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Organic-walled microfossils from the Proterozoic Vindhyan Supergroup of Son Valley, Madhya Pradesh, India

BIJAI PRASAD*, S. N. UNIYAL AND RAMSON ASHER

KDM Institute of Petroleum Exploration, Oil and Natural Gas Corporation Limited, 9 Kaulagarh Road, Dehra Dun- 248 195, India.
**Email: bijaiprasad@indiatimes.com*

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ABSTRACT

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Well-preserved and diversified organic-walled microfossil assemblages are recorded from the Vindhyan sediments of Son Valley and DMH-A well, in Madhya Pradesh. The microfossils include acritarchs, coccoid and filamentous taxa that suggest a Meso-Neoproterozoic age for the Vindhyan Supergroup which, hitherto, was assigned a Late Paleoproterozoic to Early Paleozoic age, based on fossil evidences and radiometric datings.

The Kajrahat Limestone, within the basal Semri Group, recorded abundant filamentous microfossils, viz. *Polythrichoides*, *Karamia*, *Arctacellularia* and *Siphonophycus* along with simple unornamented sphaeromorph acritarchs (*Leiosphaeridia* spp.), suggesting ca.1500-1450 Ma age of Early Mesoproterozoic. The microfossil assemblage of Deonar Formation also includes the above taxa; however, *Satka*, *Eomicrocystis* and acanthomorph acritarchs, *Tappania* spp., appear within this formation along with abundant polygonomorph acritarchs referable to *Octoedryxium*. The Deonar microfossil assemblage resembles the assemblage of Roper Group (northern Australia) and suggests ca.1450-1350 Ma age of Early to Middle Mesoproterozoic.

The sediments of Kheinjua Subgroup are marked by the appearance of various species of *Navifusa*, *Simia* and *Pterospermopsimorpha* in the Koldaha Shale with overall abundance of *Tappania*, *Satka*, *Eomicrocystis*, *Kildinosphaera* and *Leiosphaeridia*. The presence of Middle to Late Mesoproterozoic marker taxa, viz. *Tappania plana*, *T. tubata* and *Navifusa segmentata* helps to correlate the Koldaha Shale and Salkhan Limestone assemblages with the assemblage of the Ruyang Group (China), suggesting an Ectasian-Stenian (ca.1350-1050 Ma) age. In additon to the above taxa, the appearance of Early Neoproterozoic marker taxa, such as, *Vandalosphaeridium*, *Bavlinella*, *Melanocyrillium* and budding leiospherids in the Rampur Formation indicates a Late Stenian-Tonian age (ca.1050-850 Ma) for this formation.

The microfossil assemblage of the Rohtas Subgroup is quite distinct as the marker taxa of the Kheinjua Subgroup, viz. *Tappania* spp.and *Navifusa* spp. disappear. The presence of *Trachysphaeridium laufeldi*, *Vandalosphaeridium reticulatum*, *Bavlinella faveolata* and *Stictosphaeridium* spp., and the disappearance of *Eomicrocystis*, *Satka* and budding leiosphaerids within this formation allow its correlation with Middle Neoproterozoic Miroyedikha (Siberia) and Husar-Kanpa (central Australia) assemblages, suggesting an Early Cryogenian (ca.850-750 Ma) age for the Rohtas Subgroup.

The microfossil assemblages from the Kaimur and Rewa groups are represented by the species of *Symplassosphaeridium*, *Synsphaeridium* and *Leiosphaeridia*. The occurrence of *B. faveolata*, *T. laufeldi* and *Octoedryxium truncatum* in their assemblages suggest a Middle to Late Neoproterozoic (Late Cryogenian; ca.750-650 Ma) age. The sediments of the Bhander Group also include the above taxa. However, the appearance of Ediacaran (Vendian) marker species of *Obruchevella*, viz. *O. parva* and *O. valdaica* in the Ganurgarh Shale, and their abundance in the overlying Nagod Limestone and Sirbu Shale, suggests a Late Cryogenian-Early Ediacaran (ca. 650-570 Ma) age for the Bhander Group. Yet, the appearance of *Obruchevella delicata, Lophosphaeridium tentativum* and *Cymatiosphaera* sp. in the Nagod Limestone, and *Obruchevella parvissima, Cristallinium* sp. and *Dictyotidium* sp. in the Sirbu Shale suggest that the age of the Bhander Group extends into the Late Ediacaran (ca.570-544 Ma).

The record of Calymmian (ca.1500 Ma) to Late Ediacaran (ca. 544 Ma) organic-walled microfossil assemblages categorically suggests an Early Mesoproterozoic to Terminal Proterozoic age-range for the Vindhyan Supergroup. The occurrence of well-developed Middle and Late Mesoproterozoic microfossil assemblages in the Deonar Formation and Kheinjua Subgroup negates the Late Paleoproterozoic (ca. 1630 Ma) age assignment to them, based on radiometric datings. The presence of Ediacaran (Vendian) marker species of *Obruchevella* and the absence of distinctive Early Cambrian acritarchs in the Bhander Group brackets the upper age limits of Vindhyan Supergroup to the Late Ediacaran, and does not encompass the Lower Paleozoic.

Key-words—Meso-Neoproterozoic, organic-walled microfossils, Vindhyan Supergroup, Son Valley, India, acritarch biostratigraphy.

सारांश

भारत में मध्यप्रदेश की सोन घाटी के प्रोटीरोजोइक विन्ध्य महासमूह से प्राप्त जैवभित्ति सूक्ष्मजीवाश्म

बिजय प्रसाद, ऍस.ऍन. उनीयाल एवं रेमसन अशर

मध्य प्रदेश में सोन घाटी तथा डी.ऍम.ऍच.-ए कूप के विन्ध्य अवसादों से प्राप्त सुपरिरक्षित तथा विविध जैवभित्ति सूक्ष्मजीवाश्म समुच्चयों को अंकित किया गया है। इन सूक्ष्मजीवाश्मों में सम्मिलित एक्रीटार्क, गोलाभ तथा तंतुल वर्गक विन्ध्य महासमूह हेतु मीसो-निओप्रोटीरोजोइक आयु प्रस्तावित करते हैं। जिनकी अब तक जीवाश्म प्रमाणों तथा विकिरण मापीय कालनिर्धारण के आधार पर अंतिम पेलियोप्रोटीरोजोइक से प्रारम्भिक पेलियोजोइक आयु निर्धारित की गई थी।

साधारण अविभूषित स्फैरोमॉर्फ एक्रीटार्क (*लिओस्फैरीडिया* प्रजाति) के साथ प्रचुर तंतुल सूक्ष्मजीवाश्मों को आधारी सेमरी समूह में कजराहट चूनापत्थर से अंकित किया गया है जो कि प्रारम्भिक मीसोप्रोटीरोजोइक की लगभग 150-145 करोड़ वर्ष आयु प्रस्तावित करते हैं। देवनार शैलसमूह के सूक्ष्मजीवाश्म समुच्चय भी उपरोक्त वर्गकों को सम्मिलित करते हैं तथापि *ओक्टोएड्राइजियम* के संदर्भ में प्रचुर पॉलीगोनोमोर्फ एक्रीटार्क के साथ इस समुच्चय में *सट्का, इओमाइक्रोसीसटीज़* एवं अकनथोमोर्फ एक्रीटार्क, *टेप्पेनिया* प्रजाति प्रकट होती है। देवनार सूक्ष्मजीवाश्म समुच्चय रोपर समूह (उत्तरी आस्ट्रेलिया) के समुच्चय से समानता प्रदर्शित करता है तथा प्रारम्भिक से मध्य मीसोप्रोटीरोजोइक की लगभग 145-135 करोड़ वर्ष आयु प्रस्तावित करता है।

कोल्डाहा शेल में *टेप्पेनिया, सट्का, इओमाइक्रोसीसटीज, किल्डीनोस्फ़ेयरा* तथा *लिओस्फ़ेरिडिया* की समस्त बहुलता के साथ *नवीफ्यूज़ा, सीमिआ* तथा *टेरोस्पर्मोप्सीमोर्फा* की विभिन्न प्रजातियों के प्रतिनिधित्व से खीनजुआ उपसमूह के अवसादों को अंकित किया गया है। मध्य से अंतिम मीसोप्रोटीरोजोइक चिह्निक वर्गक अर्थात् *टेप्पेनिया प्लाना, टी. ट्यूबेटा* एवं *नवीफ्यूज़ा सीगमेंटेटा* की उपस्थिति रूयांग समूह (चीन) के समुच्चय के साथ कोल्डाहा शेल तथा सलखान चूनापत्थर समुच्चयों को सहसम्बन्धित करने में सहायता करती है और एक्टेसियन स्टीनियन (लगभग 135-105 करोड़ वर्ष) आयु प्रस्तावित करती है। उपरोक्त वर्गकों के अतिरिक्त रामपुर शैलसमूह में प्रारम्भिक निओप्रोटीरोजोइक चिह्निक वर्गक जैसे-*वन्डेलोस्फेयरीडियम, बेवलीनेल्ला मिलेनोसाइरीलियम* एवं बड्डिंग लीओस्फेयरीड्स का प्रतिनिधित्व इस शैलसमूह हेतु अंतिम स्टीनियन-टोनियन आयु (लगभग 105-85 करोड़ वर्ष) का संकेत करते हैं।

रोहतास उपसमूह के सूक्ष्मजीवाश्म समुच्चय बिल्कुल अलग हैं जैसे कि खीनजुआ उपसमूह के वर्गक अर्थात् *टेप्पेनिया* तथा *नेवीफ्यूज़ा* लुप्त होते हैं।

इस शैलसमूह में *ट्रेचीस्फेयरीडियम लोफेल्डी, वन्डेलोस्फेयरीडियम रेटीकुलेटम, बेवलीनेल्ला फेवियोलेटा* एवं *स्टिक्टोस्फेयरीडियम* प्रजाति की उपस्थिति तथा *इओमाइक्रोसीसटीज, सट्का* एवं बड्डिंग लीओस्फेयरीड्स का लोप मध्य निओप्रोटीरोजोइक मीरोयेधिका (साइबेरिया) तथा हुसार-कम्पा (मध्य आस्ट्रेलिया) समुच्चयों से इसका सहसम्बन्धन स्वीकार करता है और रोहतास उपसमूह हेतु प्रारम्भिक क्रिओजीनियन (लगभग 85-75 करोड़ वर्ष) आयु प्रस्तावित करते हैं।

कैमूर तथा रीवा समूहों से प्राप्त सूक्ष्मजीवाश्म समुच्चय *सिम्प्लेस्सोस्फेयरीडियम, सिनस्फेयरीडियम* एवं *लीओस्फेयरीडिया* की प्रजातियों द्वारा प्रतिनिधित्व करते हैं। इनके समुच्चयों में *बी. फेवियोलेटा, टी. लोफेल्डी* एवं *ओक्टोएड्राइजियम ट्रंकेटम* की उपस्थिति मध्य से अंतिम निओप्रोटीरोजोइक (अंतिम क्रिओजिनियन; लगभग 75-65 करोड़ वर्ष) आयु प्रस्तावित करते हैं। भंडेर समूह के अवसाद भी उक्त वर्गकों में सम्मिलित होते हैं। गनुरगढ़ शेल में *ओबरूचीवेल्ला* की ईडियाकरण (वेन्डियन) चिह्नित प्रजाति अर्थात् *ओ. परवा* एवं *ओ. वल्डाइका* की उपस्थिति तथा उपरशायी नागोड चूनापत्थर एवं सिरबू शेल में उनकी प्रचुरता भंडेर समूह हेतु अंतिम क्रिओजिनियन-प्रारम्भिक ईडियाकरण (लगभग 65-57 करोड़ वर्ष) आयु प्रस्तावित करते हैं। फिर भी नागोड चूनापत्थर में *ओबरूचीवेल्ला डेलीकेटा, लोफोस्फेयरीडियम टेन्टेटीवम* एवं *साइमेटिओस्फेयरा* प्रजाति तथा सिरबू शेल में *ओबरूचीवेल्ला पर्वीस्सीमा, क्रिस्टेल्लीनियम* प्रजाति एवं *डिक्टिओटीडियम* प्रजाति की उपस्थिति प्रस्तावित करती है कि भंडेर समूह की आयु अंतिम ईडियाकरण (लगभग 57-54.4 करोड़ वर्ष) बढ़ गई है।

जैवभित्ति सूक्ष्मजीवाश्म क्रमवार समुच्चयों का केलीम्पियन (लगभग 150 करोड़ वर्ष) से अंतिम ईडियाकरण (लगभग 54.4 करोड़ वर्ष) का अभिलेख विन्ध्य महासमूह हेतु प्रारम्भिक मीसोप्रोटीरोजोइक से टर्मिनल प्रोटीरोजोइक आयु-श्रेणी प्रस्तावित करता है। देवनार शैलसमूह तथा खीनजुआ उपसमूह में मध्य एवं अंतिम मीसोप्रोटीरोजोइक सुविकसित सूक्ष्मजीवाश्म समुच्चयों की उपस्थिति उनको दी गई अंतिम पेलियोप्रोटीरोजोइक (लगभग 163 करोड़ वर्ष) आयु विकिरणमितिय कालनिर्धारण के आधार पर अस्वीकार करती है। भंडेर समूह में *ओबरूचीवेल्ला* की ईडियाकरण (वेन्डियन) चिह्नित प्रजाति की उपस्थिति तथा विशिष्ट प्रारम्भिक कैम्ब्रियन एक्रीटार्क की अनुपस्थिति विन्ध्य महासमूह से अंतिम ईडियाकरण की ऊपरी आयु सीमा को एक समूह के रूप में साथ रखती है तथा निम्न पेलियोजोइक को घेरती नहीं है।

संकेत शब्द-मीसोप्रोटीरोजोइक, जैवभित्ति सूक्ष्मजीवाश्म, विन्ध्य महासमूह, सोन घाटी, एक्रीटार्क जैवस्तरिकीविज्ञान, भारत

INTRODUCTION

THE Vindhyan Basin represents an undisturbed and distinctive Proterozoic sedimentary succession of calcareous, argillaceous and arenaceous facies in Central India which is classed as the Vindhyan Supergroup. Yet, the age of Vindhyan Supergroup has long been remained a subject of major controversy due to the scantiness of fossils and its varied absolute age datings. Diverse and controversial ages have been assigned to the Vindhyan succession, mainly based on fossil evidences and radiometric datings at different stratigraphic levels that gave its age ranging from Late Paleoproterozoic to Early Paleozoic (Silurian). The various age evidences, suggested by a number of workers, are still unconceivable and even not accepted by many stratigraphers as doubts were raised on a number of micro-and macrofossil evidences and radiometric datings.

