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MICROBIOTA FROM THE KUSHALGARH FORMATION, DELHI SUPERGROUP, INDIA

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ABSTRACT

Well-preserved and diverse microfossils are described for the first time from the Kushalgarh Formation of Ajabgarh Group around Baraud Village in Alwar District, Rajasthan. The assemblage comprises 10 genera and 17 species belonging to filamentous and coccoid blue-green algae, of which two genera and 10 species are new. The new forms are *Myxococcoides compactus* sp. nov., *Palaeolyngbya distinctica* sp. nov., *P. elongata* sp. nov., *P. baraudensis* sp. nov., *Palaeoscytonema indica* sp. nov., *P. intermingla* sp. nov., *P. misrae* sp. nov., *Ghoshia bifurcata* gen. et sp. nov., *Primorivularia robusta* sp. nov. and *Vesicophycus problematicus* gen. et sp. nov. Morphological features and the size range of taxa suggest procaryotic nature of the assemblage. Coccoid forms are aggregated in colonies and dominated by filamentous forms. Baraud assemblage contains hormogonia, heterocysts, false branching and the most significant is the record of true branching showing Stigonematalean affinity. The composition of the microflora suggests that the rocks of Delhi Supergroup are equivalent to Vindhyans. This is also supported by the radiometric dates.

Key-words — *Ghoshia*, *Vesicophycus*, Cyanophyceae, Kushalgarh Formation, Precambrian (India).

सारांश

दिल्ली महासमूह (भारत) के कुशालगढ़ शैल-समूह से सूक्ष्मजीविता – जगन्नाथ प्रसाद मंडल, प्रभात कुमार माइती, जी० बर्मन एवं के० के० वर्मा

राजस्थान के अलवर जनपद में बड़ौद ग्राम के आस-पास अजबगढ़ समूह के कुशालगढ़ शैल-समूह से प्राप्त सुपरिरक्षित एवं विभिन्न प्रकार के सूक्ष्म-पादपाश्मों का सर्वप्रथम वर्णन किया गया है। इस समुच्चय में गोलाभ एवं तंतुवत् नील-हरित शैवालों के 10 वंश एवं 17 जातियाँ विद्यमान हैं, जिनमें से दो वंश तथा 10 जातियाँ नई हैं। ये नये प्रारूप मिक्सोकोकॉयडिस कोम्पेक्टस नव जाति, पोलियोलिंगबिया डिस्टिंक्टिका नव जाति, पे० इलोंगेटा नव जाति, पे० बड़ौदेन्सिस नव जाति, पोलियोसाइटोनीमा इन्डिका नव जाति, पे० इन्टरमिंगला नव जाति, पे० मिसराई नव जाति, घोषिया बाइफर्केटा नव वंश व नव जाति, प्राइमोरिवुलेरिया रोबस्टा नव जाति एवं वेसिकोफाइकस प्रोबलेमेटिकस नव वंश व नव जाति हैं। वर्गकों के बाह्य-आकारिकीय लक्षणों एवं आमाप परिसर से समुच्चय की प्रोकैरियोटी प्रकृति व्यक्त होती है। गोलाभ-प्रारूप निवहों में पुंजित हैं तथा तंतुवत् प्रारूपों से प्रभावी हैं। बड़ौद समुच्चय में हॉर्मोगोनिया, हेट्रोसिस्ट, अवास्तविक शाखन तथा स्टिगोनिमेटेली से सजातीयता व्यक्त करने वाली वास्तविक शाखन का विशिष्टतम् अभिलेख है। सूक्ष्म-वनस्पतिजात के संयोजन से प्रस्तावित होता है कि दिल्ली महासमूह की चट्टानें विंध्य के समतुल्य हैं। उपलब्ध रेडियोमितीय आँकड़े भी इस प्रस्ताव की पुष्टी करते हैं।

INTRODUCTION

MICROBIOTA are now well known from the Proterozoic rocks of peninsular and extrapeninsular India. So far various workers like Maithy (1969), Maithy and Shukla (1977), Maithy and Mandal (1983), Maithy and Gupta (1983), Nautiyal (1978, 1980), Schopf and Prasad (1978), Salujha *et al.* (1970, 1971a, 1971b, 1972), Singh *et al.* (1978), Venkatachala and Rawat (1972) and Viswanathiah *et al.* (1975, 1976a, 1976b, 1979-80) have reported the biota from these rocks. This assemblage consists mostly of cryptarchs and a few blue-green algae.

There is no previous microfossil record from Delhi Supergroup except a report by Dutt and Shrivastava (1975) from Alwar Group, Gurgaon District. They reported *Tasmanites* other than triletes, monoletes, septate spore, acritarchs and hystrichospheres. From the illustrations of Dutt and Shrivastava (1975) it appear that the assemblage consists of only acritarchs belonging to Sphaeromorphitae and Netromorphitae except *Tasmanites*. Stromatolites have recently been reported by Verma and Barman (1980) and Negi and Ravindra (1980) from the Kushalgarh Formation near the village Baraud. The forms are *Baicalia baicalica* (Maslov) Krylov, *Collenia columnaris* Fenton & Fenton, *Kussiella kusiensis* Krylov and *Jacutophyton* Shapovalova. The investigation of microbiota in the area was taken up due to (i) occurrence of diverse stromatolite, (ii) absence of microfossil report from this rock sequence, and (iii) to correlate this thick and widespread sequence of rocks with other areas and particularly fixing the stratigraphical position of Delhi Supergroup in relation to the Vindhyan Supergroup.

In all, 27 samples from a section belonging to the Kushalgarh Formation were collected. Out of which only one siliceous dolomite yielded excellently preserved biota. Permanent slides were prepared with polyvenyl alcohol and D.P.X. mountant. Observations were made using oil imersion objective in a Leitz Dialux — 20 microscope. Long filaments were photographed in several shots at different focal depths. These photographs were superimposed to get the complete structure of filament.

The present paper deals with the systematic description of the microbiota recovered for the first time from Ajabgarh Group. All the figured specimens are housed in the Museum of Birbal Sahni Institute of Palaeobotany.

