 32″ E; Text-fig. 1).

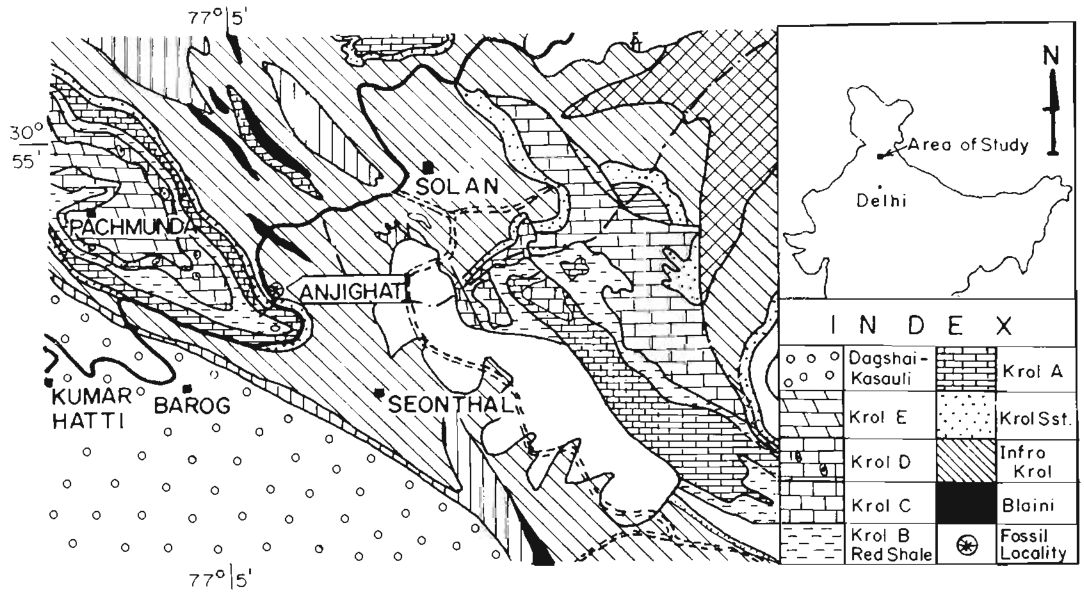
SYSTEMATICS

The present study on the organic-walled microfossils is entirely based on the thin sections of non-stromatolitic chert nodules. When viewed in transmitted light thin sections of chert nodules show even grained mosaic of microcrystalline quartz and scattered calcite crystals, iron oxide and haematite dust which darkens the microcrystalline quartz matrix and imparts turbid appearance. The microfossil walls are composed of black organic matter.

All the illustrated specimens have been deposited in the Wadia Institute Museum Repository numbers WIMF/1001 to 1024.

The organic-walled microfossils are divisible into the following five categories.

1. Non-septate straight and coiled filaments : *Eomycetopsis robusta, Siphonophycus kestron, Eomycrocoleus crassus,* and *Obruchevella* aff. *parva.*
2. Septate filaments : *Oscillatoriopsis media* and an unnamed filamentous form—'Form A'.
3. Small solitary or aggregated spherical colonies: *Diplococcus*-shaped structures, *Sphaerophycus parvum, Huroniospora psilata* and



Text-figure 1—Geological map of the area showing fossil locality (after Auden, 1934).

Palaeoanacystis vulgaris.

4. Large spherical acritarchs : *Leiosphaeridia* and acanthomorphic acritarch—'Form B'.
5. Vase-shaped microfossils.

Eomycetopsis schopf 1968

Eomycetopsis robusta Schopf 1968
Pl. 1, figs 5, 10

Three dimensionally preserved, tubular, non-septate unbranched filaments having circular and sometimes ellipsoidal opening. Diameter of tube is 2-4.5 μm and length exceeds 100 μm. Surface texture granular.

Remarks—Similar in diameter to *Eomycetopsis robusta* of Belcher Island, Canada (Hofmann, 1974).