The fossil and absolute age evidences available from the Vindhyan Supergroup leading to its diverse age assignment are the organic-walled microfossils (acritarchs, filamentous and coccoid forms), stromatolites, macrofossils, small shelly microfossils (SSMs) and radiometric absolute datings.

Organic-Walled Microfossils

Studies on acritarchs and other organic-walled microfossils from the Vindhyan sediments have been made by a number of workers (Salujha *et al*., 1971a, b; Maithy & Shukla, 1977; Maithy & Babu, 1993, 1997, 2000; Venkatachala *et al.*, 1990; Kumar & Srivastava, 1995) which were recently reviewed and summarized by Maithy (1992), Venkatachala *et al.* (1996) and Maithy and Babu (1997). These studies broadly suggested an Early Mesoproterozoic to Terminal Proterozoic (Early Riphean to Vendian) age-range for the Vindhyan Supergroup. The above age inference was made on the basis of records of mainly the smooth and microsculptured sphaeromorph acritarchs (*Kildinosphaera, Leiosphaeridia, Lophosphaeridium, Trachysphaeridium, Orygmatosphaeri-dium*) and abundant filamentous and coccoid microfossils (*Siphonophycus, Glenobotrydion, Myxococcoides, Eosynechoccus* and *Archaeoellipsoides*). However, Salujha (1973), based on the records of small acanthomorph acritarchs (*Micrhystridium* spp.) and herkomorphs (*Cymatiosphaera, Dictyotidium*) from the Rohtas Limestone and Bijaigarh Shale (Salujha *et al.*, 1971a, b), opined that the Vindhyan Supergroup encompasses the Early Paleozoic also and ranges in age from Late Precambrian to Early Silurian. Anabarasu (2001) recorded herkomorph acritarchs referable to ? *Cymatiosphaeroides kullingii* of Late Neoproterozoic aspect from the basal Semri Group (Chitrakoot Formation) of the Chitrakoot area. Prasad and Asher (2001) suggested Middle Mesoproterozoic (Ectasian) to Terminal Proterozoic (Vendian) age-range for the Vindhyan Supergroup on the basis of rich organic-walled microfossil assemblages from the DMH-A well, drilled in the Vindhyan Basin near Damoh in Madhya Pradesh.

Stromatolites

A variety of stromatolitic structures were recorded from different limestone bearing formations (Kajrahat, Salkhan, Rohtas and Nagod limestones) of the Vindhyan Supergroup which were later systematically studied and summarized by Kumar (1982, 1984). Kumar (1984) recognised two stromatolite assemblage zones, viz. the *Kussiella-Colonnella* Zone and the *Conophyton-Colonnella* Zone in the Semri Group (Lower Vindhyan), and the *Baicalia-Tungussia* Zone in the Bhander Group (Upper Vindhyan). Kumar (1982, 1999a, b) suggested an Early to Middle Riphean age for the stromatolitic assemblages of Semri Group and Late Riphaen for that from the Bhander Group.

Macro-and Megafossils

The macro-and megafossil records from the Vindhyan sediments are the carbonaceous megafossils referable to the *Chuaria-Tawuia* complex and metaphytic algae. These forms were described from the Lower as well as Upper Vindhyan successions (for details Maithy & Babu, 1988; Sharma *et al.*, 1992; Venkatachala *et al.*, 1996; Kumar & Srivastava, 1997; Kumar, 2001), and are broadly indicative of the Precambrian age. Macroscopic algal filaments, referable to *Grypania*, are reported from the Rohtas Limestone from Katni area in Central Madhya Pradesh (Kumar, 1995). Seilacher *et al.* (1998) recorded trace-fossils of probable triploblastic animals from the Chorhat Sandstone (Kheinjua Subgroup). However, doubts were raised on this finding by a number of workers and considered to be syneresis cracks (Kumar, 2001). A doubtful specimen of *Spriggina*, an Ediacaran fossil, is also reported from the Pulkoa Shale (Rohtas Subgroup) by Kathal *et al.* (2000), and this finding too is considered to be questionable (Kumar, 2001).

Small shelly microfossils and brachiopods

Azmi (1998) recorded Early Cambrian small shelly microfossils (SSMs) and brachiopods from the Rohtas Limestone from the Son valley. Based on his finding, Azmi (1998) recognised the Precambrian-Cambrian boundary at the base of the Rohtas Limestone, and regarded the Kaimur, Rewa and Bhander groups as Lower Paleozoic representatives in the Vindhyan Basin. However, this finding too, has been ruled out by several workers (for details Kumar, 2001).

Geochronology

Radiometric datings of the Vindhyan sediments at different stratigraphic levels have been attempted by a number of workers. However, these datings also gave varied ages to a number of lithounits. For instance, Deonar Formation (Chopan Porcellanite) of the basal Semri Group is dated ca. 1073-920 ± 30 Ma at high temperature and ca. 617 ± 3.5 Ma at low temperature through Ar^{40}/Ar^{39} method by Banerjee and Frank (1999). This unit has also been dated as 1631 ± 5 Ma through U-Pb Zircon method by Ray *et al.* (2002). Similarly, the glauconitic sandstone of the Rampur Formation (Kheinjua Subgroup) is also variously dated as 1110 ± 60 Ma (Vinogradov *et al.*, 1964), 1080 ± 40 Ma (Kreuzer *et al.*, 1977) and 1599 ± 8 to1628 ± 5 Ma (Rasmussen *et al.*, 2002). Recently, Sarangi *et al.* (2004) dated the Rohtas Limestone as 1599 ± 48 Ma. The above absolute ages of the Rohtas Limestone is almost alike to the radiometric ages of Deonar (1631± 5 Ma; Ray *et al.*, 2002) and Rampur formations (1599 ± 8 to1628 ± 5 Ma; Rasmussen *et al.*, 2002), although, Deonar and Rampur formations lie at the lower stratigraphic levels in respect to the Rohtas Limestone.

Vinogradov *et al.* (1964) estimated the age of the Lower Kaimur 940 ± 30 Ma, and 910 ± 30 Ma for the upper Kaimur rocks; whereas, Crawford and Compston (1970) dated Kimberlite pipes of Kaimur rocks at Majhgawan as 1140 ± 12 Ma by the Rb-Sr method. But Kreuzer *et al.* (1977) revised the Vinogradov *et al.* (1964) dating of the Kaimur Sandstone as 890± 40 Ma on the basis of newly recommended decay constants (λ). Srivastava and Rajagopalan (1988, 1990) dated the Upper Rewa Sandstone and Lower Bhander Sandstone as 710-675 Ma and 625 ± 24 Ma respectively by the Fission-Track method which is suggestive of the Late Neoproterozoic age for the Rewa and Bhander groups. Crawford and Compston (1970) dated the Maihar sandstone as 550 Ma (Late Ediacaran); whereas, Friedman *et al.* (1996) and Friedman and Chakraborty (1997) suggested the Precambrian-Cambrian boundary at the base of Sirbu Shale (Magardha Limestone) in the Bhander Group on the basis of $\delta\ ^{13}C$ data.

It is apparent from the above review that the radiometric data from the Vindhyan sediments are also quite diverse, and gave varied ages to a number of lithounits which consequently suggested the age-range of the Vindhyan Supergroup from Late Paleoproterozoic to Early Paleozoic (Early Cambrian).

The records of Late Neoproterozoic herkomorph acritarchs ? *Cymatiosphaeroides kullingii* from basal parts of the Semri Group (Anabarasu, 2001), Ediacaran fossils (Kathal *et al.*, 2000) from the Pulkoa Shale (Rohtas Subgroup) and Early Cambrian small shelly microfossils (Azmi, 1998) from the Rohtas Limestone broadly indicated a Late Neoproterozoic-Terminal Proterozoic age for the Semri Group with the Precambrian-Cambrian boundary within the Rohtas Limestone. On the other hand, the absolute ages of the Deonar, Rampur and Rohtas formations of the same group (Semri Group) as old as ca.1635 Ma (Late Paleoproterozoic) are very perplexing. Adding to the above controversy, the Fission-Track method gave a Late Neoproterozoic (ca. 700-600 Ma) age to the Rewa and Bhander groups (Srivatava & Rajagopalan, 1988, 1990), whereas stable $\delta\ ^{13}C$ isotope excursion values suggested the Precambrian-Cambrian boundary within the Bhander Group (Friedman & Chakraborty, 1997) in the uppermost part of the upper Vindhyan succession.

A perusal of the above fossils and radiometric age data indicates that there were no conclusive evidences to ascertain

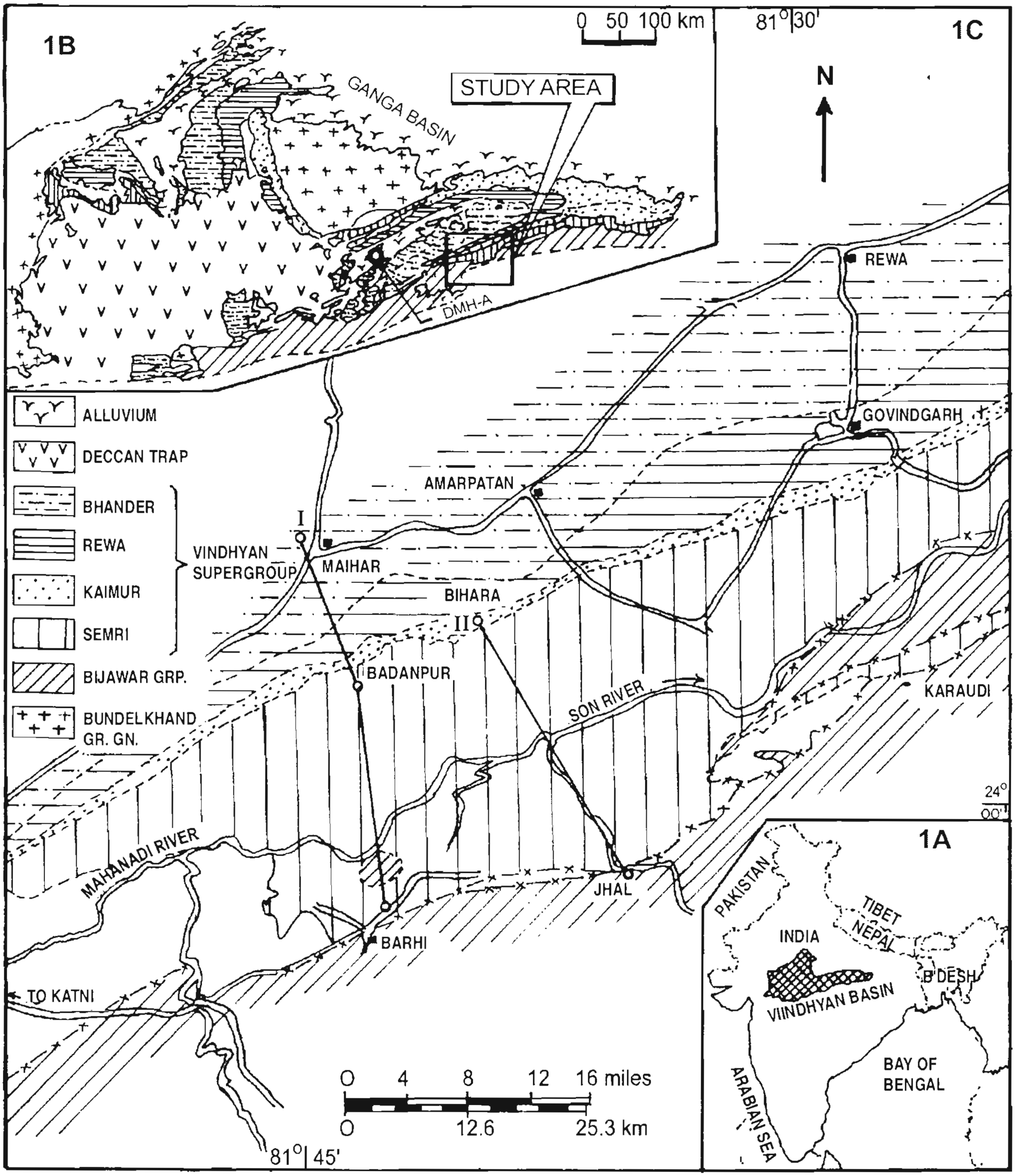

Fig. 1—A, B & C. 1A). Index map of India, showing the setting of the Vindhyan Basin. 1B). Outline map of the Vindhyan Basin (*after* Ahmad, 1962), showing studied outcrop area (in box), and location of the DMH-A well. 1C). Detailed geological map of western Son Valley, northern Madhya Pradesh (*after* Dutta *et al.*, 1998), showing different Vindhyan formations and studied sections of the Barhi-Badanpur-Maihar (section-I) and the Jhal-Bihara (section-II).

the authentic age of the Vindhyan Supergroup, and new findings further adding to its age controversies. It appears that the diverse ages were given to this unique Proterozoic sedimentary succession because a number of studies were limited to particular or some lithounits, and the complete Vindhyan succession was not taken into account in many studies, and the evidences were not interpreted with respect to its distinctive sedimentary history.