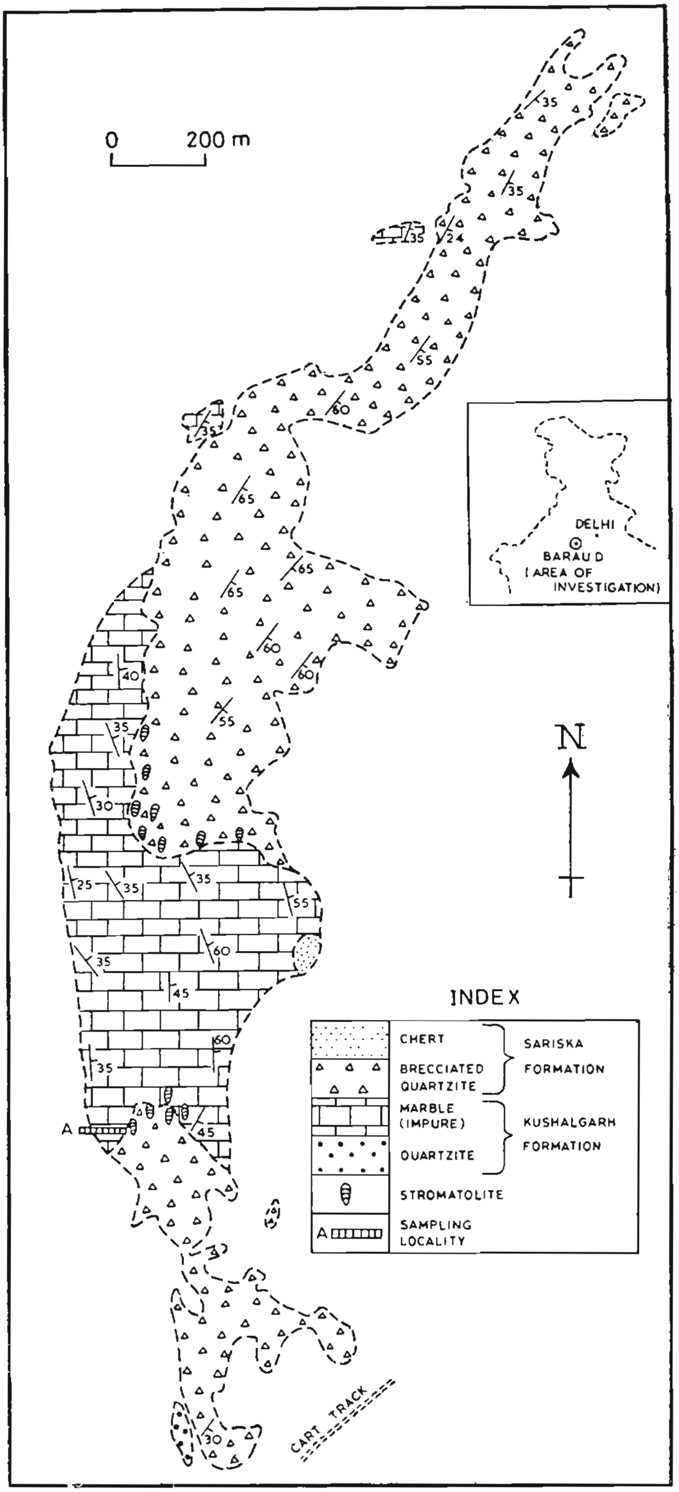
GEOLOGY

General Geology — Delhi Supergroup extends along the main axis of folding of the Aravalli mountains and is named after the city — Delhi and has a very wide geographical distribution from near Delhi in the north, through Ajmer and Mewar to Idar and Palanpur in the South (Krishnan 1982). In the north (Gupta, 1977) the, rocks of Delhi Supergroup are concealed under the alluvium and are found in the form of isolated patches. The rocks lie above the gneisses or the Aravallis or the Gwaliors or the Raialos with a great unconformity and in turn overlain unconformably by the Vindhyans. Lithologically, the rocks consist essentially of quartzites, mica schists, limestones and calcium chloride gneisses. The entire succession shows extensive folding, faulting and is affected by igneous intrusions in the form of pegmatites, granites and epidiorites.

Geology of the area — The microfossil bearing locality lies on the western flank of the north-south trending hill (Text-fig. 1), about a kilometer to the east of Baraud Village (27°54′: 76°23′, Survey of India toposheet no. 54 A/5), Alwar District, Rajasthan. The village is located on Alwar-Behror State Highway at 7th km from Behror which is locally known as 'Midway' and is situated on National Highway No. 8, halfway between Delhi and Jaipur. The area which is situated on the road side is approachable round the year as it is free from any vegetation. The rock formations which occur in this area belong to the Ajabgarh Group of the Delhi Supergroup (Precambrian). Of the Delhi Supergroup, the older Raialo and Alwar groups are missing in this area and the sequence commences directly with the Kushalgarh Formation of the Ajabgarh Group. As such, the stratigraphical succession of the area stands as shown in Table 1.

The Kushalgarh Formation comprises a sequence of marble beds (100 m in exposed section) intercalated with 3 to 5 cm thick bands of shale and chert. Bioherms of stromatolites are seen to have developed towards the top of this formation. The stromatolite forms include mostly of *Baicalia baicalica* (Maslov) Krylov, *Collenia columnaris* Fenton & Fenton, *Jacutophyton* Shapovalova and *Kussiella kusiensis* Krylov (Verma & Barman, 1980). The stromatolites, in general, are made up of milky white chert. The microfossils reported in this paper are from a thin chert band lying between marble beds, a few metres below the stromatolite bearing horizon in the upper part of the Kushalgarh Formation (Text-fig. 1).

Age of the rocks — The geological span of the deposition of Delhi Supergroup rocks



TEXT-FIG. 1 — Showing the type locality (after Verma & Barman, 1980).

TABLE 1 — STRATIGRAPHICAL SUCCESSION AROUND BARAUD, ALWAR DISTRICT, RAJASTHAN (MODIFIED AFTER NEGI & RAVINDRA, 1980)

Vindhyan Supergroup			Not developed
(Acid, basic and ultrabasic intrusives and extrusives)			
Delhi Supergroup (Precambrian)	Ajabgarh Group	Bhakrol Formation	Interbedded quartzites and phyllite with carbonaceous bands
		Thanagazi Formation	Andalusite-biotite-sericite schist, garnet-chlorite schist
		Seriska Formation	Brecciated and ferruginous-quartzites with stromatolites at the base
		Kushalgarh Formation	Impure siliceous marble with thin bands of chert and shale and stromatolites at upper part
	Alwar Group	(Missing)	
	Raialo Group	(Missing)	
(Granite, basic and ultrabasic intrusives)			
Aravalli Supergroup			Not developed

ranges in time from at least 1900 m.y. with two cycles of folding and a younger metamorphism (Crawford, 1970). Gupta (1977) mentioned that the rocks have been subjected to repeated granitic activity at 1660 m.y., 1010 m.y., 950 m.y., 790 m.y. and 735 m.y. Holmes (1949) carried out radiometric dating (733 m.y.) of Uraninite from a pegmatite in the biotite gneiss at Bisundri, Ajmer-Merwara and Monzanite from a pegmatite at Soniana, Mewar. According to him the date, i.e. 735 ± 30 m.y. of Bisundri Uraninite is one of the very few acceptable ages as being of first class reliability. Aswathanarayana (1959) dated 580 ± 20 m.y. from the Samarskite from a pegmatite near Kishangarh, Rajasthan. However, these younger dates support the observation of Heron (1953) that the pegmatitic intrusions all along the Delhi Synclinorium did not take place at the same time. Vinogradov *et al.* (1966a) recorded 900 ± 50 m.y. by K-Ar muscovite age from an Erinpura pegmatite near Ajmer. The total rock age of Erinpura type granite from Ajmer is approximately 930 m.y. While the Erinpura granite from Chhapoli was dated to 1000 m.y. (Crawford, 1975).

A rock sample collected from the outer flank of Baraud anticline on northern side belonging to the Bhakrol Formation has been dated 533 ± 24 m.y. by Fission Track method of biotite. The Kushalgarh Formation is the oldest formation of the Group, and obviously the age will be more than 533 m.y. of the youngest Bhakrol Formation. On the basis of stromatolite Verma and Barman (1980) commented that the Kushalgarh sedimentation started in the Lower Riphean and continued up to Middle Riphean time (1800-1000 m.y.).

On geological evidences, Delhi Group of rocks has been placed below Vindhyans and equated with Cuddapahs. However, Crawford (1969) has correlated the Cuddapah sequence with the Lower Vindhyans. Cuddapah sedimentation took place from 1400 to 980 m.y. (Aswathanarayana, 1962; Balasundaram & Balasubrahmanyan, 1973). On the other hand Vindhyans covered a span of 1400 to 900 m.y. (Misra, 1969).