Siphonophycus Schopf 1968

Siphonophycus kestron Schopf 1968
Pl. 1, fig. 8

Non-septate, unbranched filaments tapering towards one end. Filament diameter 8-11 μm and length 100 μm.

Remarks—The specimen is comparable to *Siphonophycus kestron* reported from the Infrakrol Formation of Nainital (Venkatachala *et al.*, 1990).

Eomycrocoleus Horodyski & Donaldson 1980

Eomycrocoleus crassus Horodyski & Donaldson 1980
Pl. 1, figs 6, 11

Large sheath with a diameter of 30-50 μm, contains 2 to more trichome of <4 μm diameter. Length of filament is 250 μm. In one specimen the sheath twisted at one end (Pl. 1, fig. 6). This may be interpreted as a diagenetic feature.

Remarks—It is comparable to *E. crassus* Horodyski & Donaldson 1980 but has a larger diameter of sheath and trichome.

Oscillatoriopsis Schopf 1968

Oscillatoriopsis media Mendelson & Schopf 1982
Pl. 1, fig. 9

Unbranched, multicellular and uniseriate trichome of 7-15 μm diameter, not constricted at septa, distinct cross walls, disc-shaped. Sheath not present.

Remarks—Comparable to *Oscillatoriopsis media* reported from Deoban Formation, Lesser Himalaya (Shukla *et al.*, 1987).

Obruchevella Reitlinger 1948

Obruchevella aff. *parva* Reitlinger 1948
Pl. 1, figs 1, 2, 7

Spirally coiled tubular filament, in cross section the complete helix is nearly circular and is slightly curved along its length. Helix outer diameter is 10-12 μm and inner diameter 3-3.5 μm. Filament diameter is 4 μm. In one specimen length of filament is 45 μm and number of coils are 11. No cross partitioning of cells or septa observed, coiling loose.

Remarks—Similar to its morphology with *O. parva* Reitlinger but differs in having very small diameter of tube and coiling.

Diplococcus-shaped structures
Pl. 1, fig. 18

Ovoidal cells, length varies from 8-16 μm and width is 6-10 μm, length 1.3 times more than width. These cell-like units occur in pairs with adjacent flattened surface, the pair occurs singly. Surface of cell smooth.

Remarks—The *Diplococcus*-shaped micro-structure resembles chrooccocacean cells at division. Cell-like units as undivided pairs are reported from Bitter Springs Formation (Schopf, 1968). The present forms resemble those reported from the earliest Phanerozoic, Eastern Siberia (Lo, 1980).

Huroniospora Barghoorn & Tyler 1965

Huroniospora psilata Barghoorn & Tyler 1965
Pl. 1, figs 21, 22, 23

Spherical to oval solitary cells, psilate, cell size 3-10 μm.

Remarks—Comparable in morphology to that reported from Infrakrol of Nainital (Venkatachala *et al.*, 1990), but smaller in size.

Sphaerophycus Schopf 1968

Sphaerophycus parvum Schopf 1968
Pl. 1, figs 16, 17, 20

Spherical cells with 1.4-4.6 μm in diameter, some forms having a diameter of 11 μm. Cells occur commonly solitary or form group of four cells. Surface texture granular.

Remarks—This form is identical to *Sphaerophycus parvum* reported from the Deoban Formation, Lesser Himalaya (Shukla *et al.*, 1987).

Palaeoanacystis Schopf 1968

Palaeoanacystis vulgaris Schopf 1968
Pl. 1, fig. 14

Spheroidal cells, clumped in spherical and ovoidal colonies. Individual cells compressed. Cell diameter varies from 2.8 to 3.5 μm and colony diameter ranges from 24-30 μm.

Remarks—The colony has small diameter of cells in comparison to that reported from Bitter Springs flora (Schopf, 1968) and also from the Infrakrol of Nainital (Venkatachala *et al.*, 1990).