To overcome the above age controversies, a detailed organic-walled microfossils study has been made on the Vindhyan sediments of Madhya Pradesh in outcrops as well as subsurface sections, covering almost the complete Vindhyan succession. A number of samples recorded abundant and well-preserved organic-walled microfossils including some age potential Meso-and Neoproterozoic taxa that provided a more authentic age for the different lithounits of Vindhyan Supergroup as well as to the complete succession. In the present work, a detailed account of organic-walled microfossil assemblages, recovered from different lithounits of this succession, is presented with discussion on their age and the total age-range of the Vindhyan Supergroup.

GEOLOGICAL SETTING

The Vindhyan Basin is a large arcuate intracratonic Proterozoic basin developed in the Central India, covering parts of eastern Rajasthan, Madhya Pradesh, southern Uttar Pradesh and western Bihar (Figs 1A, 1B). The southern margin of the basin is bounded by the Son-Narmada Lineament Zone; whereas the northern margin is marked by the southern limits of the Ganga Basin (Fig. 1B). Biswas *et al.* (1993) considered that the Vindhyan Basin was an Interior Sag basin formed by the localised simple sagging of the continental crust. However, Ram *et al.* (1996) are of the opinion that it is a pericratonic basin having pre-rift, syn-rift and post-rift phases of development. Detailed accounts on the geology of Vindhyan Basin are available by the classic works of Mallet (1869), Heron (1932) and Auden (1933). Later on, Prasad (1976, 1984), Sastri and Moitra (1984) and Ram *et al.* (1996) have added further data on the geology, structure and sedimentary history of the Vindhyan Basin.

The entire sedimentary succession (approx. 4500 m thick) of the Vindhyan Basin is classed as the Vindhyan Supergroup. It is characterised by two distinct shallow marine depositional facies, and accordingly subdivided into two, viz. Lower and Upper Vindhyan successions which are separated by a major regional unconformity (Fig. 2A). A number of lithostratigraphic classifications were attempted on the Vindhyan Supergroup by many stratigraphers. However, Auden's (1933) classification is widely accepted. This classification was modified later by Sastri and Moitra (1984) considering the latest Code of Stratigraphic Nomenclature, which is followed in the present work. The entire Vindhyan succession is divided into four groups, viz. Semri, Kaimur, Rewa and Bhander (Auden, 1933; Sastri & Moitra, 1984). The Semri Group represents the Lower Vindhyan succession, whereas the Kaimur, Rewa and Bhander groups characterise the Upper Vindhyan succession (Fig. 2A). Sastri and Moitra (1984) further subdivided the Semri Group of the Son valley into four subgroups. The lowermost is the Mirzapur Subgroup which includes the Deoland (Basal Conglomerate) and Arangi formations, and the Kajrahat Limestone. The porcellanite succession that rests over the Mirzapur Subgroup is named the Deonar Formation. The Kheinjua Subgroup overlies the Deonar Formation and comprises the Koldaha Shale, Salkhan Limestone and Rampur Formation. The youngest succession of the Semri Group includes the Rohtas Limestone and Bhagwar Shale and comprises the Rohtas Subgroup. The Kaimur, Rewa and Bhander groups of the Upper Vindhyan succession are also subdivided into a number of lithounits as shown in Fig. 2A.

MATERIAL AND METHODS

Outcrop samples for microfossil studies were collected in two sections from the Maihar-Govindhgarh area of western Son Valley in northern Madhya Pradesh (Figs 1B, 1C), viz. the Barhi-Badanpur-Maihar section and the Jhal-Bihara section (Fig. 1C). Dutta *et al.* (1998) and the first author (B.P.) made detailed geological studies in these sections and collected the samples. The stratigraphic position of the studied samples is shown in the lithocolumn of the respective sections (Figs 2B, 2C). The Vindhyan succession of DMH -A well (surface to 3500 m drilled depth), recently drilled in the Vindhyan Basin near Damoh town in Madhya Pradesh (Fig. 1B), and representing an almost complete Vindhyan succession (Fig. 4), has also been studied for organic-walled microfossils to suppliment the outcrop microfossil data. The organic-walled microfossils were isolated by acid maceration technique, applying the simple Schulz's method, and palynomorphs were separated by the heavy liquid method.

MICROFOSSIL ASSEMBLAGES AND BIOSTRATIGRAPHY

The organic-walled microfossils from Vindhyan sediments include acritarchs, coccoids (synaplomorphs) as well as filamentous (nematomorphs) forms and vase-shaped microfossils (*Melanocyrillium*). An account of the microfossil assemblages, recovered from different lithounits of Vindhyan Supergroup, is outlined below with discussion on their age. The stratigraphic distribution of selected organic-walled microfossils in the Vindhyan Supergroup, in outcrops as well as subsurface, is presented through frequency distributions (Figs 3, 4), and the distinguishing microfossils of each lithounit is shown in Fig. 5.

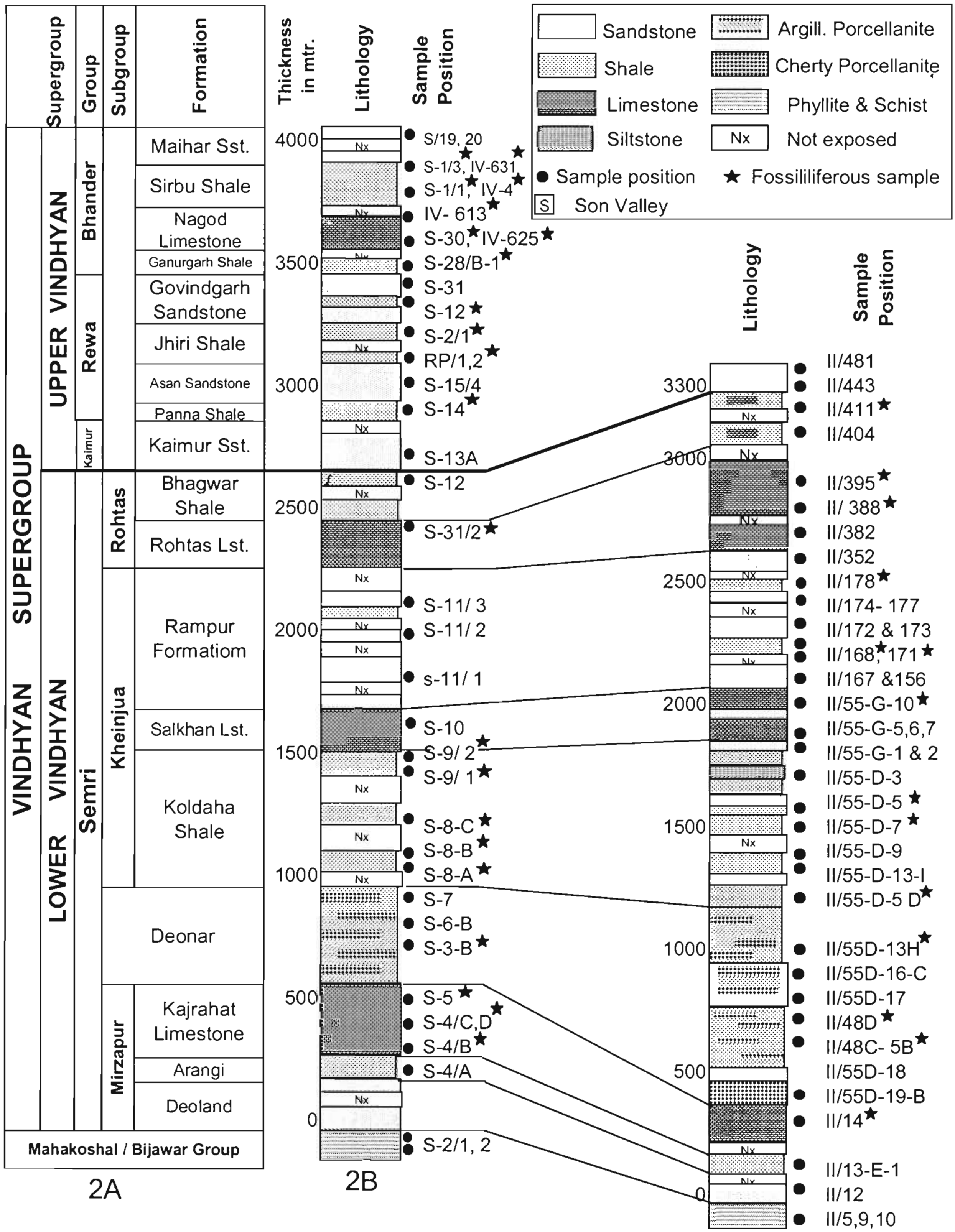

Fig. 2—A, B & C. 2A). Generalised stratigraphic succession of theVindhyan Supergroup in western Son Valley, northern Madhya Pradesh (*after* Sastri and Moitra, 1984). 2B, C). Generalised lithological succession of Vindhyan sediments in the Maihar-Govindgarh area (*after* Dutta *et al.*, 1998), showing stratigraphic position of studied samples; 2B. Barhi-Badanpur-Maihar Section, 2C. Jhal-Bihara section.

Semri Group (Lower Vindhyan)

Kajrahat Limestone

The limestone and the associated thin shale partings of the Kajrahat Limestone from the Barhi-Badanpur-Maihar (S-4/B, S-4/D; S-5) and the Jhal-Bihara (II/14) sections (Figs 2B, 2C), and the depth intervals from 3500-3147 m in DMH-A well (Fig. 4) representing the Kajrahat Limestone, yielded abundant filamentous microfossils along with frequent occurrence of simple unornamented sphaeromorph acritarchs (Pl. 1.1-14). The filamentous forms include *Polythrichoides lineatus, Karamia segmentata, Tortunema pseudoseptata, Arctacellularia ellipsoidea, Oscillatoriopsis psilata* and *Siphonophycus* spp. (*S. septatum, S. robustum, S. rugosum, S. kestron*), along with a large number of dark opaque filamentous sheaths (Pl. 1. 6-14). *Kildinosphaera chagrinata, Leiosphaeridia asperata, L. tenuissima, L. crassa* and *L. minutissima* represent the unornamented sphaeromorph acritarchs (Pl. 1 1-5).

The Kajrahat assemblage by and large compares with the Early Mesoproterozoic microfossil assemblages of Buryan Formation, Southern Urals (Jankauskas, 1982) and Billyakh Group (Anabar Uplift), northern Siberia (Golovenok & Belova, 1984; Yakshin, 1991; Sergeev *et al.*, 1995) which are roughly estimated as 1600-1300 Ma. Acritarch assemblages from the above two formations of the Russian Platform and the Kajrahat Limestone are of low diversity, and represented by simple unornamented sphaeromorph acritarchs (*Leiosphaeridia* spp. and *Kildinosphaera chagrinata*) only, and are associated with abundant filamentous microfossils. The Kajrahat assemblage also broadly compares with the microfossil assemblage of the Late Paleoproterozoic (ca. 1800 Ma) Chuanlingguo Formation of northern China (Zhang, 1986; Hofmann & Chen, 1981), as simple unornamented sphaeromorph acritarchs and filamentous forms are common in both the assemblages. However, the Kajrahat assemblage shows Early Mesoproterozoic features as it also includes abundant coccoid and filamentous microfossils (Venkatachala *et al.*, 1990) and Lower to Middle Riphean stromatolites (Misra *et al.*, 1977; Kumar, 1976). Venkatachala *et al.* (1990) recorded a rich assemblage of coccoid and filamentous microfossils from the Kajrahat Limestone of Rohtasgarh area (Bihar) which is mainly represented by the various species of *Eoentophysalis, Sphaerophycus, Tetraphycus, Eosynechococcus, Myxococcoides, Diplococcus, Glenobotrydion, Siphonophycus, Eomycetopsis, Paleoanacystis* and *Biocatenoides*. Although, Venkatachala *et al.* (1990) suggested a Middle to Late Mesoproterozoic (ca.1400-1000 Ma) age to this assemblage, it shows close resemblence with the Early Mesoproterozoic (ca.1500 Ma) microfossil assemblage of the Balbirini Dolomite (McArthur Group) of northern Australia, described by Oehler (1978). The radiometric age of the Balbirini Dolomite is estimated to be approximately 1500 Ma (Oehler, 1978) which is overlain by the Roper Group having a well constrained absolute age of 1492-1429Ma (Kralik, 1982; Jackson *et al.*, 1999). The microfossil assemblage of the Jalboi and Corcoran formations (Early Mesoproterozoic; ca. 1450-1429 Ma) of the Roper Group, northern Australia (Peat *et al.*, 1978; Javaux *et al.*, 2001) also broadly correlates with the Kajrahat assemblage, as abundant filamentous forms and leiosphaerids are common in both the assemblages. However, the Kajrahat assemblage lacks the presence of much developed forms, such as *Tappania, Valeria, Dictyosphaera* and *Satka*, which are present in the Jalboi-Corcoran assemblage of the Roper Group (Javaux *et al.*, 2001) and appears little older than the Jalboi and Corcoran assemblages. It is worth mentioning that the Kajrahat Limestone is overlain by the Deonar Formation in the Vindhyan Basin which also contains a microfossil assemblage showing the first appearance of the characteristic acanthomorph acritarch *Tappania*, along with *Satka* and *Eomicrocystis*, and is comparable with the Jalboi-Corcoran microfossil assemblage of the Roper Group that has been dated at 1450-1429 Ma (Kralik, 1982; Jackson *et al.*, 1999).

It appears that the Kajrahat assemblage is little older than the Jalboi-Corcoran assemblage, and represents an Early Mesoproterozoic (Late Calymmian; ca.1500-1450 Ma) microfossil assemblage in the Vindhyan Basin. Knoll (1996) also opined that Early Mesoproterozoic (1600-1400 Ma) sediments are characterised by low diversity acritarchs, mainly represented by simple unornamented leiosphaerids along with small leiosphaerids (*Eomicrocystis, Synsphaeridium*) and cyanophycean filamentous sheaths, as is the case with the microfossil assemblage of the Kajrahat Limestone.