While dealing with Precambrian stratigraphy in India on the basis of stromatolites, Raha and Sastry (1982) also proposed that the Delhi Supergroup may be correlated with the Lower Vindhyan. However, the new idea that Delhi is time equivalent, at last in part, with Vindhyan needs more support from various disciplines.

Palaeoenvironment — The study of stromatolites in the horizon indicates that these stromatolites building algal community grew in the form of a laminar sheet or mat in shallow marine conditions possibly in the intertidal zones. The silica rich solution buried the community very quickly and preserved the micro-organisms *in situ.*

TAXONOMY

The recorded assemblage consists of 10 genera and 17 species. The microbiota described here are taxonomically distinct from each other particularly in their characteristic morphology. Presence of branching, mode of septation, heterocyst, sheath and the reproductive structures (e.g. hormogonia) are considered to be distinctive in generic delimitation. The shape, size and detail measurements have been given secondary importance and used only for the specific identifications. The microfossils recovered here show very little or no degradation at all. According to Schopf (1977) the coccoid forms are referred to Cyanophyceae on the basis of size and morphological features. The filamentous forms are presumed to be cyanophycean in the presence of hormogonia, heterocyst in some of the forms (e.g. hormogonia in *Palaeoscytonema misrae* and heterocyst in *Primorivularia robusta*), branching (false branching in *Palaeoscytonema intermingla* sp. nov. and true branching in *Ghoshia bifurcata* gen. et sp. nov) and very thick sheath in most of the forms.

The empty sheaths of Chroococcacean colony (e.g. *Vesicophycus problematicus* gen. et sp. nov.) and of filamentous forms (e.g. *Animikiea septata*) are most likely derived from the form recovered here. It is difficult to say with certainty that to which forms they actually belong. Empty sheath of colonial form in all probability belongs to *Myxococcoides compactus* as *Vesicophycus* rarely contains few cells inside (Pl. 2, fig. 17) identical to the cells of *M. compactus* in shape and size. On the contrary, the empty sheath of filaments (e.g. *Animikiea septata*) are derived from more than one taxon as they have different types of apices.

SYSTEMATIC DESCRIPTION

ALGAE

FAMILY — CHROOCOCCACEAE

Genus — *Myxococcoides* Schopf, 1968

Type Species — *Myxococcoides minor* Schopf, 1968.

Myxococcoides inornata Schopf, 1968

Pl. 1, fig. 1

Description — Cells in cluster or rarely solitary, 9—18.7 μm in diameter (average 12.7 μm on 96 counts), spheroidal or variously shaped due to mutual compression in a colony; surface psilate; walls thick about 0.5 μm; distinct sheath around the colony, individual cells not ensheathed.

Remarks — The shape and habit of these fossils are identical to *Myxococcoides inornata* Schopf (1968, pl. 83, fig. 7) from the Bitter Spring Formation. However, the present specimens are smaller in size than the Bitter Spring. On the basis of the size the cells compare with *M. reticulata* Schopf (1968), but in *M. inornata* the cells are smooth and not finely punctate or reticulate as in *M. reticulata.*

The taxon is common in the assemblage. Solitary cells are rarely found (Pl. 1, fig. 5), which actually have originated from colonies by fragmentation. These isolated cells appear identical to *Huronispora* Barghoorn (in Barghoorn & Tyler, 1965).

Myxococcoides compactus sp. nov. Mandal & Maithy

Pl. 1, fig. 2; Pl. 3, fig. 5

Diagnosis — Colony spheroidal up to 70 μm in diameter consisting of hundreds of cell bounded by a thick, about 1.5 μm, non-lamellated granular sheath; cells 2.7-4.4 μm (average 3.7 μm on 38 counts) in diameter, arranged irregularly; surface psilate to finely granulose; wall about 0.2 μm thick; individual cells not ensheathed. Reproduction possibly by vegetative division in more than one plane.

Holotype — Pl. 1, fig. 2; slide no. 6818; stage coordinate 12.5 × 100.

Type Locality — 1 km east of Baraud Village.

Etymology — With reference to compact arrangement of cells.

Comparison & Discussion — *Myxococcoides compactus* sp. nov. is observed frequently in the assemblage. The species differs from the known species of *Myxococcoides* in its smaller cell size and colony consisting of about hundreds of cells.

Myxococcoides minor Schopf, 1968

Pl. 1, figs 3, 4; Pl. 3, fig. 24

Description—Globular colony up to 58 μm in diameter, composed of few to 20 cells embedded within a non-lamellated sheath of about 1.2 μ thick; cell outline spheroidal or polygonal due to compression, 4.4-8.5 μm in diameter (average 6.6 μm on 16 counts); adjacent walls of cells appear to be common; wall about 0.5 μm thick; surface psilate.

Remarks — Present specimens are smaller than the specimen of Schopf (1968) from Bitter Spring. The taxon is common in the assemblage.

Genus — *Palaeoanacystis* Schopf, 1968

Type Species — *Palaeoanacystis vulgaris* Schopf, 1968.

Palaeoanacystis vulgaris Schopf, 1968

Pl. 4, figs 26-28

Description — Large colony made up of a number of coccoid cells, palmelloid or cylindrical, generally dome-shaped and apparently without any mucilage covering. Individual cells spheroidal to elliptical due to mutual compaction, not ensheathed, 4.5-11 μm in size (average 6.5 μm on 55 measurements), cells appear to have marginal walls in common with the neighbouring cells which are pronounced near the margin; surface smooth.

Discussion — *Palaeoanacystis* is the monospecific genus erected by Schopf (1968) from the Bitter Spring Formation. Baraud specimens are commonly palmelloid and marginal walls of the neighbouring cells appear to be common. The present specimens compare exactly with the photograph of *P. vulgaris* given by Schopf (1968, pl. 82, fig. 7) from the Bitter Spring Formation of Australia. The taxon is not common in the assemblage.

Genus — *Gloeocapsamorpha* Zalessky, 1916

Type Species — *Gloeocapsamorpha prisca* Zalessky, 1916.

Gloeoeapsamorpha prisca Zalessky, 1916

Pl. 1, fig. 7

Description — Colony large forming stiff mat with a number of concentric sheaths; cells form secondary colonies, 10-15 in number arranged irregularly, 9-15.2 μm in diameter, spherical or oval in shape due to compaction; sheath around the colony and individual cells present, about 1.5 μm thick.

Remarks — *Gloeocapsamorpha prisca* is uncommon in the assemblage.

Gloeocapsamorpha karauliensis Maithy & Mandal, 1982

Pl. 1, fig. 6

Description — Cells spherical to oval due to mutual compaction, thin-walled and smooth, 4.4 to 9 μm in diameter (5.5 μm on average on 27 counts). Cells form secondary colonies within the parent colony; 11 secondary colonies observed to form a big colony; individual cells and colony ensheathed, colony about 10 to 33.2 μm in diameter.

Remarks — The taxon is rare in the assemblage. Cells are smaller in size than *G. karauliensis* described from Vindhyans of Rajasthan by Maithy and Mandal (1983).

FAMILY — OSCILLATORIACEAE

Genus — *Palaeolyngbya* Schopf, 1968 emend.