Leiosphaeridia Eisenack 1958

Leiosphaeridia sp.
Pl. 1, fig. 13

Spherical cell with diameter ranging from 35-64 μm. Surface texture granular.

Remarks—Similar to the size range of latest Proterozoic microfossils from the Nama Group, Namibia (Germs *et al.*, 1986).

Form 'A'

Pl. 1, figs 3, 4, 12

Unbranched chain of polyhedral grain of iron oxide with more or less uniform diameter, sometimes decreasing towards one end. Size ranges from 3.5-7 μm.

Remarks—The present specimen has close resemblance with 'small septate filament' of Late Proterozoic of central Australia (Barghoorn & Schopf, 1965).

Form 'B'

Pl. 1, fig. 15

Large acanthomorphic acritarchs with a diameter of 400 μm and spiny processes. This form shows some characteristic features and requires more detailed observation and study.

Vase-shaped microfossils

Pl. 1, fig. 19

A few flask-shaped bodies tapering to apertural end and rounded at the base occur in the assemblage. These bodies vary in length from 130 to 180 μm. Due to rarity as well as poor preservation their taxonomic placement is deferred for the time being.

Further studies on vase-shaped microfossils and 'Form B' are in progress and will be reported later.

AFFINITY, AGE AND CORRELATION

As stated above, the organic-walled microfossils assemblage recovered from the Infrakrol chert nodules comprises filamentous and coccoid cyanophycean algae, acritarchs and vase-shaped microfossils. The assemblage is dominated by filamentous algae, an evolutionarily conservative group, hence not useful as age indicators. Filamentous forms represent 48 per cent of the total assemblage. *Eomycetopsis* in the present assemblage ranges from 1.5-4 μm in diameter with an average of 2 μm (see Text-fig. 2) comparable to that of Bitter Springs Formation. *Eomycetopsis* is interpreted as sheath of *Phormidium-Leptothrix* type of filamentous bacteria (Hofmann, 1976; Knoll & Golubic, 1979). Previously it was assigned as fungal hyphae (Schopf, 1968). *Siphonophycus* ranges from 8-15 μm and represents sheath of *Oscillatoria-Lyngbya* like cyanobacteria (Schopf, 1968). Knoll (pers. com. to M.T.), however, synonimizes *Siphonophycus* and *Eomycetopsis* retaining the former being a senior synonym. Among larger filaments are *Eomicrocoelus* with a well defined sheath of 20-50 μm diameter and trichomes of <4 μm in diameter. It is comparable to modern oscillatoriacean *Microcoleus* (Horodyski & Donaldson, 1980). *Oscillatoriopsis* is comparable to modern oscillatoriacean cyanophyte. It is reported that tubes of 30 μm or more in diameter occur from the sediments of Late Proterozoic or younger ages (Schopf, 1977).

Among coiled filaments is *Obruchevella* aff. *parva*. The present specimens have close similarity with *O. parva* on morphological grounds but they have very small coil and filament diameters. *Obruchevella* had been variously assigned as foraminifera, genus of uncertain affinity, cyanophyte *Spirulina* and is recently included within oscillatoriacean algae (see Song, 1984). It is

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PLATE 1

Microfossils from Infrakrol chert nodule—Sample no. 1K/AG/3; Bar in fig. 16 is same for 17, 21, 22, 23 and in fig. 18 is same for 20.