Deonar Formation

This formation represents a very conspicuous lithology in the Lower Vindhyan succession (Semri Group) and is characterised by a porcellanite succession having silicified tuffs, cherts and porcellanised silicified shale. Three samples from the Jhal-Bihara section (II/48C-5B, II/48D, II/55D-13H) and one (S-3B) from the Barhi-Badanpur-Maihar section (Figs 2B, 2C) and the porcellanite succession of DMH-A well from 3147-1930 m depth intervals (Fig. 4) yielded moderate but significant organic-walled microfossils (Pl. 2 1-17).

Simple unornamented sphaeromorph acritarchs are the main constituents of the Deonar assemblage which include *Leiosphaeridia asperata, L. ternata, L. minutissima, L. tenuissima, Kildinosphara chagrinata, K. granulata* and *Dictyosphaera* sp. (Pl. 2 10-11, 14-16). Forms, such as *Eomicrocystis elegans, E. malgica, Synsphaeridium sorediforme, Symplassosphaeridium tumidulum* and *Satka* sp. cf. *S. squamifera* represent the coccoid microfossils, and show their first appearance here. Filamentous forms, viz. *Siphonophycus* spp., *Karamia segmentata, Polythrichoides* *lineatus, Tortunema pseudoseptata* and *Oscillatoriopsis psilata* that occur in the Kajrahat Limestone, also persist in this formation. However, the most distinctive feature of Deonar assemblage is the appearance of acanthomorph acritarchs, viz. *Tappania* spp. (*T. plana* & *T. tubata*) in rarity (Pl. 2 5-6), and several polygonomorph acritarchs attributable to *Octoedryxium* (Rudavskaia) Vidal (Pl. 2 1-4) which are referred to as a new species of *Octoedryxium*, viz. *O. vindhyanense*.

Except for the record of polygonomorphic acritarchs (*Octoedryxium vindhyanense*), the Deonar microfossil assemblage resembles the Early Mesoproterozoic assemblages recorded from the Jalboi, Corcoran and McMinn formations (Peat *et al.*, 1978; Javaux *et al.*, 2001) of the Roper Group (northern Australia), which have been dated ca.1450-1429 Ma by SHRIMP and Rb-Sr methods (Kralik, 1982; Jackson *et al.*, 1999). Species of *Tappania* and *Satka*, unornamented sphaeromorph acritarchs (*Leiosphaeridia* spp., *Kildinosphaera* spp.) and filament (*Siphonophycus* spp.) as well as coccoid forms (*Synsphaeridium* spp., *Eomicrocystis* spp.) are common in both the assemblages. The appearance of *Tappania* in the Deonar Formation, though in rarity, is very significant. *Tappania* is an acanthomorph acritarch with the oldest record from the Early Mesoproterozoic Jalboi Formation (ca. 1450 Ma) of the Roper Group in northern Australia (Javaux *et al.*, 2001). The Jalboi Formation is about 400 m above the stratigraphic level of Mainoru Formation that has been radiometrically constrained approximately 1492 ± 4 Ma (Jackson *et al.*, 1999), and about 700m down below the stratigraphic level of McMinn Formation which is dated ca. 1429 ± 31Ma (Kralik, 1982). The absolute ages of the above two horizons suggest the depositional age of the Jalboi and Corcoran formations of the Roper Group to ca.1450 Ma. Thus, the appearance of acanthomorph acritarchs, viz. *Tappania plana* and *T. tubata*, coccoid forms *Satka* sp. cf. *S. squamifera* and *Eomicrocystis* spp., with associated occurrence of smooth sphaeromorph acritarchs and abundant filamentous microfossils suggests an age similar to the Jalboi and Corcoran formations of the Roper Group for the Deonar Formation. This assemblage also resembles the late Early Mesoproterozoic (ca.1400 Ma) Chamberlain Shale (lower Belt Supergroup) assemblage of Montana, U.S.A. (Horodyski, 1980) and the Dismal Lakes Group, Arctic Canada (Horodyski and Donaldson, 1980, 1983) as abundant unornamented sphaeromorph acritarchs (*Kildinosphaera* spp. & *Leiosphaeridia* spp.), filamentous (*Siphonophycus* spp.) and coccoid (*Satka* spp.) forms are common in both the assemblages.

The occurrence of polygonomorph acritarchs (*Octoedryxium*) in Deonar Formation is perplexing. Its oldest record is from the Late Neoproterozoic Upper Visingsö Beds of Sweden (Vidal, 1976a). The occurrence of polygonomorph acritarchs in this lithounit extend the age of Deonar assemblage to a little younger than the Roper Group assemblage. But, in any case, this assemblage appears undoubtebly older than the Middle to Late Mesoproterozoic *Tappania* dominated assemblages of Ruyang Group (ca. 1256-1140 Ma) of Eastern China (Yin, 1997; Yin & Yuan, 2002) and the Bahraich Group (ca. 1350-1150 Ma) of Northern India (Prasad & Asher, 2001), as *Tappania* is rarely represented in this assemblage and it is also succeeded by a *Tappania* dominated assemblage corresponding to the Koldaha Shale.

It is inferred that the Deonar Formation represents a late Early Mesoproterozoic to Middle Mesoproterozoic (Late Calymmian-Early Ectasian; ca.1450-1350 Ma) organic-walled microfossil assemblage in the Vindhyan Basin. This age inference is corroborated by the fact that the Deonar assemblage is immediately succeeded by the *Tappania* dominated microfossil assemblage of the Koldaha Shale in the Vindhyan Basin which is well correlatable with the Middle to Late Mesoproterozoic (ca. 1350-1150 Ma) microfossil assemblages of the Ruyang Group (eastern China) and the Bahraich Group (Ganga Basin, India) due to the dominant occurrence of *Tappania* in these assemblages.

Recently, the absolute age dating of the Deonar Formation is estimated as 1631 ± 5 Ma (Late Paleoproterozoic) by the U-Pb zircon method (Ray *et al.*, 2002). If this dating is taken into account, then the taxa, such as *Tappania* (acanthomorphs), *Octoedryxium* (polygonomorhs), *Dictyosphaera* and *Satka*, representing a well-developed and diversified acritarch assemblage, seem appeared during the Late Paleoproterozoic (1631 ± 5 Ma). But, the well-developed acritarch assemblages having acanthomorph and microsculptured sphaeromorph acritarchs are known from the later part of Early Mesoproterozoic and younger Proterozoic sequences only (for details Knoll, 1996). So, the recent absolute dating of the Deonar Formation as 1631 ± 5 Ma needs reconsideration in view of the present record of a well-developed and rich late Early Mesoproterozoic to Middle Mesoproterozoic (ca. 1450-1350 Ma) microfossil assemblage from this formation.

Koldaha Shale

This formation represents the lowermost lithounit in the Kheinjua Subgroup and comprises a thick succession of grey to olive green shale, and unconformably overlies the Deonar Formation. It is about 500 m thick in the outcrop areas, but thicker (approx. 800 m) in the subsurface. Four samples (S-8A, B, C; S-9) from the Barhi-Badanpur-Maihar section (Fig. 2B) and three (II/55D-5D, D-7; D-5) from the Jhal-Bihara section (Fig. 2C), and the Koldaha Shale succession from 1930-940 m depth intervals in the DMH-A well (Fig. 4) contain a rich and diversified assemblage of organic-walled microfossils (Pl. 3.1-16; Pl. 4.1-18).

The abundant occurrence of acanthomorph acritarchs, viz. *Tappania plana*, *T. tubata* and *T. gangaei* (Pl. 3.1-5); netromorph acritarchs, such as *Navifusa segmentata*, *N. majensis* and *N. granulatus* (Pl. 3.6, 10) and filamentous forms, viz. *Arctacellularia ellipsoidea* and *A. tetragonala* (Pl. 3.11-12) are the most distinctive features of the Koldaha Shale assemblage. The above enlisted species of *Navifusa* make their first appearance in this formation along with *Tappania gangaei*; whereas, *Tappania plana*, *T. tubata*, *Arctacellularia tetragonala* and *A. ellipsoidea* persist from the underlying Deonar Formation. In addition, taxa such as *Pterospermopsimorpha insolita*, *P. saccata*, *Simia annulare* (Pl. 3.7-9) and *Lophosphaeridium granulatum* (Pl. 4.18) also appear in this formation (Figs 3, 4, 5). Besides, abundant simple sphaeromorph acritarchs, represented by various species of *Leiosphaeridia* (*L. asperata*, *L. jacutica*, *L. crassa*, *L. tenuissima*) and *Kildinosphaera* (*K. chagrinata*, *K. granulata*) persist from the Deonar Formation.

Coccoid forms, such as *Eomicrocystis malgica*, *E. elegans*, *Satka colonialica*, *S. squamifera*, *Synsphaeridium sorediforme* and *Symplassosphaeridium tumidulum* (Pl. 4.5-6, 8-13, 15) continued to occur here from the underlying Deonar Formation with increased frequency. However, other coccoid forms, such as *Eohyella dichotoma*, *Eosynechococcus moorei*, *Tetraphycus diminutivus*, *A. acinulus*, *Eoentophysalis* sp., *Sphaerophycus parvum* and *Spumosina rubiginosa* (Pl. 4.1-4, 7) also make their appearance here, and form an important constituent of the assemblage. Filamentous microfossils, viz. *Siphonophycus* spp. and *Oscillatoriopsis* spp. are also very common in this assemblage and persist from the underlying Deonar Formation (Figs 3, 4).

The Koldaha Shale assemblage closely resembles Middle to Late Mesoproterozoic microfossil assemblages of Ruyang Group (ca. 1256-1140 Ma), southern Shanxi, Eastern China (Yin, 1997; Yin & Yuan, 2002) and Bahraich Group (ca. 1350-1150 Ma), Northern India (Prasad & Asher, 2001) as the various species of *Tappania* occur abundantly in the above three assemblages. The above three assemblages are also associated with the occurrence of *Navifusa* spp. and *Arctacellularia* spp. along with a large number of unornamented sphaeromorph acritarchs and filamentous as well as coccoid microfossils. The record of acanthomorph acritarchs *Tappania* spp. (*T. plana*, *T. tubata*, *T. gangaei*), netromorph acritarchs *Navifusa* spp. (*N. segmentata*, *N. majensis*) and filamentous form *Arctacellularia* spp. (*A. tetragonala*, *A. ellipsoidea)* is very significant in dating the Koldaha Shale assemblage. *Tappania* was first recorded in abundance from the Baicaoping and Beidajian formations of the Ruyang Group, Shanxi Province (eastern China) and forms an important constituent of the Ruyang Group assemblage (Yin, 1997; Yin & Yuan, 2002). The age of the Beidajian Formation was determined by K-Ar method as 1256-1140 Ma (Ma *et al.*, 1980; Guan *et al.*, 1988). Later, Yin and Yuan (2002) recorded *Navifusa segmentata* and *A. tetragonala* from the Ruyang Group and regarded them as important constituents of the Ruyang assemblage. Based on the microfossil data and radiometric dates, the Ruyang microfossil assemblage was assigned to the Middle to Late Mesoproterozoic (1256-1140 Ma) age (Yin, 1997; Yin & Yuan, 2002). Prasad and Asher (2001) also recorded a rich acritarch assemblage, quite similar to the Ruyang assemblage, from the subsurface metasedimentary succession (Bahraich Group) of the Ganga Basin in Northern India which is also dominated by *Tappania plana*, *T. tubata*, *Navifusa segmentata*, *N. granulata* and *Arctacellularia tetragonala*. Prasad and Asher (2001) assigned a Late Ectasian-Early Stenian (ca.1350-1150 Ma) age of Middle to Late Mesoproterozoic to the *Tappania*-dominated Bahraich assemblage, as the radiometric dating of igneous intrusives in the Bahraich Group gave the absolute age of 1320 ± 30 Ma (Chug *et al.*, 1989) and its assemblage was equated with Ruyang Group assemblage.

The Koldaha Shale assemblage also compares with the Middle to Late Mesoproterozoic microfossil assemblages of the Eqalulik and Uluksan groups of the Bylot Supergroup (Hofmann & Jackson 1991, 1994) and the Baffin Bay Group of the Thule Supergroup (Hofmann & Jackson, 1996; Samuelsson *et al.*, 1999) in having abundant sphaeromorph and netromorph acritarchs, with associated filamentous and coccoid forms. The diabase in the basal unit of the Thule Supergroup (Wolstenholme Formation) provided an isochron age of ca. 1268 Ma (LeCheminant & Heaman, 1991), whereas Knight and Jackson (1994) suggested the age of the Bylot Supergroup to be the 1270-1190 Ma.

Thus, the close comparable relationship of Koldaha Shale assemblage with the known Middle to Late Mesoproterozoic organic-walled microfossil assemblages suggests that the Koldaha Shale belongs to the Middle to Late Mesoproterozoic (ca. 1350-1150 Ma) age.

Salkhan Limestone

One sample (II/ 55G/10) from the Jhal-Bihara section (Fig. 2C), and from the 940-780 m depth interval in the DMH-A well (Fig. 4) recorded moderate occurrence of organic-walled microfossils in the Salkhan Limestone (Pl. 5.1-19). Unornamented sphaeromorph acritarchs are the main constituents of the assemblage and represented by the various species of *Kildinosphaera* and *Leiosphaeridia*. Important forms of the underlying Koldaha Shale, viz. *Tappania plana*, *T. tubata*, *Navifusa majensis*, *N. segmentata*, *Pterospermopsimorpha saccata*, *Simia annulare*, *Satka squamifera*, *Eomicrocystis* spp., *Sphaerophycus parvum*, *Eoentophysalis* sp. cf. *E. belcherensis*, *Tetraphycus gregalis*

→

Fig. 3—Stratigraphic distribution of selected Meso-Neoproterozoic organic-walled microfossils in outcropping Vindhyan sediments of western Son Valley, northern Madhya Pradesh.