Type Species — *Palaeolyngbya barghoorniana* Schopf, 1968.

Remarks — The generic diagnosis of *Palaeolyngbya* Schopf (1968) is based on the monotypic species — *P. barghoorniana*. Therefore, it has limited the scope to accommodate other forms. As our form is overlapping in all significant morphological characters with extant *Lyngbya*, the generic diagnosis of *Palaeolyngbya* is enlarged here to accommodate other forms having comparable morphology with extant *Lyngbya*.

Emended Diagnosis — Filament broad, multicellular, uniseriate, unbranched, slightly to strongly constricted at septa; cross wall distinct, either partial or complete, sheath distinct, hyaline, non-lamellated and firm. Trichomes solitary, straight to variously curved. Apical cell may be distinct. Reproduction by hormogonia.

Palaeolyngbya distinctica sp. nov. Mandal & Maithy

Pl. 2, figs 10, 11

Diagnosis — Filament in bunch, variously curved up to 200 µm long (incomplete specimen); trichome solitary, multicellular, uniseriate and unbranched; septa distinct, widely spaced towards apices, faintly to moderately constricted at septa point; basal cell swollen, 10 to 13 µm long and 5 to 7 µm broad (on 4 counts); medial cells nearly quadrangular (as long as broad), 5 to 8 µm; side walls often depressed, smooth to finely granular surface; sheath firm, thin, non-lamellated; reproduction possibly by hormogonia.

Holotype — Pl. 2, fig. 10; slide no. 6818; stage coordinates 53×103.5.

Type Locality — 1 km east of Baraud Village.

Etymology — With reference to distinct quadrangular medial cells.

Comparison & Discussion — *Palaeolyngbya barghoorniana* Schopf (1968) differs from *P. distinctica* sp. nov. in having partially septate disc-shaped medial cells whereas in present species the medial cells are quadrangular, completely septate and sheath is distinct. *P. elongata* sp. nov. compares with *P. distincta* in having broad basal cell but medial cells are discoid. On the basis of exomorphic features *P. distinctica* sp. nov. compares with the extant *Lyngbya baculum* Gomont. The taxon is rare in occurrence.

Palaeolyngbya elongata sp. nov. Mandal & Maithy

Pl. 3, fig. 20

Diagnosis — Filament up to 500 µm long, isolated, variously curved; trichome single, unbranched and septate; medial cells disc-shaped, 5.3 µm long, 7 µm broad; basal cell larger than the medial cell, spindle-shaped, granulose; sheath firm, thin and adpressed to trichome; reproduction possibly by hormogonia.

Holotype — Pl. 3, fig. 20; slide no. 6816; stage coordinates 36.8×97.

Locality — 1 km east of Baraud Village.

Etymology — With reference to long filament.

Comparison & Discussion — Only one complete specimen observed which is 500 µm long. The terminal portion of the filament is broad possibly due to compression. Reproductive structure was not observed. *P. elongata* sp. nov. is characterised by granular spindle-shaped basal cell larger than the rectangular medial cells which make the species distinct and differs from other known species of *Palaeolyngbya.*

Palaeolyngbya baraudensis sp. nov. Mandal & Maithy

Pl. 1, fig. 9

Diagnosis — Filaments in bunch, up to 200 µm long, trichome single with broad basal cell; medial cells discoid, broader than long, 2/3 to 3/4, not constricted at septa, 13-18 µm broad and 2-4 µm long, terminal cells 4-6 µm broad and 2-3 µm long, cell surface granular; septa straight or concave; sheath thick, adpressed to trichome, faintly laminated; reproduction not known.

Holotype — Pl. 1, fig. 9; slide no. 6816; stage coordinates 1×94.6.

Locality — 1 km east of Baraud Village.

Etymology — With reference to the Baraud Village from where the sample was collected.

Comparison — *Palaeolyngbya baraudensis* sp. nov. compares with *P. elongata* sp. nov. in morphology, but the former differs in having curved basal cell. Moreover, basal cell is not spindle-shaped.

Genus — *Oscillatoriopsis* Schopf, 1968

Type Species — *Oscillatoriopsis obtusa* Schopf, 1968.

Oscillatoriopsis obtusa Schopf, 1968

Pl. 3, fig. 23A

Description — Trichome multicellular, variously curved, uniseriate, unbranched, solitary, up to 175 µm long, not constricted at septa, septation complete; medial cells cylindrical, nearly isodiametric, 8 to 11.1 µm long and 8.5 to 10.1 µm broad; apical cell gum-drop shaped, cylindrical, 10 µm long and 8.5 µm broad; sheath not obscured; reproduction not known.

Remarks — Only one specimen observed in the assemblage.

Genus — *Animikiea* Barghoorn, 1965 emend. Mandal & Maithy

Synonym:

1968 *Siphonophycus* Schopf, p. 671.

Remarks — Barghoorn (1965 in Barghoorn & Tyler, 1965) proposed *Animikiea* for the multicellular unbranched filaments (without trichome) straight or curved with closely spaced septa. Individual cell much wider than long. Enclosing sheath of filament distinct, thick-walled and granular. This genus was later restudied by Awramik and Barghoorn (1977) and according to them the septate appearance may be due to the wrinkling of external sheath and actually is only surficial feature. Schopf (1968) while instituting the genus *Siphonophycus* from the Bitter Spring Formation of Australia opined that it resembles closely to *Animikiea* Barghoorn. The only difference was the presence of closely spaced septa, which Schopf (1968) considered to be closely-spaced, punctate surficial ridges, and not penetrating in the tubular lumen. According to Schopf (1968, p. 671) " the septa " of *Animikiea septata*, therefore, seem quite analogus to the finely punctate surface ornamentation of *Siphonophycus kestron* (pl. 80, fig. 2). Although morphology of these two microfossil genera seems quite similar but the apical portion of *A. septata* is unknown. The apical part can not be taken as character for generic separation, as the presence of apex is only a chance of preservation. In our study we have found specimens with and without apices. Surface features of these specimens range from psilate to granular and aseptate to septa-like structure which could be due to preservation. We, therefore, feel that the characters of *Animikiea* and *Siphonophycus* are overlapping and not distinct enough for the institution of two distinct genera. Hence, we propose here to consider *Siphonophycus* Schopf (1968) as junior synonym of *Animikiea* Barghoorn (1965).

Emended Diagnosis — Unbranched, aseptate, tubular empty sheath of filamentous algae.

Genotype — *Animikiea septata* Barghoorn, 1965.

Due to this change in the generic status of *Siphonophycus* the following transfers become necessary and is being done here accordingly.

Animikiea septata Barghoorn emend. Mandal & Maithy

Pl. 2, fig. 16; Pl. 3, figs 18, 19

Synonymy:

1965 *Animikiea septata* Barghoorn in Barghoorn & Tyler, p. 576, fig. 3.
1968 *Siphonophycus kestron* Schopf, p. 671, pl. 80, figs 1-3.
1971 *Siphonophycus kestron* Schopf in Schopf & Blacic, p. 948, pl. 109, figs 3, 4.
1977 Sheaths, Oehler, 1977, figs A, G, H.
1977 *Animikiea septata* Barghoorn in Awramik & Barghoorn, p. 139, fig. 7A.

Emended Diagnosis — Sheath (without trichome) cylindrical, tubular, aseptate, unbranched, variously curved; surface smooth to granulose; apices broad, capitate to bluntly pointed.