1, 2, 7. *Obruchevella* aff. *parva* Reitlinger, 1940. WIMF/A 1004, 1005.
3, 4, 12. 'Form A' WIMF/A 1019, 1020, 1021.
5, 10. *Eomycetopsis robusta* Schopf 1968, WIMF/A 1001, 1002.
6, 11. *Eomicrocoleus crassus* Horodysky & Donaldson 1980, WIMF/A 1006, 1007.
8. *Siphonophycus kestron* Schopf 1968, WIMF/A 1003.
9. *Oscillatoriopsis media* Schopf 1968, WIMF/A 1008.
13. *Leiospheridia* Eisenack 1958 WIMF/A 1017.
14. *Palaeoanacystis vulgaris* Schopf 1968, WIMF/A 1018.
15. 'Form B' (Acanthomorphic acritarch) WIMF/A 1024.
16, 17, 20. *Sphaerophycus parvum* Schopf 1968, WIMF/A 1013, 1014, 1015.
18. *Diplococcus*-shaped structure WIMF/A 1022.
19. Vase-shaped microfossils. WIMF/A 1023 (bar represents 50 μm).
21, 22, 23. *Huroniospora psilata* Barghoorn & Tyler 1965. WIMF/A 1009, 1010, 1011.

Bar represents 10 μm except otherwise mentioned.

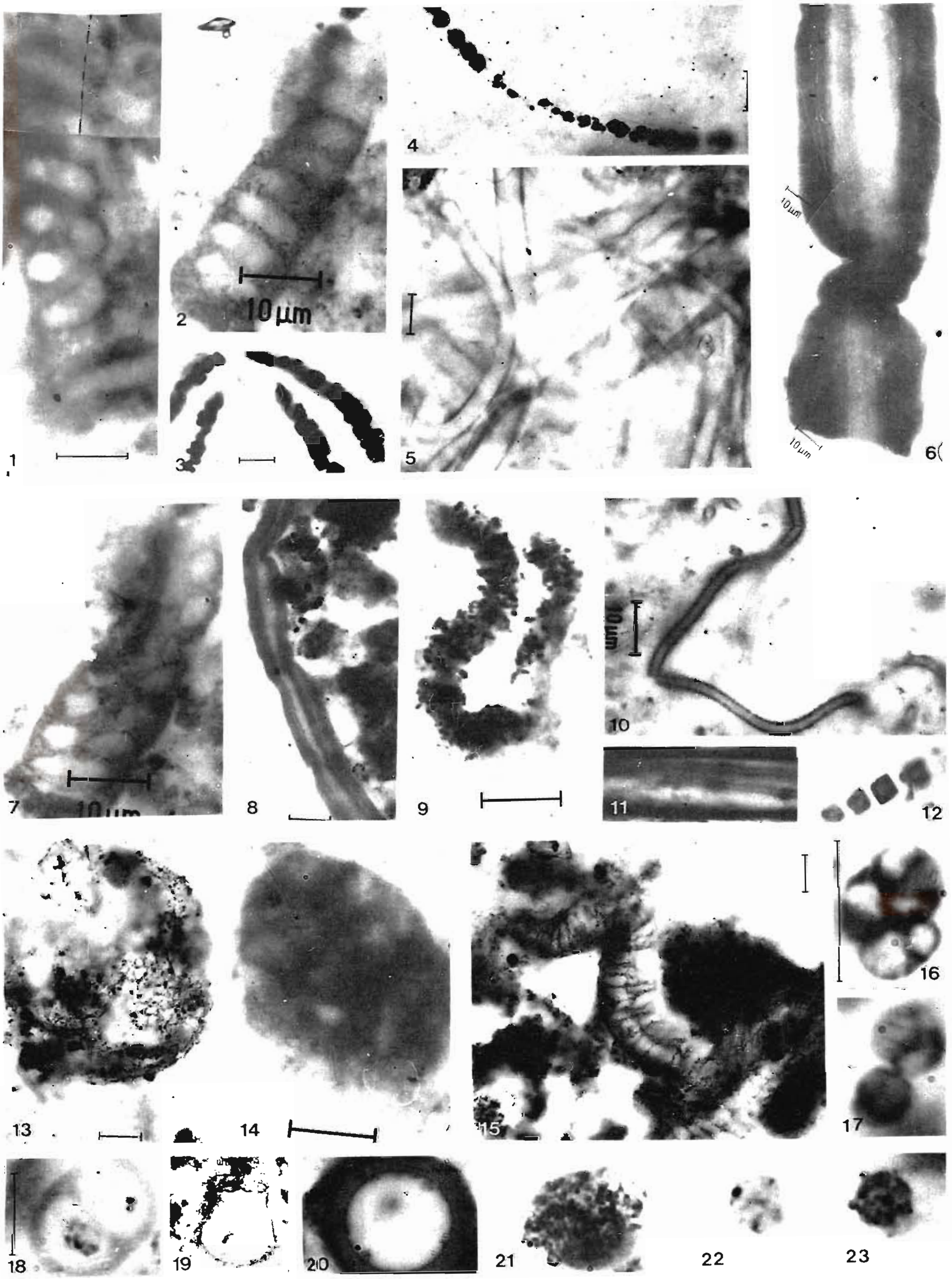
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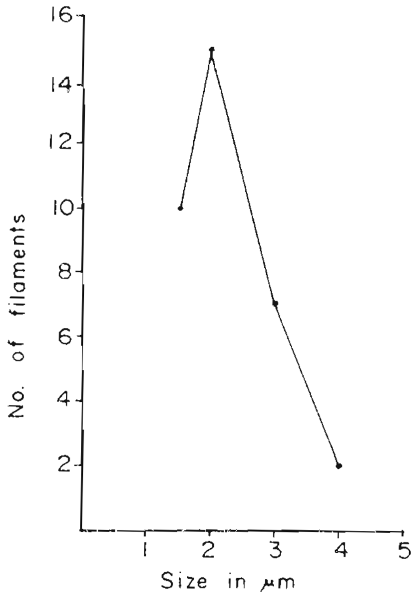
PLATE 1