VINDHYAN SUPERGROUP
LOWER VINDHYAN (SEMRI)
UPPER VINDHYAN
SUPERGROUP
MIRZA-PUR
KHEINJUA
ROHTAS
KAIMUR
REWA
BHANDER
GROUP/SUBGROUP
FORMATION
Microfossils
MAHAKOSHAL / BIJAWAR GROUP
DEOLAND
KAJRAHAT LST.
DEONAR
KOLDAHA SHALE
SALKHAN LST.
RAMPUR
ROHTAS LST.
BHAGAWAR SHALE
DOMARKHOKA QRTZ
BIJAIGARH SHALE
SONAM SST.
PANNA SHALE
ASAN SST.
JHIRI SHALE
GIVINDGARH SST.
GANURGARH SHALE
NAGOD LST
SIRBU SHALE
MAIHAR SST
Leiosphaeridia spp.
Kildinosphaera spp.
Siphonophycus spp.
Polythrichoides lineatus / Karamia spp.
Arctacellularia tetragonala / ellipsoidea
Synsphaeridium sorediforme
Symplassosphaeridium tumidulum
Eomicrocystis elegans / E. malgica
Satkaa colonialica / S. squamifera
Octoedryxium vindhyanense sp. nov.
Tappania plana
Tappania tubata / T. gangaei
Navifusa segmentata / N. majensis
Simia annulare
Pterospermopsimorpha insolita
Eosynechococcus spp./ Tetraphycus spp.
Trachysphaeridium laminaritum
Stictosphaeridium sinapticulum
Leiosphaeridia kulgunica
Trachysphaeridium laufeldi
Budding Leiosphaerids / Melanocyrillium sp.
Trachyhystrichosphaera truncata
Bavlinella faveolata
Vandalosphaeridium reticulatum
Stictosphaeridium sinapticulum
Octoedryxium truncatum
Germinosphaera unispinosa / G. bispinosa
Obruchevella valdaica / O. parva
Lophosphaeridium rarum/ L. truncatum
Cymatiosphaera sp.
Obruchevella delicata
Obruchevella parvissima
Dictyotidium sp.
Cristallinium sp. cf. C. cambriense
Polythichoides - Karamia - Leiosphaeridia spp. Assemblage
Leiosphaeridia spp.- Tappania spp.- Octoedryxium vindhyanense - Satka spp. Asmblg.
Tappania - Navifusa - Satka - Eomicrocystis Assemblage
Tappania - Navifusa - Satka Eomicrocystis Assemblage
Satka - Budding leiosphaerids - Melanocyrillium - Tappania - Navifusa Assemblage
Trachysphaeridium - Satka - Bavlinella Assemblage
Stictosphaeridium - Leiosphaeridia Assemblage
Symplassosphaeridium - Synsphaeridium - Bavlinella - O. truncatum Asmblg.
Synsphaeridium - Leiosphaeridia - Symplassosphaeridium - Bavlinella - Lophosphaeridium Asmblg.
Obruchevella - Germinosphaera - Vandalosphaeridium - Bavlinella -
Obruchevella spp. - Cristallinium sp. - Dictyotidium sp. Asmblg.
organic-walled microfossil assemblages / associations
LATE PALEOPROTEROZOIC (ca 1800-1600 Ma)
Late Calymmian (ca 1550-1500 Ma (ca.1500-1450 Ma)
Lt. Calymmian - Early Ectasian (ca 1450-1350 Ma)
Late Ectasian - Early Stenian (ca 1350-1150 Ma)
Late Stenian (ca 1150-1050 Ma)
Lt. Stenian - Tonian (ca.1050-850 Ma)
Early Cryogenian (ca. 850-750 Ma)
Middle to Late Cryogenian (ca. 750-700 Ma)
Late Cryogenian (ca. 700-650 Ma)
Lt. Cryogenian - Early Ediacaran (ca. 650-560 Ma)
Late Ediacaran (ca. 560-544 Ma)
? Late Ediacaran
PERIOD
AGE
MESOPROTEROZOIC
1000 Ma
NEOPROTEROZOIC
600 Ma
TERMINAL PROTEROZ.
ERA
Rare
Common
Subdominant
Dominant

and *T. dichotoma* persist here (Pl. 5.1-19); whereas *Leiosphaeridea kulgunica* (Pl. 5.14-15) and *Stictosphaeridium sinapticulum* (Pl. 5.13) appear in this formation. *Siphonophycus septatum, S. rugosum* and *Oscillatoriopsis psilata* represent the filamentous forms (Figs 3, 4, 5).

Kumar and Srivastava (1995) also recorded a large number of coccoid and filamentous microfossils from this unit in Son Valley; these are represented by different species of *Myxococcoides, Eosynechococcus, Eoentophysalis, Sphaerophycus, Oscillatoriopsis Tetraphycus, Palaeolyngbya* and *Siphonophycus*, along with *Trachysphaeridium* sp. and *Leiosphaeridia jacutica*.

The palynofossil assemblage of the Salkhan Limestone is very similar to that from the underlying Koldaha Shale, except that there are fewer individual taxa. It is also represented by the age markers *Tappania plana, T. tubata Navifusa segmentata*, and suggestive of a Middle to Late Mesoproterozoic age, similar to the Koldaha shale. However, the appearance of *Leiosphaeridia kulgunica* (Pl. 5.14, 19), *Stictosphaeridium sinapticulum* (Pl. 5.13) and *S. implexum* which, till now, are recorded from Late Mesoproterozoic and younger sediments, suggest a little younger age to this assemblage than the Koldaha Shale. It appears that the Salkhan Limestone represents a Late Mesoproterozoic (Late Stenian; 1150-1050 Ma) assemblage in the Vindhyan Basin, as *Tappania* spp. and *Navifusa* spp. are the common constituents of the Salkhan microfossil assemblage. This inference is corroborated by the fact that the Salkhan Limestone is immediately overlain by the Rampur Formation which has yielded a well-developed and diversified microfossil assemblage of latest Mesoproterozoic-Early Neoproterozoic (1050-850 Ma) age.

Rampur Formation

This formation includes glauconitic sandstone succession with intercalated siltstones and shales. Three shale samples (II/168, II/171, II/178) from the Jhal-Bihara section (Fig. 2C) and the depth intervals between 780-620 m in DMH-A (Fig. 4), representing this formation, yielded a well-preserved and diversified organic-walled microfossil assemblage (Pl. 6.1-13; Pl. 7.1-19).

The microfossil assemblage of the Rampur Formation is broadly similar to that of the Koldaha Shale and the Salkhan Limestone. However, the species of *Satka* (*S. colonialica* and *S. squamifera*) and *Navifusa* (*N. segmentata, N. majensis, N. granulata*) dominate quantitatively over the acanthomorph (*Tappania* spp.), sphaeromorph (*Kildinosphaera* spp., *Leiosphaeridia* spp.) and pterosprmorph (*Pterospermopsimorpha* spp., *Simia* spp.) acritarchs. Several coccoid forms, such as *Eomicrocystis* spp., *Sphaerophycus parvum, Tetraphycus acinulus, Eoentophysalis* sp. cf. *E. belcherensis, Symplassosphaeridium* spp., *Synsphaeridium* spp., and filamentous forms, viz. *Siphonophycus* spp. and *Oscillatoriopsis* spp. persist here from the underlying Koldaha Shale and Salkhan Limestone with almost the same frequency. However, the age potential taxa, such as *Tappania plana* (Pl. 6 11), *T. tubata* (Pl. 6.12-13), *Navifusa segmentata* (Pl. 7.10, 16) and *Arctacellularia tetragonala* (Pl. 7.15), which were abundant in underlying Koldaha Shale and Salkhan Limestone, become rare in this assemblage, and completely disappear in the upper part of this formation (Figs 3, 4).

The most important feature of the Rampur assemblage is the appearance of other acanthomorph acritarchs, viz. *Vandalosphaeridium reticulatum* (Pl. 6.5-6), *V. varangeri* (Pl. 6.7) and *Trachyhystrichosphaera truncata* (Pl. 6.3), coccoid forms, viz. *Bavlinella faveolata*, ornamented sphaeromorph acritarchs, *viz. Kildinosphaera verrucata* (Pl. 7.19) and *Trachysphaeridium laminaritum* (Pl. 6.1), and filamentous microfossils, viz. *Chlorogloeaopsis kanshiensis* and *C. contexta* (Pl. 7. 7, 9). In addition, a large number of budding leiosphaerids (Pl. 7.2-3, 5) and vase-shaped microfossils assignable to *Melanocyrillium* Bloeser, 1985 (Pl. 6.8-10) also make their appearance within this formation, and all the above newly appearing taxa form an important constituent of the Rampur assemblage (Figs 3, 4).

The presence of various species of *Tappania* (*T. plana, T. tubata*), *Navifusa* (*N. segmentata, N. majensis*) and *Arctacellularia* (*A. tetragonala, A. ellipsoidea*), though in rarity, largely allow the comparison of Rampur assemblage with Late Mesoproterozoic microfossil assemblages, as discussed above. Nevertheless, this assemblage also includes several taxa, such as *Vandalosphaeridium* spp., *Trachyhystrichosphaera truncata, Bavlinella faveolata*, ornamented sphaeromorph acritarchs (*K. verrucata, T. laminaritum*), budding leiosphaerids and *Melanocyrillium* that generally appear in Early Neoproterozoic or near the Meso-Neoproterozoic boundary (Knoll, 1996, 2000). Indeed, the microfossil assemblage of Rampur Formation shows more akinness to Early Neoproterozoic assemblages and resembles the Lakhanda (ca. 1000-900 Ma) assemblage of Siberia (Jankauskas, 1989; German, 1990). Forms, such as, *Navifusa majensis, N. bacillaris, Pterospermopsimorpha insolita, Leiosphaeridia* spp., *Arctacellularia tetragonala, Chlorogloeaopsis* spp., *Satka* spp., *Eomicrocystis* spp., *Synsphaeridium* spp., *Symplassosphaeridium* spp., *Siphonophycus* spp. and budding leiosphaerids are common in both the assemblages. The present assemblage also compares with the latest Mesoproterozoic-Early Neoproterozoic (ca. 1050-940 Ma) microfossil assemblage of the Bushimay Group (Zaire) from central Africa (Maithy, 1975), as the species of *Siphonophycus, Arctacellularia, Pterospermopsimorpha, Chlorogloeaopsis, Navifusa, Leiosphaeridia* and *Kildinosphaera* are common in both the assemblages. The microfossil assemblage from Rampur Formation and one that from the Early Neoproterozoic (900-800 Ma) Veteranen Group, Spitsbergen (Knoll & Swett, 1985) are also quite similar and broadly correlatable to each others as majority of the forms are common in both the assemblages,

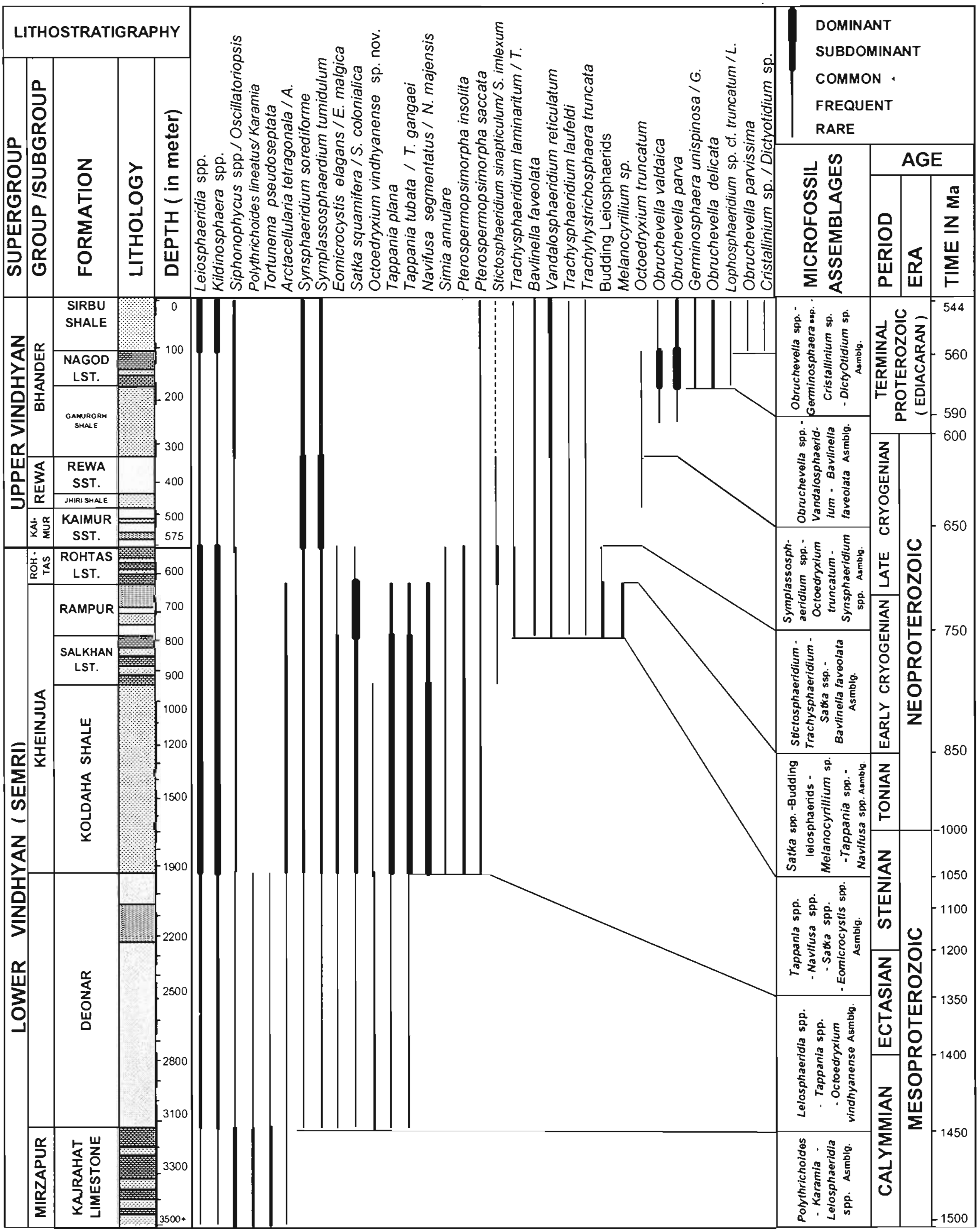

Fig. 4—Stratigraphic distribution of selected Meso-Neoproterozoic organic-walled microfossils in Vindhyan sediments of the DMH-A well, central Madhya Pradesh.

except the species of *Tappania* and *Navifusa* which are absent in the Veteranen Group.