Type Species — Fig. 3, Part 2, Barghoorn, 1965 in Barghoorn and Tyler, 1965.

Remarks — The tubular cylindrical sheath from the Delhi Supergroup is much broader than the type specimen. The surface of the studied specimens show various surficial pattern from smooth to granulose. The granulose surface gives a pseudosepta appearance. Several specimens show the presence of apices which are variable in shape. This taxon is very common in the assemblage.

Animikiea punctata (Maithy) comb. nov. Mandal & Maithy

Synonymy:

1975 *Siphonophycus punctatus* Maithy, p. 137, pl. 1, fig. 5.

Diagnosis — As in Maithy, 1975.

Animikiea indica (Nautiyal) comb. nov. Mandal & Maithy

Synonymy:

1978 *Siphonophycus* sp. A, Nautiyal, p. 261, fig. 9
1980 *Siphonophycus indicus* Nautiyal, p. 3, fig. 1A

Diagnosis — As in Nautiyal, 1980.

Animikiea beltensis (Horodyski) comb. nov. Mandal & Maithy

Synonymy:

1980 *Siphonophycus beltensis* Horodyski, p. 654, pl. 1, fig. 4.

Diagnosis — As in Horodyski, 1980.

Animikiea crassiuscula (Horodyski) comb. nov. Mandal & Maithy

Synonymy:

1980 *Siphonophycus crassiusculum* Horodyski, p. 656, pl. 1, figs 6, 7

Diagnosis — As in Horodyski, 1980

FAMILY — SCYTONEMATACEAE

Genus — *Palaeoscytonema* Edhorn, 1973

Type Species — *Palaeoscytonema moorhousii* Edhorn, 1973.

Remarks — Edhorn (1973) and Maithy and Shukla (1977) recorded microfossils showing affinities with the living *Scytonema* and separately erected the genus *Palaeoscytonema* with different types. Later, Maithy (1980) transferred *Palaeoscytonema* of Maithy and Shukla (1977) to a new genus *Neoscytonema* to validate the same. The present taxon possesses false branch, hormogonia and thick sheath which overlap with the generic circumscription of *Palaeoscytonema* Edhorn (1973).

Palaeoscytonema indica sp. nov. Mandal & Maithy

Pl. 2, fig. 12

Diagnosis — Filament single up to 250 µm long; trichome solitary, sheathed; sheath 1.2 µm thick, multicellular and false branched laterally; trichome and branches enclosed in the same sheath; septa distinct, thin but indistinct towards terminal portion, inflated and curved at base, cells discoid, broader than long, nearly 3/4; width of trichome 11-13.2 µm at base, 5.5-8.5 µm at middle and 2 µm at tip, surface granulose; sheath adpressed to trichome and diffluent at the apices. Reproduction not known.

Holotype — Pl. 2, fig. 12; slide no. 6816; stage coordinates 62.7×95.

Locality — 1 km east of Baraud Village.

Etymology — With reference to occurrence in India.

Comparison & Discussion — The present taxon is characterised by false branching and the sheath encloses trichome and branches. However, reproductive structures have not been observed. *Palaeoscytonema indica* sp. nov. differs from *P. moorhousii* Edhorn (1973) in being the trichome and branches within the sheath, robust in form and having curved inflated base. Moreover, reproductive structures are not known. *P. intermingla* sp. nov. compares with *P. indica* in laterally false branched characters but differs in the absence of curved inflated base. *P. misrae* sp. nov. differs as it reproduces by 6-7 cells long hormognia and has a thin filament. The taxon is common in the Baraud assemblage.

Palaeoscytonema intermingla sp. nov. Mandal & Maithy

Pl. 3, figs 22, 23

Diagnosis — Filaments interwoven, 10.5 to 13 µm broad (on 6 counts), false branched; false branches lateral; sheath thick, adpressed to trichome; trichome about 5.5 to 7 µm broad; cells rectangular, septa faint, not attenuated at septa point; branches swollen at the tips with rounded apices.

Holotype — Pl. 3, fig. 22; slide no. 6816; stage coordinates 4×92.9.

Locality — 1 km east of Baraud Village.

Etymology — With reference to intermingling nature of branches.

Comparison — *Palaeoscytonema intermingla* sp. nov. differs from *P. moorhousii* Edhorn (1973), *P. indica* sp. nov. and *P. misrae* sp. nov. in possessing intermingling filaments and false branches with swollen and rounded apices. The taxon is rare in the assemblage.

Palaeoscytonema misrae sp. nov. Mandal & Maithy

Pl. 2, fig. 13

Diagnosis — Filaments isolated, variously curved, up to 50 µm long; trichome solitary, unbranched, faintly constricted at septa; cells drum-shaped, 6 to 10 µm long, 4 to 7 µm broad, side walls straight to convex, basal cells larger than medial ones, 10 to 12.2 µm long and 6.5 to 8 µm broad; sheath firm, thick about 1.2 µm; reproduction by hormogonia, 2 to 3 hormogonia formed at a time, up to 7 cells long.

Holotype — Pl. 2, fig. 13; slide no. 6816; stage coordinates 47.1×97.3.

Locality — 1 km east of Baraud Village.

Etymology — In honour of Prof. R. C. Misra, former Head of the Geology Department, Lucknow University for his contribution to the Precambrian research work in India.

Comparison & Discussion — *Palaeoscytonema misrae* sp. nov. is very distinct in morphology and differs from other species of *Palaeoscytonema* in possessing 6-7 cells long hormogonia formed 2-3 at a time. However, filament in the assemblage is being observed (Pl. 2, fig. 14) with broad apical cell nearly identical in measurement with *P. misrae*. In this filament the hormogonia consist of only two cells. Isolated hormogonia, as figured in Pl. 2, fig. 15, present in the assemblage are being supposed to belong to *P. misrae* on the basis of size measurements. The form is very rare in the assemblage.

FAMILY — RIVULARIACEAE

Genus — *Primorivularia* Edhorn, 1973

Type Species — *Primorivularia thunderbayensis* Edhorn, 1973.

Primorivularia robusta sp. nov. Mandal & Maithy

Pl. 3, fig. 23B

Diagnosis — Filaments solitary, up to 150 µm; trichome uniseriate, multicellular, unbranched, ensheathed fully; constricted at septa basally; sheath non-lamellated about 1 µm thick; basal cells spherical, broader than long, 12.2 µm long and 18 µm broad; medial cells rectangular, closely placed, septa faint; heterocyst basal, single hemispherical, 18 µm long and 15.5 µm broad; akinite not known.

Holotype — Pl. 3, fig. 23B, slide no. 6817; stage coordinates 61.6×94.2.

Locality — As noted above.

Etymology — With reference to robust morphology.

Comparison & Discussion — The taxon is represented by only three specimens. The terminal portion in all the specimens are broken, therfore, the presence of terminal hair could not be ascertained. However, the basal heterocyst, broader basal cells and gradual attenuated trichome overlap with the circumscription of *Primorivularia* Edhorn (1973) except the character of terminal hair. *Primorivularia robusta* sp. nov. differs from *P. thunderbayensis* Edhorn (1973) in being robust and the trichome fully covered by sheath.

ORDER — STIGONEMATALES

FAMILY — CAPSOSIRACEAE

Genus — *Ghoshia* gen. nov. Mandal & Maithy

Type Species — *Ghoshia bifurcata* gen. et sp. nov.