Text-figure 2—Size variation in *Eomycetopsis robusta* Schopf 1968.

reported from Riphean to Early Cambrian of USSR, China, Saudi Arabia, Alaska and in Ordovician rocks of southeastern Canada (Golovenok & Belova, 1983; Song, 1984; Peel, 1989). It is reported that the diameter of helices and tube is larger in Cambrian whereas it is smaller in the Precambrian forms (Song, 1984).

Coccoid forms represent 30 per cent of the total assemblage. Amongst these, *Huroniospora* has a size range of 3-10 μm in the present assemblage. Earlier it was variously interpreted as dinoflagellate or fungal spore and red algae (Barghoorn & Tyler, 1965; Darby, 1974). Recently, Strother and Tobins (1987) put *Huroniospora* as the spore or encysted cell rather than a vegetative cell. *Palaeoanacystis* is comparable in morphological details to extant alga *Anacystis* (Golubic & Barghoorn, 1977). Among eukaryotic cells *Sphaerophycus* is included which contains opaque granular bodies occuring within its cell (Oehler, 1976, 1977). However, these bodies were also interpreted as protoplasmic remnants of coccoid cyanophytes.

The acritarchs are represented by simple spherical forms such as *Leiospheridia* and acanthomorphic acritarch ('Form B'). *Leiospheridia* represents 5 per cent of the total assemblage. They are long ranging forms, appeared around 1400 Ma and continue up to Precambrian-Cambrian boundary level (ca 570 Ma). Forms such as large acanthomorphic acritarchs ('Form B') are known so far mostly from Early Vendian sediments (Knoll, pers. com.) and represent 2 per cent of the total assemblage.

Vase-shaped microfossils were originally described as probable chitinozoans (Bloeser *et al.*, 1977). Later, Bloeser (1985) classified these as encystment of unidentified alga. Fairchild *et al.* (1978) and Knoll and Vidal (1980) suggested their protistan affinity, while a tintinnid affinity was proposed by Reid and John (1980). Maithy and Babu (1988) recently described vase-shaped microfossils from Vindhyan Supergroup of Son Valley and regarded them as Chitinozoans. They appeared around 800 Ma and extend into Vendian representing 2 per cent of the total assemblage.