Thus, the appearance of ornamented sphaeromorphs (*K. verrucata, T. laminaritum*), newly incoming acanthomorph acritarchs (*T. truncata* and *V. reticulatum*), vase-shaped microfossils (*Melanocyrillium*) and budding leiosphaerids that generally appear in Early Neoproterozoic (Knoll, 1996; Knoll, 2000) strongly favours for a Tonian (ca. 1000-850 Ma) age of Early Neoproterozoic to this formation. The presence of above mentioned characteristic Early Neoproterozoic taxa, in association with the rare occurrence of Late Mesoproterozoic marker taxa, viz. *Tappania* spp. and *Navifusa segmentata*, suggests that the Rampur Formation ranges in age from latest Mesoproterozoic to Early Neoproterozoic (ca. 1050-850 Ma).

The K/Ar absolute datings of Rampur Formation by Kruezer *et al.* (1977) as 1080 ± 40 Ma broadly corroborates the present age assignement of this formation on the basis of organic-walled microfossils. However, the recent dating of this lithounit as old as 1628 ± 8 Ma (Late Paleoproterozoic) by Rasmussen *et al.* (2002) needs reconsideration in view of the record of a rich and diversified organic-walled microfossil assemblage of latest Mesoproterozoic-Early Neoproterozoic age.

Rohtas Subgroup

This subgroup represents the uppermost sedimentary succession in the Semri Group and includes two formations, viz. the Rohtas Limestone and the Bhagwar Shale in the Son Valley. Two samples (II/388, II/395) from the Rohtas Limestone and one sample (II/411) from the Bhagwar Shale in the Jhal-Bihara section (Fig. 2C) and depth intervals from 620- 575m in the DMH-A well, representing Rohtas Limestone (Fig. 4), yielded moderate occurrence of organic-walled microfossils (Pl. 8.1-17).

The Rohtas assemblage is mainly represented by abundant sphaeromorph acritarchs. It includes *Leiosphaeridia tenuissima, L. asperata, Kildinopshaera granulata, K. verrucata, Trachysphaeridium laminaritum, Stictosphaeridium sinapticulum, S. implexum* and *Lophosphaeridium jansoniusii*. They occur in association with coccoid forms, viz. *Satka colonialica, S. squamifera, Synsphaeridium sorediforme* and *Symplassosphaeridium tumidulum*. Filamentous forms are also present, but in rarity, and mainly represented by various species of *Siphonophycus, Oscillatoriopsis, Karamia* and *Chlorogloeaopsis* (Pl. 8.1-17).

Important taxa of the underlying Rampur Formation, viz. *Vandalosphaeridium reticulatum, Trachysphaeridium laminaritum, Pterospermopsimorpha saccata, Bavlinella faveolata* and *Stictosphaerdium sinapticulum* persist in the Rohtas Subgroup. In addition, taxa such as *Satka* spp., *Eomicrocystis* spp., *Pterospermopsimorpha insolita, Simia annulare* and budding leiosphaerids also continue to occur in this lithounit, but disappear at different stratigraphic levels within this subgroup. On the other hand, species of *Tappnia, Navifusa* and *Arctacellularia*, which were the important constituents in the underlying Kheinjua Subgroup, are completely absent in the Rohtas Subgroup (Figs 3, 4).

The Rohtas assemblage compares with the Middle Neoproterozoic Miroyedikha acritarch assemblage (ca. 850 Ma) of Siberia (Jankauskas, 1989; German, 1990) since smooth and ornamented sphaeromorph acritarchs are abundant in both the assemblages, as are coccoid (*Satka* spp., *Symplassosphaeridium* spp., *Synsphaeridium* spp.) and filamentous forms (*Siphonophycus* spp, *Chlorogloeaopsis*). The characteristic budding leiosphaerids are also present in both assemblages. The species of *Eomicrocystis* and *Pterospermopsimorpha insolita*, which were very common in the immediately underlying assemblage of Rampur Formation and its comparable asemblages of Lakhanda and Veteranen groups, are conspicuously absent in the Rohtas as well as in the Miroyedikha assemblages. The Rohtas assemblage also resembles the Middle Neoproterozoic organic-walled microfossil assemblage of the Husar-Kanpa formations, recovered from the subsurface (Husar-1 well) in the western Officer Basin, central Australia (Hill *et al.*, 2000) as these forms are common in both the assemblages. The species of *Satka, Eomicrocystis, Pterospermopsimorpha insolita* and *Simia* disappear at different stratigraphic levels in both assemblages. It is inferred that the Rohtas assemblage is a little younger in age than the Miroyedikha (ca. 850 Ma) assemblage, and resembles the Husar-Kanpa assemblage of the western Officer Basin (Australia) which is assigned a Middle Neoproterozoic (ca. 802-777 Ma) age as its homotaxial sediments in Adelaide Basin were radiometrically constrained as 802 ± 10 Ma to 777 ± 7 Ma.

Based on the above comparisons and the stratigraphic relationship of the Rohtas Limestone with the underlying latest Mesoproterozoic-Early Neoproterozoic (1050-850 Ma) Rampur Formation, an Early Cryogenian (ca. 850-750 Ma) age of Middle Neoproterozoic is envisaged for the Rohtas Subgroup.

Kaimur Group

The sediments of the Kaimur Group rest with a pronounced unconformity over the Lower Vindhyan Semri Group, and are represented by the Domarkhoka Quartzite and the Bijaigarh Shale in the studied area. Although the outcrop samples are poorly fossiliferous, the subsurface sediments in the DMH-A well from the 575-480 m depth-interval, representing undifferentiated Kaimur Group (Fig. 4), yielded a moderate occurrence of organic-walled microfossils (Pl. 9.1-17).

Coccoid forms are the main constituents of the Kaimur assemblage and are represented by *Symplassosphaeridium* *tumidulum, Synsphaeridium sorediforme* and *Bavlinella faveolata* (Pl. 9.4-9, 13-15). Sphaeromorph acritarchs are the subdominant constituents and are represented by *Leiosphaeridia minutissima, L. tenuissima, L. asperata, L. jacutica, L. crassa, Kildinopshaera chagrinata, K. granulata* and *K. verrucata*. Important forms, such as *Vandalosphaeridium reticulatum, Pterospermopsimorpha saccata, Trachysphaeridium laufeldi, T. laminaritum* and *Stictosphaeridium sinapticulum* are also rarely represented along with species of *Siphonophycus* and *Oscillatoriopsis*. Important taxa of the underlying Rohtas Subgroup, viz. *Pterospermopsimorpha insolita, Simia annulare, Eomicrocystis* spp., *Satka* spp. and budding leiosphaerids become absent here (Figs 3, 4).

The correlation of the Kaimur assemblage is rather difficult due to its meagre microfossil content. However, the assemblage broadly compares with the Middle Visingsö assemblage of Sweden (Vidal, 1976a; Vidal & Knoll, 1983) and the upper Eleonore Bay Group assemblage of East Greenland (Vidal, 1976b) which have been dated Middle to Late Neoproterozoic (ca. 800-700 Ma). The age potential taxa, such as *Bavlinella faveolata, Trachysphaeridium laufeldi* and *Vandalosphaeridium reticulatum* and other forms, such as *Stictosphaeridium* spp., *Trachysphaeridium laminaritum* and *Pterospermopsimorpha saccata* are common in both the assemblages. *V. reticulatum, T. laufeldi* and *B. faveolata* are regarded as age marker taxa that range from Middle Neoproterozoic (ca. 850 Ma.) to Late Ediacaran-Early Cambrian and occur quite abundantly in Late Neoproterozoic-Terminal Proterozoic sediments (Vidal, 1981; Vidal & Knoll, 1983; Knoll, 1996). Thus, the occurrence of the above marker taxa in the Kaimur Group broadly suggests Middle to Late Neoproterozoic age that broadly corresponds to the Middle Cryogenian (ca. 750-700 Ma).

Rewa Group

Four samples from the Panna and Jhiri shales (S-14, RP/2, S-2/1, S-12) from the Barhi-Badanpur-Maihar section (Fig. 2B) and the subsurface sequence in the DMH-A well from 480-320m depth-intervals, representing undifferentiated Rewa Group (Fig. 4), yielded a poor occurrence of acritarchs, coccoid and filamentous microfossils (Pl. 9.18-26).

The microfossil assemblage of the Rewa Group is marked by the abundant occurrence of coccoid forms that include *Synsphaeridium sorediforme, S. gotlandicum* (Pl. 9.18, 21-22), *Symplassosphaeridium tumidulum* and *Bavlinella faveolata* (Pl. 9.24). Sphaeromorph acritarchs, viz. *Leiospharidia crassa, L. asperata, L. tenuissima, Kildinosphaera chagrinata, K. granulata, K. verrucata, Trachysphaeridium laminaritum, T. laufeldi, Stictosphaeridium sinapticulum* and *Vandalosphaeridium reticulatum* (Pl. 9.23) are also frequent in this assemblage along with *Pterospermopsimorpha saccata*, and persist from the underlying Kaimur Group. In addition, polygonomorph acritarchs, viz. *Octoedryxium truncatum* (Pl. 9.20) appear in this formation.

The recovered assemblage from the Rewa Group is also very poor and less diversified. However, the assemblage broadly compares with the Late Neoproterozoic microfossil assemblage from the Upper Visingsö Beds of Sweden (Vidal, 1976a). Marker taxa such as *Octoedryxium truncatum, Vandalosphaeridium reticulatum* and *Bavlinella faveolata* (Pl. 9.20, 23, 24) are common in both assemblages, and are associated with the above mentioned abundant sphaeromorph acritarchs. Vidal (1976a) and Vidal and Knoll (1983) recorded the above three taxa in abundance from the upper Visingsö Beds in Sweden, which is dated as ca. 700-610 Ma (Vidal, 1976a). Thus, a Late Cryogenian (ca. 700-650 Ma) age is suggested to the Rewa Group on the basis of the above microfossils. This age inference is corroborated by the observation that the youngest unit of Rewa Group, viz. Govindgarh Sandstone (Upper Rewa Sandstone) from eastern Rajasthan gave an absolute age of ca. 710-675 Ma (Srivastava & Rajagopalan, 1988), and the Rewa assemblage is succeeded by the *Obruchevella*-dominated latest Neoproterozoic to Terminal Proterozoic (Ediacaran) microfossil assemblage of the Bhander Group.

Bhander Group

The Bhander Group represents the uppermost sedimentary succession in the Upper Vindhyan sequence, and includes the Ganurgarh Shale, Nagod Limestone, Sirbu Shale and Maihar Sandstone in the Son Valley. Samples from the Ganurgarh Shale, Nagod Limestone and Sirbu Shale from the Barhi-Badanpur-Maihar section (Fig. 2B) and the DMH-A well (320-00 m) provided fairly rich and diversified organic-walled microfossil assemblages with some Ediacaran (Vendian) age diagnostic microfossils that help in age interpretation of the Bhander Group (Figs 3, 4, 5).

Ganurgarh Shale

The microfossil contents of this formation are rather moderate in the outcrop areas, and only the two samples from the Barhi-Badanpur-Maihar section (Fig. 2B; S-28/B-1, S-31/6) yielded the microfossils. The assemblage is represented by the rare occurrence of coccoid forms, viz. *Synsphaeridium sorediforme, Symplassosphaeridium tumidulum* and *Bavlinella faveolata* along with a number of species of *Leiosphaeridia, Kildinosphaera, Trachysphaeridium, Stictosphaeridium, Siphonopphycus, Oscillatoriopsis* (Pl. 10.1) and *Chlorogloeaopsis*. However, this lithounit in the subsurface (320-165 m) from DMH-A well (Fig. 4) yielded a rich microfossil assemblage and includes the above forms in abundance.

Above all, the most important aspect of Ganurgarh Shale assemblage is the appearance of Terminal Proterozoic (Ediacaran) age marker and helically coiled filamentous microfossils, referable to *Obruchevella,* in the upper part of this lithounit. It is represented by *O. parva* (Pl. 10. 4) and *O. valdaica* (Pl. 10.5) and rarely occurs in this assemblage. The above species of *Obruchevella* occur in association with other Late Neoproterozoic-Terminal Proterozoic marker taxa, viz. *Vandalosphaeridium reticulatum, Trachysphaeridium laufeldi, Octoedryxium truncatum* and *Bavlinella faveolata* which persisted from the underlying Rewa Group (Figs 3, 4).