Diagnosis — Thallus heterotrichous, erect filaments arising from a basal horizontally creeping thallus, densely packed, truely laterally branched, with cells in one or two series; sheath absent; reproduction not observed.

Etymology — In honour of Prof. A. K. Ghosh, emeritus scientist, Department of Botany, Calcutta University, Calcutta.

Ghoshia bifurcata sp. nov. Mandal & Maithy

Pl. 4, figs 29-31

Diagnosis — As for the genus with the following characters; cells drum-shaped to rectangular, dark coloured, constricted at septa, 5 to 9.3 µm in diameter (average 5.5 µm on 33 counts), wall about 0.5 µm thick and surface psilate; branching irregular, *Locality* — 1 km east of Baraud Village.

Holotype — Pl. 4, fig. 30; slide no. 6817; stage coordinates 52.5×95.2.

Etymology — With reference to forking nature of erect filaments.

Discussion — Stigonematales is the most evolved order among the blue-green algae. This group of algae is characterised by heterotrichous filaments with true branching and multiplication by hormogonia and hormocysts. The present taxon exhibits heterotrichous habit and lateral branching which appears to be true. Reproductive structures, however, are not known. On the basis of known vegetative characters, putting more stress upon the true branching of heterotrichous filaments, this form compares well with the living algae *Stauromatonema* Fremy (Desikachary, 1959, p. 567) belonging to Stigonematales. Thus this is the earliest fossil record of Stigonematalean algae. This group of algae is known previously from the Middle Devonian of Rhynie Chert (Croft & George, 1959). The present record will materialistically contribute to the understanding of the early evolution of form. The genus *Ghoshia* is common in the assemblage.

INCERTAE SEDIS

Genus—*Vesicophycus* gen. nov. Mandal & Maithy

Type Species — *Vesicophycus problematicus* n. sp.

Pl. 3, fig. 25; Pl. 4, fig. 32

Diagnosis — Solitary empty envelope, mainly spherical or oval due to various foldings on the surface; folds common and irregular, surface without any ornamentation but rough. No pore or mark on surface.

Etymology — With reference to nature of vesicle and possible algal affinity.

Vesicophycus problematicus sp. nov.
Mandal & Maithy

Diagnosis — As for the genus.

Etymology — With reference to doubtful nature of vesicles.

Holotype — Pl. 4, fig. 32; slide no. 6816; stage coordinates 43.2×101.4.

Locality — 1 km east of Baraud Village.

Comparison & Discussion — Horodyski and Donaldson (1980) described some large envelopes as *Archaeoellipsoides* from Arctic Canada which differs from *Vesicophycus* in being ellipsoidal, pear or sausage-shaped.

In all probability, these are the empty colony sheaths of coccoid forms which are abundant in the assemblage. Two vesicles were observed where 3-5 coccoid cells are still present inside. These coccoid cells are similar to the cells of *Myxococcoides compactus* sp. nov. (Pl. 2, fig. 17). In other cases the rupture of the wall indicates possibly the path for the outlet of the coccoids. Other possibility is that some of these vesicles used to contain zygospores and after their liberation from the vesicles the empty vesicles become collapsed with crumpled surface. As no comparable structure with the present form is known a new name *Vesicophycus* is erected to accommodate the spherical empty sheaths.

DISCUSSION

Structurally well-preserved microbiota comprising blue-green algae is recorded for the first time from the Ajabgarh Group. This is the most diversified Precambrian biota from India. The assemblage comprises 10 genera and 17 species. These taxa represent four natural families belonging to three orders — Chroococcales, Nostocales and Stigonematales. The presence of Stigonematales in the assemblage has been suggested by vegetative characters.

The diversification of the assemblage is evidenced by the varying morphology they exhibit. Sheath is present conspicuously in all the forms except *Ghoshia*, which may adpressed to the trichome (e.g. *Palaeoscytonema indica*) or loose (e.g. *Palaeolyngbya distinctica*). In *Primorivularia robusta* sheath is not discernible in the apical portion of the trichome. The reproductive structure observed in the filamentous forms is hormogonia (e.g. *Palaeoscytonema misrae*). Isolated hormogonia are also found in the assemblage (Pl. 2, fig. 15) which may belong to *P. misrae* like forms. Heterocyst is rare (Pl. 3, fig. 23), but akinite or other types of spores are totally absent. Vegetative cells also show various shapes — quadrangular (e.g. *Palaeolyngbya distinctica*), rectangular (e.g. *Palaeoscytonema baraudensis*) and discoidal (e.g. *P. indica*).

Basal cells in *Palaeolyngbya indica* is bigger than the medial cell whereas they are smaller or of the same size as in *Palaeoscytonema indica*. The assemblage is dominated by the filamentous forms which constitute 65 per cent of the total assemblage. However, coccoid forms are common in occurrence. It is interesting to note that there is no taxa of a single cell. The colonial habit suggests higher level of evolutionary stage. The colonies are in the form of algal mat which ultimately form the biostrome of the stromatolite.

Branching perhaps has emerged as most significant event in the assemblage. Record of false (lateral) branching is meagre in the early rocks. Earlier Edhorn (1973) reported false branching in *Plaeoscytonema moorhousii* from Canada. Baraud microbiota frequently exhibits false branching (e.g. *Palaeoscytonema intermingla* and *P. indica*). The branching in *Ghoshia bifurcata* has been suggested to be true one and therefore it has been placed in Stigonematales, where true branching commonly occur. If the suggested affinity of *Ghoshia* with the more advanced order of blue-green algae stands right on the basis of true branching then highest level of development of vegetative characters occurred in Delhi Supergroup. No other record of true branching is known so far from the Proterozoic. The earliest record of the preserved Stigonematalean form is available from the Middle Devonian Rhynie chert by Croft and George (1959).

Comparison with other assemblages — Structurally preserved microbiota are now known from the various Proterozoic rocks of India. However, the assemblages reported earlier by Maithy and Shukla (1977), Maithy and Gupta (1983), Maithy and Mandal (1983) from Vindhyans and Nautiyal (1978) from the Kumaun Himalaya are comparable as they comprise coccoid and filamentous forms comparable with blue-green algae. Chroococcaceae and Oscillatoriaceae are also common in all the assemblages. However, the Baraud assemblage is entirely different from all the above described assemblages in the dominance of filamentous forms and total absence of cryptarchs. In the Suket Shale microflora (Maithy & Shukla, 1977) well-preserved diverse biota is known till today, which is represented by Chroococcaceae, Oscillatoriaceae and Scytonemataceae. The present assemblage also contains these families with more developed structures such as hormogonia, heterocysts and with frequently branched filaments, which make the assemblage unique. On the whole the Baraud assemblage demonstrates advancement in evolutionary level than the Vindhyan biota though on geological evidences it is believed that Vindhyans are younger than Delhi Supergroup.