In the absence of any absolute radiometric age data, the time span of Infrakrol sediments can not be estimated with certainty. However, acritarchs and vase-shaped microfossils have been proved to be biostratigraphically useful (Vidal & Knoll, 1983).

Table 1—Comparative chart of present assemblage of organic-walled microfossils with other assemblages of the world

	Eomycetopsis	*Siphonophycus*	*Eomicrocoleus*	*Obruchevella*	*Oscillatoriopsis*	*Sphaerophycus*	*Palaeoanacystis*	*Huroniospora*	*Liospheridia*	VSMs
Infrakrol Formation of Nainital, India	*	*	—	—	—	—	*	*	—	*
Deoban Formation, India	*	*	—	—	*	—	—	—	—	*
Gangolihat Dolomite, India	*	*	—	—	—	—	—	—	—	—
Suket Shale, India	*	—	—	—	—	—	*	—	—	—
Hecla Hoek sequence, Svalbard	*	*	—	—	—	—	—	—	—	*
Draken conglomerate, Svalbard	*	*	—	—	—	—	—	—	—	—
Bitter Springs Formation, Australia	*	*	—	—	*	—	*	—	—	—
Balbirini Dolomite, Australia	*	*	—	—	—	*	*	—	—	—
HYC pyritic shale, Australia	*	*	—	—	*	*	—	*	—	—
Yudoma suite, USSR	*	—	—	—	*	—	—	*	—	—
Doushantuo Formation, China	*	*	—	—	—	—	—	*	—	—
Wernecke Mountains, Canada	*	*	—	*	—	—	—	—	—	—
Dismal Lake Group, Canada	—	—	*	—	*	*	—	—	—	—
Tindir Group, Canada	*	*	—	—	—	—	*	—	—	—
Visingo beds, Sweden	—	—	—	—	—	—	—	—	—	*
Nama Group, Namibia	—	—	—	—	—	—	—	—	*	—

* = present; — = not present

Establishment of the latest Precambrian and Cambrian age for Krol and Tal formations based on small shelly fossils, trilobites and other fossil evidences, it becomes obvious to assign a Late Proterozoic (possibly Early Vendian) age to the Infrakrol sediments as also evidenced especially by the large acanthomorphs and the vase-shaped microfossils. Additional data such as the presence of *Chuaria* Walcott and metaphytic algae—Vendotaenoids, widely distributed during the Vendian is needed to strengthen an Early Vendian age for the Infrakrol sediments.

Distribution of microbiota of Riphean-Vendian age on global scale (Table 1) shows that the present assemblage is comparable in India to that of the Infrakrol Formation (Acharyya *et al.*, 1989; Venkatachala *et al.*, 1990), Deoban Formation (Shukla *et al.*, 1987), Gangolihat Dolomite (Nautiyal, 1980), Suket shales (Maithy & Shukla, 1977), and also with those reported from Hecla Hoek sequence and Draken Conglomerate of Svalbard (Knoll, 1982a, 1982b), Tindir Group of Canada (Allison & Awramik, 1989), HYC pyritic shale Balbirini Dolomite of Australia (Oehler, 1977, 1978), Wernecke Mountains, Canada (Hofmann, 1984), Bitter Springs Formation, Australia (Schopf, 1968; Oehler, 1978), Dismal Lake Group, Canada (Horodysky & Donaldson, 1980), Yudoma Suite, USSR (Lo, 1980), Daushantuo Formation, China (Zhang, 1985), Visingo beds, Sweden (Knoll & Vidal, 1980), and Nama Group, Namibia (Germs *et al.*, 1986). In these sequences, it is seen that Lieospherids are reported only from Nama Group, Namibia and biostratigraphically useful vase-shaped microfossils and acritarchs are reported only in the Infrakrol Formation and Deoban Formation in India and Hecla Hoek sequence of Svalbard, Visingo beds of Sweden and Tindir Group of Canada.

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