The appearance of various species of *Obruchevella,* viz. *O. parva* and *O. valdaica* in the Ganurgarh Shale, though rare, is very significant. Particularly the appearance of *O. parva* in this lithounit is very significant. This species, till now, is only recorded from the Terminal Proterozoic and Lower Cambrian sequences with its earliest records from the Early Ediacaran (Early Vendian) sediments (Golovenok & Belova, 1983; Knoll & Ohta, 1988; Knoll, 1992). Moreover, *O. parva* is recorded in quite abundance from the Late Ediacaran (Late Vendian) sediments (Reitlinger, 1959; Yakshin & Luchinina, 1981; Kolosov, 1977, 1982; Cloud *et al.*, 1979) as well as Early Cambrian sediments (Wang *et al.*, 1983; Song, 1984; Peel, 1988), and seems to disappear in the Early Cambrian (Mankiewicz, 1992). Similarly, *Obruchevella valdaica* is quite abundant in Terminal Proterozoic (Ediacaran = Vendian) sediments (Aseeva, 1974; German, 1985; German *et al.,* 1989) and observed to disappear in the Late Vendian (Mankiewicz, 1992). Although its oldest record is known from the Late Mesoproterozoic sediments of Greenland (Hofmann & Jackson, 1994; Samuelsson *et al.*, 1999) and India (Prasad & Asher, 2001), its abundance in the Ediacaran (Vendian) sediments is well established (Mankiewicz, 1992; Knoll, 1996) and seams to disappear in Late Ediacaran (Late Vendian). Consequently, the appearance of *O. parva* and *O. valdaica* in the upper part of this unit suggests an Early Ediacaran (Early Vendian) age to the upper part of the Ganurgarh Shale. However, the lower part of this unit appears to be latest Cryogenian (Late Neoproterozoic) in age as it is characterised by the occurrence of *Vandalosphaeridium reticulatum, Trachysphaeridium laufeldi* and *Bavlinella faveolata,* and the species of *Obruchevella* are evidently absent.

Thus, the microfossil data, suggest a latest Cryogenian (Late Neoproterozoic)-Early Terminal Proterozoic (Early Ediacaran) age (ca. 650-590 Ma) for the Ganurgarh Shale. This inference is corroborated by the fact that the absolute age of the Govindgarh Sandstone (Rewa Group), which immediately underlies the Ganurgarh Shale, was estimated as 710-675 Ma by the F-T method (Srivastava & Rajagopalan, 1988). In addition, the Ganurgarh Shale assemblage is succeeded by the *Obruchevella*-dominated Terminal Proterozoic (Early to Late Ediacaran; ca. 590-560 Ma) assemblage in the Nagod Limestone.

Nagod Limestone

The microfossil assemblage of this formation is quite similar to those from the Ganurgarh Shale, but relatively rich. Three samples from the Barhi-Badanpur-Maihar section (S-30, IV-625, IV-613) and depth intervals from 165-105 m in the DMH-A well (Fig. 4), representing Nagod Limestone, recorded a well preserved organic-walled microfossils (Pl. 10.2-3, 6-14, 16-18). Various species of *Leiosphaeridia, Kildinosphaera, Trachysphaeridium, Stictosphaeridium, Favososphaeridium, Vandalosphaeridium* and *Germinosphaera* represent the sphaeromorph and acanthomorph acritarchs. *Synsphaeridium sorediforme, Symplassosphaeridium tumidulum* and *Bavlinella faveolata* include the coccoid forms; whereas filamentous microfossils are represented by abundant occurrences of various species of *Obruchevella, Chlorogloeaopsis, Oscillatoriopsis* and *Siphonophycus* (Figs 3, 4).

The most distinguishing aspect of the Nagod Limestone assemblage is the abundance of the Ediacaran (Vendian) marker species of *Obruchevella,* viz. *O. delicata* (Pl. 10.7, 11) and *O. parva* (Pl. 10.12) along with *O. valdaica* (Pl. 10.6), and the appearance of *O. delicata*. In addition, *Germinosphaera unispinosa* (Pl. 10.3), *Favososphaerdium favosum* (Pl. 10.18), *Lophosphaeridium* sp. cf. *L. truncatum* (Pl. 10.8, 14), *Lophosphaeridium rarum* (Pl. 10.9-10) and *Cymatiosphaera* sp. (Pl. 10.17) make their appearance in this formation (Figs 3, 4).

The abundance of *O. parva* and *O. delicata* in the Nagod Limestone is very important. As stated above, the oldest records of *O. parva* are from the Early Ediacaran (Early Vendian) sediments (Golovenok & Belova, 1983; Knoll & Ohta, 1988; Knoll, 1992). It become quite abundant in the Late Ediacaran (Reitlinger, 1959; Yakshin & Luchinina, 1981; Kolosov, 1977, 1982; Cloud *et al.*, 1979) and Early Cambrian (Wang *et al.*, 1983; Song, 1984; Peel, 1988) sediments, and appears to range upto Early Cambrian (for details Mankiewicz, 1992). Similarly, the earliest record of *O. delicata* is from the Late Ediacaran (Late Vendian) sediments (Zabit Formation) of Siberia (Shenfil, 1983). It is also recorded in abundance from the Early Cambrian sediments of the Siberian Platform (Reitlinger, 1948; Luchinina, 1975; Yakshin & Luchinina, 1981), western Mongolia (Drozdova, 1980), eastern China (Song, 1984), South Australia (Bengtson *et al.,* 1990) and Canada (Voronova *et al.*, 1987), and ranges upto Early Ordovician (Bykova, 1961; Mankiewicz, 1992). *O. valdaica* is also originally recorded in abundance from the Ediacaran (Vendian) sediments of USSR (Aseeva, 1974; German, 1985; German *et al.*, 1989). Although, *O. valdaica* was later recorded from the Late Mesoproterozoic (Hofmann & Jackson, 1994; Samuelsson *et al.*, 1999; Prasad & Asher, 2001) sediments, its abundance in Terminal Proterozoic (Ediacaran=Vendian) is well established (Knoll, 1996; Mankiewicz, 1992), and seems to disappear in Late Ediacaran

SUPER-GROUP	GROUP		FORMATION	CHARACTERISTIC ORGANIC-WALLED MICROFOSSILS	AGE: PERIOD (Time in Ma)	AGE: ERA
VINDHYAN SUPERGROUP	UPPER VINDHYAN	BHANDER	MAIHAR SST.	Unfossiliferous	544	EDIACARAN (TERMINAL PROTEROZOIC)
			SIRBU SHALE	Abundance - *Leiosphaeridia* spp., *Siphonophycus* spp., *Obruchevella* spp. (*O. parva*, *O. delicata*); common- *Kildinosphaera* spp., *Germinosphaera* spp., *V. reticulatum*, *T. laufeldi*, *B. faveolata*, *Lophosphaeridium* spp., *Cymatiosphaera* sp.; appearance - *O. parvissima*, *Cristallinium* sp., *Dictyotidium* sp., small micrhystrids & *G. bispinosa* (Pl. 11, figs 1-18)	LATE EDIACARAN; 570	
			NAGOD LST.	Abundance- *Obruchevella parva*, *O. delicata*, *O. valdaica*; common- *B. faveolata*, *V. reticulatum*, *Leiosphaeridia* spp., *Kildinosphaera* spp.; Appearance- *O. delicata*, *Lophosphaeridium rarum*, *L.. truncatum*, *Cymatiosphaera* sp., *Germinosphaera unispinosa*, *Favososphaeridium favosum* (Pl. 10, rest figs)	EARLY EDIACARAN; 600	
			GANURGARH SHALE	Abundance - *Siphonophycus* spp., *Oscillatoriopsis* spp., *Chlorogloeaopsis* spp., *Leiosphaeridia* spp.; rare - *V. reticulatum*, *B. faveolata*, *Kildinosphaera* spp., *T. laufeldi*; Appearance - *Obruchevella parva*, *O. valdaica* (Pl. 10, figs 1,4,5,15)	LATE CRYOGENIAN	NEOPROTEROZOIC
		REWA	GIVINDGARH SST.	Unfossiliferous		
			JHIRI SHALE	Abundance- *Symplassosphaeridium* spp., *Synsphaeridium* spp.,*Leiosphaeridia* spp.; common - *Kildinosphaera* spp., *Pterospermopsimorpha* saccata, *Siphonophycus* spp.; rare - *Vandalosphaeridium reticulatum*, *Bavlinella faveolata*, *T. laufeldi*; Appearance - *Octoedryxium truncatum* (Pl. 9, figs 18-26)		
			ASAN SST.	Unfossiliferous		
			PANNA SHALE	*Synsphaeridium* spp., *Symplassosphaeridium* spp., *Trachysphaeridium* spp., *Stictosphaeridium* spp., *Leiosphaeridia* spp. (Pl. 9, figs. 18-26)		
		KAIMUR	SONAM SST.	Unfossiliferous		
			BIJAIGARH SHALE	*Leiosphaeridia* spp., *Kildinosphaera* spp., *Pterospermopsimorpha saccata*, *Trachysphaeridium* spp., *T. laufeldi*, *Bavlinella foveolata*, *Vandalosphaeridium* spp., *Symplassosphaeridium* spp., *Synsphaeridium* spp. (Pl. 9, Figs.1-17)	725	
			DOMARKHOKA QRTZ	Unfossiliferous	EARLY CRYOGENIAN	
	LOWER VINDHYAN (SEMRI)	ROHTAS	BHAGAWAR SHALE; ROHTAS LST.	Abundance -*Stictosphaeridium* spp., *Satka* spp, *Trachysphaeridium* spp.; common - *Kildinosphaera* spp., *Leiosphaeridia* spp., *Oscillatoriapsis* spp., *Pterospermopsimorpha* spp., *Siphonophycus* spp., *Vandalosphaeridium reticulatum*, *Bavlinella faveolata*, *Trachysphaeridium laufeldi* (Pl. 8, figs.1-17)	850	
		KHEINJUA	RAMPUR	Abundance - *Satka* spp., *Navifusa* spp., *Trachysphaeridium* spp.; Common - *Tappania* spp., *Eomicrocystis* spp., *Leiosphaeridia* spp., *Kildinosphaera* spp., *Arctacellularia* spp.; Appearance - *Mellanocyrillium* spp., budding leiosphaerids, *Bavlinella faveolata*, *K. verrucata*, *Trachyhystrichosphaera truncata*, *Vandalosphaeridium* spp. (Pl. 6, figs.1-13; Pl. 7, figs.1-19)	TONIAN	1000
			SALKHAN (FAWN) LST.	Abundance- *Tappania* spp., *Navifusa* spp., *Satka* spp.; common-*Eomicrocystis* spp., *Pterospermopsimorpha* spp., *Kildinosphaera* spp., *Leiosphaeridia kulgunica*, *Siphonophycus* spp., *Tetraphycus* spp. (Pl. 5, figs. 1-19)	STENIAN	MESOPROTEROZOIC
			KOLDAHA SHALE	Abundance - *Tappania* spp., *Navifusa* spp., *Eomicrocystis* spp.; common - *Arctacellularia* spp., *Pterospermopsimorpha* spp., *Trachysphaeridium* spp., *Satka* spp., *Kildinosphaera* spp., *Leiosphaeridia* spp.; rare - *Sphaerophycus* spp., *Eosynechococcus* spp., *Siphonophycus* spp., *Tetraphycus* spp.; Appearance - *Navifusa* spp., *T. gangaei* (Pl. 3, figs. 1-16; Pl. 4, figs. 1-18)	1200; ECTASIAN	
			DEONAR (PORCELLANITE)	Abundance - *Leiosphaeridia* spp., *Kildiosphaera chagrinata*, *K. granulata*, *Polythrichoides lineatus*, *Siphonophycus* spp., *Synsphaeridium* spp. Appearance - *Tappania* spp., *Satka* spp., *Eomicrocystis* spp., *Octoedryxium vindhyanense*, *Dictyosphaera* sp. (Pl. 2, figs 1-17)	1400; CALYMMIAN	
		MIRZAPUR	KAJRAHAT LST.	Abundance - *Siphonophycus* spp., *Polythrichoides lineatus*, *Tortunema pseudoseptata*, *Karamia segmentata*, opaque filamentous forms; rare - *Arctacellularia* spp. and unornamented sphaeromorphs - *Leiosphaeridia* spp., *K. chagrinata* (Pl. 1, figs 1-14)		
			DEOLAND FM.	Unfossiliferous		1600
MAHAKOSHAL / BIJAWAR GROUP				Unfossiliferous - Late Paleoproterozoic	ca. 1800 - 1600	

Fig. 5—Characteristic organic-walled microfossil assemblages from different lithounits of Vindhyan Supergroup, and their inferred geological age.

(Late Vendian) of Terminal Proterozoic (German *et al.*, 1989). Thus, the abundance of above species of *Obruchevella* in the Nagod Limestone is alone suggestive of the Early to Late Ediacaran (Vendian) age for this lithounit.

The Nagod Limestone assemblage also resembles Early Ediacaran (upper Early Vendian; ca. 580-570 Ma) microfossil assemblage of the Scotia Group, Svalbard (Knoll, 1992) as the species of *Obruchevella, Siphonophycus, Myxococcoides* (*Synsphaeridium*), *Trachyhystrichosphaera* and *Leiosphaeridia* are common to both the assemblages, and suggestive of an age similar to the Scotia Group. However, the characteristic large acanthomorph acritarchs of the Scotia Group, viz. *Papillomembrana, Ericiasphaera, Echinosphaeridium, Asterocapsoides* and *Briareus* are absent in the the Nagod Limestone assemblage. The *Germinosphaera unispinosa* (Pl. 10.3) seems to be the lone representive of the purported large acanthomorph acritarchs in this assemblage which is absent in the Scotia Group. Moreover the presence of Ediacaran marker species of *Obruchevella*, viz. *O. parva* and *O. delicata* in abundance, with associated occurrence of *Bavlinella faveolata, Trachysphaeridium laufeldi, Vandalosphaeridium reticulatum* and *Favososphaeridium favosum* is undoubtedly suggestive of an Early to Late Ediacaran age for the Nagod Limestone. Yet the morphologically complex and distinctive large acanthomorph acritarchs of upper Early Ediacaran (ca. 580-570 Ma), viz. *Eotylotopalla, Papillomembrana, Megahystrichosphaeridium, Ericiasphaera* and *Briareus,* which were recorded from the Doushantuo Formation, eastern China (Zhang *et al.*, 1998), Biskopas Conglomerate, southern Norway (Vidal, 1990), Kursovsky Formation, eastern Siberia (Kolosova, 1990, 1991; Moczydlowska *et al.*, 1993), Scotia Group, Svalbard (Knoll, 1992) and Partataka Formation, central Australia (Zang & Walter, 1989), are absent. It appears that the Nagod Limestone assemblage is little older than the acritarch assemblages of large and complex acanthomorph acritarchs or coeval to them, and belongs to upper Early Ediacaran (ca. 590-570 Ma) age. Yet the occurrence of taxa, such as *O. delicata, Lophosphaeridium* sp. cf. *L. truncatum, L. rarum* and *Cymatiosphaera* sp., which are known to appear in Late Ediacaran (Late Vendian), extends the age of this lithounit into the Late Ediacaran also.