The assemblage compares well with Bitter Spring flora of Australia (Schopf, 1968; Schopf & Blacic, 1971). In both the assemblages Chroococcaceae, Oscillatoriaceae and Rivulariaceae appear to be common. The Bitter Spring microflora is very rich and much more diversified which contain probable Chlorophycean and Rhodophycean algae, fungi and bacteria, which are absent in Baraud. Similarly in Scytonemataceae, true and false branching and reproductive structures are totally absent from the Bitter Spring Formation. Thus on one hand the appearance of eucaryotic organism is significant in Bitter Spring while the appearance of true branching habit is most significant feature in Baraud. This coincidence indicates that true branching and nucleated cells probably appeared within short time interval. Assemblages reported by Edhorn (1973)—Animekie, Thunder Bay, Ontario; Hofmann and Jackson (1969)—Belchar island, Hudson Bay; Hofmann (1976) — Belcher island; Oehler (1977) — H.Y.C. Pyritic Shale Member, Australia; Muir (1976)—Amelia Dolomite, Australia; and Maithy (1975)—Bushimay Supergroup, Zaire differ in the constituents of microbiota. Moreover, both false and true branching present in this assemblage is characteristic.

From the above comparison it is evident that all the assemblages resemble in common occurrence of Chroococcaceae and Oscillatoriaceae. However, all of them differ in point to point comparison due to different climatic factors and evolutionary scales. It is possible that the evolution proceeded in more or less same direction but with different forces in different basins. According to Schopf and Blacic (1971) the correlation is possible only over short distances and when factors influencing species dispersed are thoroughly considered.

The occurrence of such diverse microbiota is a significant addition to the Indian Precambrian record. Microbiota known so far from the Vindhyans is not diverse like from Baraud. However, more sampling covering wide ecologically varying strata will certainly strengthen the basis for closer correlation. It appears that serious attempt is now needed before putting any final comment on the correlation between Delhi Supergroup and Vindhyans.

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EXPLANATION OF PLATES

(All figures are × 1000 unless otherwise stated; stage coordinates given for Leitz Dialux-20)

PLATE 1

1. *Myxococcoides inornata* Schopf showing a small cluster within organic matrix; phase interference photograph, slide no. 6816, stage coordinates 58.4 × 98.2.
2. *M. compactus* sp. nov., holotype; phase interference photograph; slide no. 6818, stage coordinates 12.5 × 100.
3, 4. *M. minor* Schopf showing different number of cells in the colony, slide no. 6818; fig. 3. Stage coordinates 36 × 106; fig. 4. 43 × 107.4.
5. A solitary cell, comparable with *Huronispora* Barghoorn, seems to be detached from *M. inornata* colony, slide no. 6818, stage coordinates 44.5 × 99.
6. *Gloeocapsamorpha karauliensis* Maithy & Mandal, slide no. 6817, stage coordinates 30.7 × 106.
7. *G. prisca* Zalessky, slide no. 6818, stage coordinates 35 × 105.5.
8. *Animikiea septata* Barghoorn showing apical part, slide no. 6816, stage coordinates 49.5 × 97.
9. *Palaeolyngbya baraudensis* sp. nov., slide no. 6816, stage coordinates 51.1 × 94.6.

PLATE 2

10, 11. *Palaeolyngbya distinctica* sp. nov. showing thick sheath, quadrangular cells; phase interference photograph; slide no. 6818; fig. 10, holotype, stage coordinates 53 × 103.5; fig. 11, 31.3 × 100.2.
12. *Palaeoscytonema indica* sp. nov., holotype, slide no. 6816, stage coordinates 62.7 × 95; × 500.
13. *Palaeoscytonema misrae* sp. nov., holotype, slide no. 6816, stage coordinates 47.1 × 97.3.
14. A filament showing two-celled hormogonia, slide no. 6816, stage coordinates 53.2 × 106.3.
15. An isolated hormogonia comparable with the hormogonia of *P. misrae*; slide no. 6818, stage coordinates 53.3 × 103.3.
16. *Animikiea septata* Barghoorn, apical portion, slide no. 6816, stage coordinates 33.2 × 97.5.
17. An empty sheath of colony identical to *Vesicophycus* gen. nov. still containing 3 cells inside which are similar to *Myxococcoides compactus*, slide no. 6816, stage coordinates 49.8 × 500.

PLATE 3

18, 19. *Animikiea septata* Barghoorn, fig. 18, without apex showing false septation, slide no. 6816, stage coordinates 38.7 × 96.4; fig. 19 showing apex, false septation, slide no. 6816, stage coordinates 43.5 × 92.1.

20. *Palaeolyngbya elongata* sp. nov., holotype, note granular nature of trichome prominent in the apical part, slide no. 6816, stage coordinates 36.8 × 97; × 750.

21, 22. *Palaeoscytonema intermingla* sp. nov., showing false lateral branching; fig. 21, holotype, slide no. 6817, stage coordinates 48.2 × 96.8; fig. 22, slide no. 6816, stage coordinates, 44.4 × 92.9.

23. A, *Oscillatoriopsis obtusa* Schopf and B, *Primorivularia robusta* sp. nov., holotype, slide no. 6817, stage coordinates 61.6 × 94.2.

24. *Myxococcoides minor* Schopf, slide no. 6818, stage coordinates 59.4 × 107.2.

25. *M. compactus* sp. nov., slide no. 6818, stage coordinates 36.5, × 107.5, × 500.

PLATE 4

26-28. *Palaeoanacystis vulgaris* Schopf, fig. 26, slide no. 6817, stage coordinates, 60 × 99, × 500; fig. 27, a portion enlarged of fig. 26, × 1000; fig. 28, slide no. 6816, stage coordinates 30.5 × 95.9, × 500.

29-31. *Ghoshia bifurcata* gen. et sp. nov., fig. 29 showing initiation of heterotrichous condition, slide no. 6818, stage coordinates 39.3 × 106.8; fig. 30, holotype showing true branching in aerial filament, slide no. 6817, stage coordinates 52.5 × 95.2; fig. 31, slide no. 6817, stage coordinates 36 × 96.4.

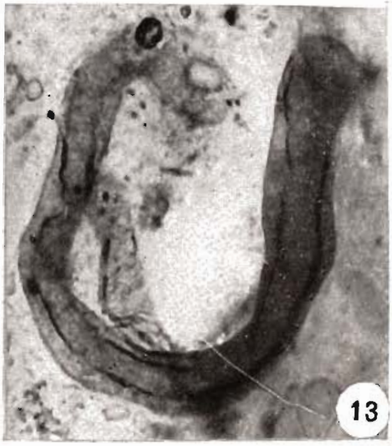
32. *Vesicophycus problematicus* gen. et sp. nov., holotype, slide no. 6816, stage coordinates, 43.2 × 101.4.

PLATE 1


12


15


11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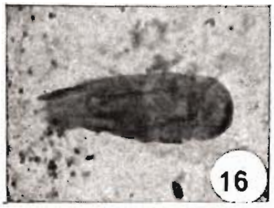
10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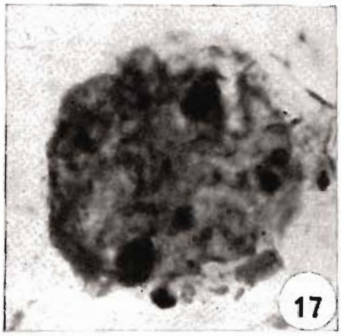
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PLATE 2

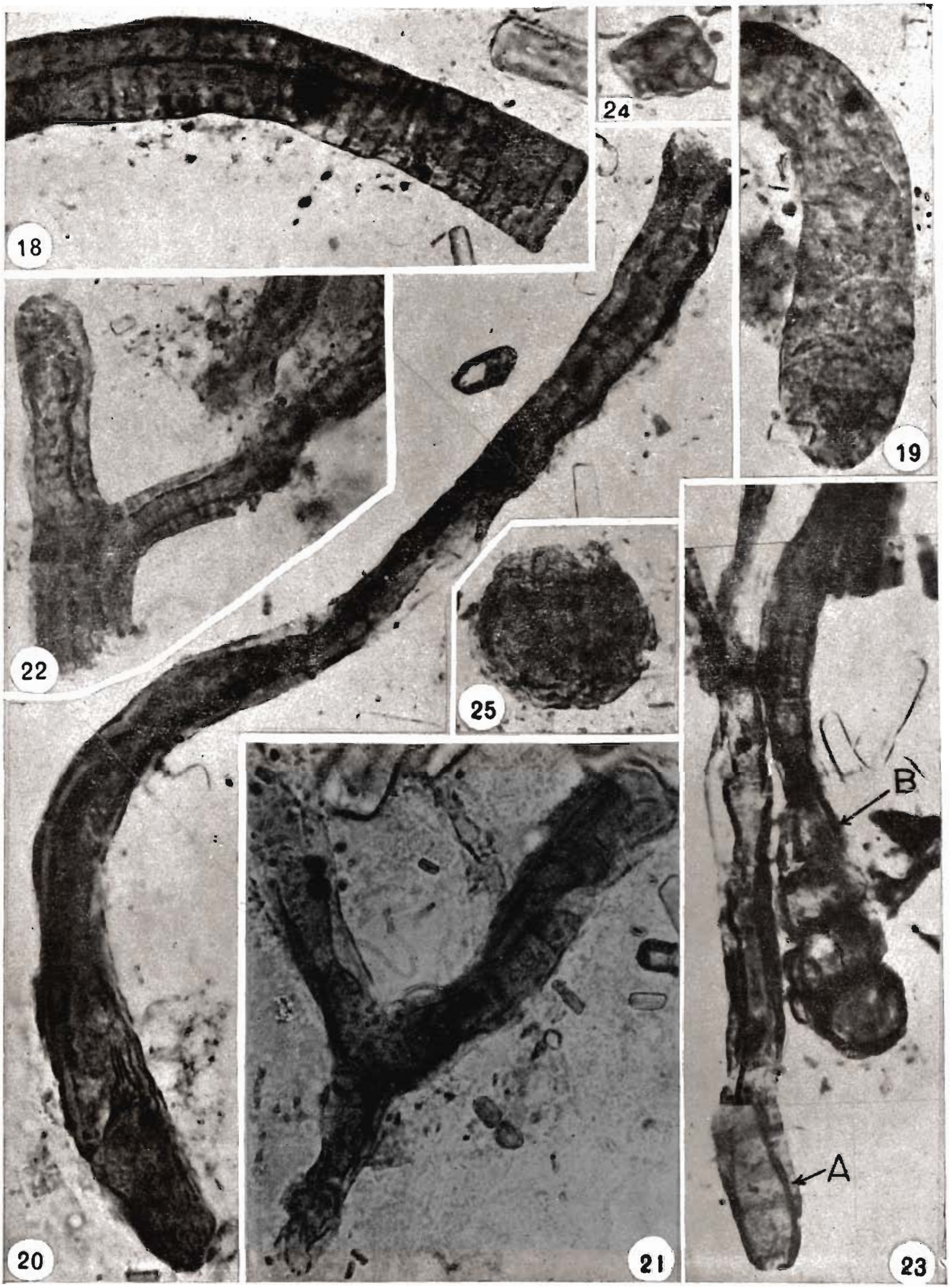

PLATE 3

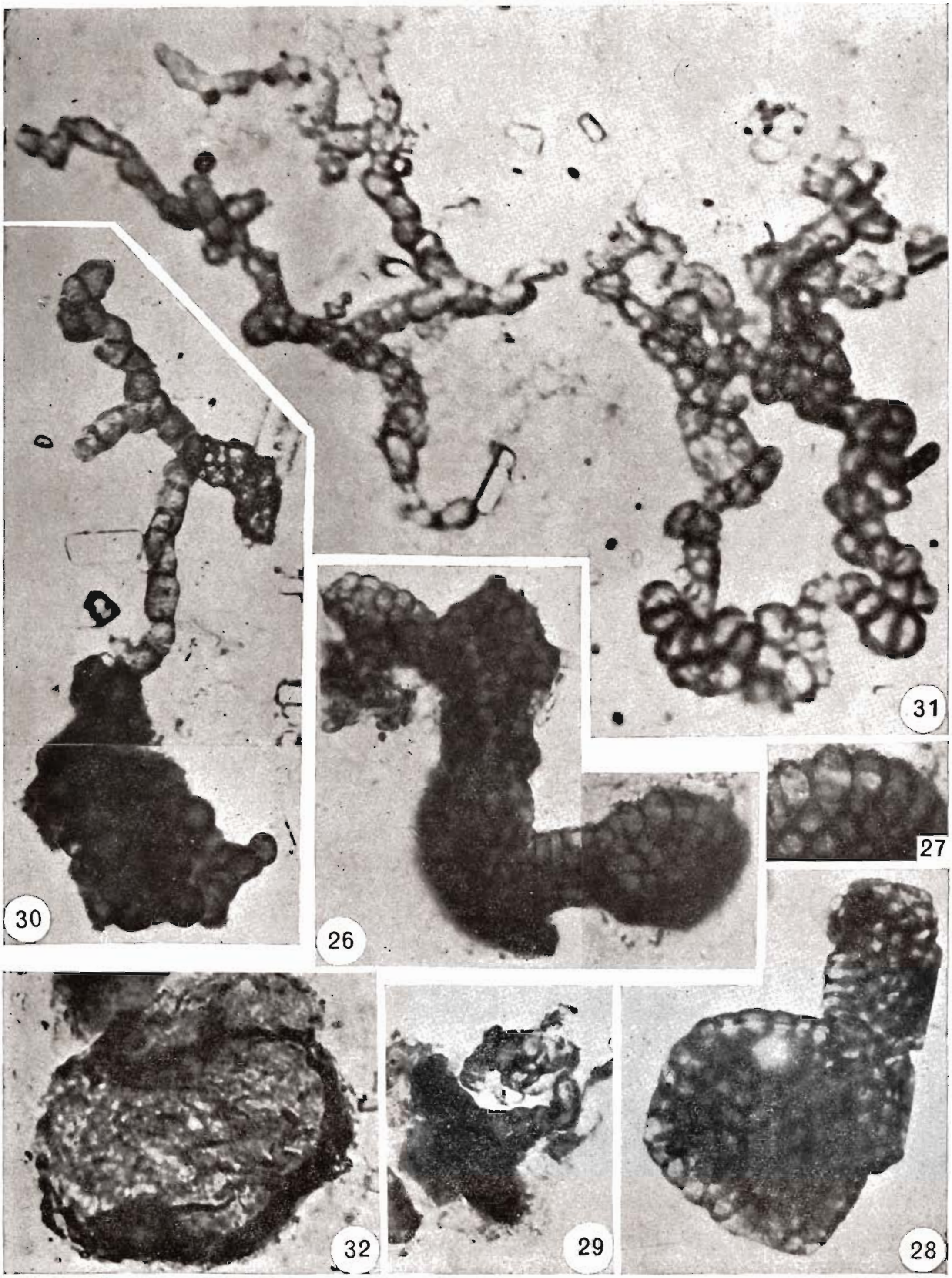

PLATE 4