Thus, the recovered microfossil assemblage suggests an upper Early Ediacaran to Late Ediacaran (ca. 590-560 Ma) age for the Nagod Limestone, as the above species of *Lophosphaeridium, Cymatiosphaera* and *O. delicata* also make their appearances in this lithounit. It is worth mentioning that the F-T dating of the immediately overlying Lower Bhander Sandstone gave the absolute age of 625 ± 24 Ma (Srivastava & Rajagopalan, 1990) which is very close to the age inferred by the recovered microfossil assemblage.

Sirbu Shale

Four samples (S-1/1, IV-4, S-1/3, IV-631) from the Barhi-Badanpur-Maihar section (Fig. 2B) and the subsurface sedimentary succession from 105-00 m (surface) depth intervals in the DMH-A well (Fig. 4), representing Sirbu Shale succession, provided a well-preserved organic-walled microfossil assemblage. The microfossil contents are moderate in outcrops, but they are very rich and diversified in the subsurface (Pl. 11.1-18).

Helically coiled filamentous microfossils (*Obruchevella* spp.) are the most common constituent of the Sirbu Shale assemblage and are represented by *O. parva, O. parvissima* and *O. delicata* (Pl. 11.9-11). These forms are also associated with various species of *Siphonophycus, Oscillatoriopsis* and *Chlorogloeaopsis* (Pl. 11.14). The acritarch assemblage commonly includes sphaeromorph acritarchs, viz. *Leiosphaeridia* spp., *Kildinosphaera* spp., *Trachysphaeridium laminaritum, T. laufeldi* (Pl. 11.8) and *Cymatiosphaera* sp. (Pl. 11.18). In addition, *Germinosphaera unispinosa* (Pl. 11.1-2), *G. bispinosa* (Pl. 11.3) and *Vandalosphaeridium reticulatum* (Pl. 11.12-13) are also very abundant. Forms such as *Synsphaeridium servediforme, Symplassosphaeridium tumidulum, Myxococcoides* spp. and *Bavlinella faveolata* represent the coccoid forms and persist here from the underlying Nagod Limestone, as do *Obruchuvella parva, O. delicata, Vandalosphaeridium reticulatum, Trachysphaeridium laufeldi, Favososphaeridium favosum, Bavlinella faveolata, Lophosphaeridium* sp. cf. *L. rarum, Lophosphaeridium* sp. cf. *L. truncatum* and *Cymatiosphaera* sp.

Yet the most distinctive feature of this assemblage is the consistent occurrence of the purported acanthomorph acritarch *Germinosphaera,* which is represented by *G. unispinosa* and *G. bispinosa*. In addition, *Obruchevella parvissima* (Pl. 11.10), *Dictyotidium* sp. (Pl. 11.4-7) and *Cristallinium* sp. cf. *C. cambriense* (Pl. 11.17), which generally make their appearance at the Precanmbrian-Cambrian boundary or in the Early Cambrian, appear in this formation (Figs 3, 4).

The Sirbu Shale assemblage is broadly comparable with the Late Ediacaran (Late Vendian) microfossil assemblages recorded from the Valdaian sequences of the Northern European Platform (Vidal, 1976b, 1981; Vidal & Knoll, 1983) and the Eastern European Platform (Volkova, 1968; Volkova *et al.*, 1979). Abundant leiosphaerids and filamentous microfossils are common in the Sirbu Shale as well as in the above areas, except that *Germinosphaera* and *Obruchevella* are absent in the Valdaian assemblages. Microfossil assemblages from the latest Proterozoic (Late Ediacaran) Redkino and Kotlin formations (Volkova, 1985; Burzin, 1996) also compare with the Sirbu Shale assemblage as simple leiosphaerids and filamentous microfossils abundantly occur in these assemblages. Knoll (1996, 2000), while reviewing the Proterozoic microfossil assemblages, opined that the Late

Ediacaran (Late Vendian, ca. 570-544 Ma) assemblages are mainly characterised by the dominance of thin-walled *Leiosphaeridia* spp., abundant *Obruchevella* spp., acme of vendotaenids, and appearance of small micrhystrids. Although the vendotaenids are absent in this assemblage, the abundance of Vendian marker species of *Obruchuvella* (*O. parva* and *O. delicata*), *Leiosphaeridia* and filamentous microfossils, and the rare occurrence of unidentifiable small micrhystrids, with associated occurrence of *Vandalosphaeridium reticulatum, Trachysphaeridium laufeldi* and *Bavlinella faveolata* strongly suggests a Late Ediacaran age for the Sirbu Shale assemblage. However the appearance of *Dictyotidium* sp. (Pl. 11.4-7), *Cristallinium* sp. cf. *C. cambriense* (Pl. 11.17) and *Obruchevella parvissima* (Pl. 11.10) in the Sirbu Shale that appear in Early Cambrian indicates that the age of the Sirbu Shale extends into the Early Cambrian also. But, the absence of distinctive Early Cambrian marker acritarchs, viz. *Asteridium tornatum, Skiagia ciliosa, Lophosphaeridium tentativum, Dictyotidium birvetense, Globosphaeridium cerinum, Annulum squamaceum* and *Comasphaeridium* spp. corresponding to the Rovno-Lontova (sub-*Holmia* Stage) assemblages of the Eastern European Platform (Volkova *et al.*, 1979; 1983) and the Lublin Slope, eastern Poland (Moczydlowska, 1991), favours a Late Ediacaran (ca. 560- 544 Ma) age for the Sirbu Shale. Cloud *et al.* (1979) and Song (1984) observed that the filament diameters of Vendian *Obruchevella* species are generally small (< 20 µm) and that of Early Cambrian are large (> 20 µm), although, Mankiewicz (1992) did not observe this type of trends. However, the absence of Early Cambrian marker species of *Obruchevella*, viz. *O. meishucunensis* and other species of *Obruchevella* having large filament diameter (> 20 µm) in this assemblage, also suggest that the Sirbu Shale microfossil assemblage belongs to the Late Ediacaran (ca. 560-544 Ma), and does not encompass into the Early Cambrian.

Maihar Sandstone

The Maihar Sandstone represents the youngest lithounit in the Bhander Group as well as the Vindhyan Supergroup. It comprises a massive reddish-brown sandstone succession and is devoid of organic-walled microfossils. It seems that this lithounit of the Bhander Group was also deposited during Late Ediacaran (Terminal Proterozoic). Crawford and Compston (1970) estimated the radiometric (K/Ar) age of this unit as ca. 550 Ma; whereas, Rai (1999) reported some algal microbial mats, and suggested a Late Ediacaran (Late Vendian) age for the Maihar Sandstone.

DISCUSSION

The recovered organic-walled microfossils from Vindhyan sediments of the Son valley and DMH-A well from Madhya Pradesh include acritarchs, coccoid and filamentous microfossils that generally characterise Meso-Neoproterozoic sediments worldwide. Among these, some age marker taxa are also present which helped in dating the different lithounits of the Vindhyan Supergroup and ascertaining its total age-range. The stratigraphic distribution of organic-walled microfossils through different lithounits of the Vindhyan Supergroup also reflects the pattern of distribution of these microfossils in the Meso-Neoproterozoic sediments of India.

The basal two lithounits of the Semri Group, viz. Deoland and Arangi formations (Mirzapur Subgroup) are devoid of organic-walled microfossils. However, the occurrence of abundant filamentous forms (*Siphonophycus, Polythri--choides, Karamia & Arctacellularia*) and unornamented sphaeromorph acritarchs (*Leiosphaeridia* spp) in Kajrahat Limestone, which represents the youngest lithounit of Mirzapur Subgroup, suggests an Early Mesoproterozoic (Late Calymmian; ca. 1500-1450 Ma) age. The earlier age evidences through the records of stromatolitic assemblages (Misra *et al.*, 1977) and organic-walled microfossils (Venkatachala *et al.*, 1990) from this unit also suggested an Early to Middle Riphean age, which is very close to the present suggested age. The older two units of the Mirzapur Subgroup, viz. Deoland and Arangi formations seem to represent the basal Mesoproterozoic (Early Calymmian; ca. 1550-1500 Ma) sediments in the Vindhyan Basin, as they immediately underly the Kajrahat Limestone, and the Arangi Formation is characterised by the Early Riphean stromatolites (Kumar, 1976). It is noteworthy that the oldest mafic volcanics inter-bedded with the Bijawar Group, above which the Vindhyan Supergroup rests, have been dated at ca. 1791 Ma (Crawford & Compston, 1970; Sarkar *et al.*, 1997) and it was opined that the Bijawar sedimentation was initiated at ca. 1800 Ma and terminated at about 1600 Ma corresponding to the Zhongyuean orogenic movement (Shankar *et al.*, 1999). It appears that the basal Vindhyan sediments are not older than the ca.1600 Ma, and the sedimention in the Vindhyan Basin was initiated during Early Mesoproterozoic.

The appearance of *Tappania* (acanthomorph acritarch), *Satka* and *Eomicrocystis* in the Deonar Formation was observed to be the very important biostratigraphic event in Vindhyan stratigraphy. The oldest record of *Tappania* is from Early Mesoproterozoic (ca.1450 Ma) sediments (Jalboi Formation, Roper Group) in northern Australia (Javaux *et al.*, 2001). It was recorded in abundance from Middle to Late Mesoproterozoic sediments of eastern China (Yin, 1997) and India (Prasad & Asher, 2001). Its appearance in the Deonar Formation indicated an age similar to the Roper Group (ca. 1450-1400 Ma). However, the appearance of abundant polygonomorph acritarchs (*Octoedryxium*) in the Deonar Formation extends its age to early Middle Mesoproterozoic (ca. 1400-1350 Ma). The record of *Octoedryxium* in this formation also suggests that polygonomorph acritarchs were flourishing even during early Middle Mesoproterozoic time.

The presence of a distinctive late Early to Middle Mesoproterozoic microfossil assemblage in the Deonar Formation does not support its absolute age of 1630 ± 5 Ma, as suggested by Ray *et al.* (2002). The well-developed acritarch assemblages having acanthomorph and microsculptured sphaeromorph acritarchs are known from the later part of Early Mesoproterozoic and younger Meso-Neoterozoic sequences only (Knoll, 1996).

The dominance of acanthomorph acritarchs (*Tappania* spp.) in the Koldaha Shale is also a significant feature. As stated earlier, *Tappania* was recorded in abundance from Middle to Late Mesoproterozoic (ca. 1200-1100 Ma) Ruyang Group sediments of China (Yin, 1997) and Bahraich Group (ca. 1350-1150 Ma) from Northern India (Prasad & Asher, 2001). The abundance of *Tappania* in the Koldaha Shale and Salkhan Limestone assemblages is similar to the Mid- to Late Mesoproterozoic Ruyang and Bahraich microfossil assemblages, suggesting a Late Ectasian-Early Stenian (ca. 1350-1050 Ma) age for the above two units of the Kheinjua Subgroup. Although the presence of *Tappania* in the Rampur Formation is indicative of a Late Mesoproterozoic (ca. 1100-1000 Ma) age, the appearance of *Vandalosphaeridium*, budding leiospharids and *Melanocyrillium* undoubtably suggest an Early Neoproterozoic (ca. 850 Ma) age for this formation. It appears that the Rampur Formation ranges in age from latest Mesoproterozoic to Early Neoproterozoic (ca. 1050-850 Ma). The absolute age of the Rampur Formation by Kruezer *et al.* (1977) as 1080 ± 40 Ma is consistent with the present age assignment. However, the 1628 ± 8 Ma radiometric dating of this lithounit (Rasmussen *et al.*, 2002) needs reconsideration in view of the record of distinctive latest Mesoproterozoic-Early Neoproterozoic microfossils assemblage.

As discussed earlier, the Rohtas assemblage equates with the Middle Neoproterozoic (ca. 850 Ma) Miroyedikha assemblage of Siberia (German, 1990), suggesting an Early Cryogenian (ca. 850-750 Ma) age. The absolute dating of the Rohtas Limestone as 1599 ± 48 Ma (Sarangi *et al.*, 2004) seems incompatiable in view of the record of distinctive Middle Neoproterozoic microfossil assemblage. Similarly, the absence of Terminal Proterozoic or Early Cambrian organic-walled microfossils does not suggest Late Ediacaran or Early Cambrian age to this lithounit, as suggested by Azami (1998).

The organic-walled microfossil assemblages of the Kaimur and Rewa groups are quite different, as the *Symplassosphaeridium-Synsphaeridium* complex dominates over the *Leiosphaeridia-Kildinosphaera* association of the Semri Group. The only innovative features of the Kaimur and Rewa assemblages are the occurrence of *Trachysphaeridium laufeldi*, *Vandalosphaeridium reticulatum* and *Bavlinella faveolata*, and the appearance of *Octoedryxium truncatum* in the Rewa Group, whose oldest records are from the Late Neoproterozoic (Middle Visingsö Beds; ca. 700-610 Ma) of Sweden (Vidal, 1976a). Thus, the presence of *T. laufeldi* and *V. reticulatum* and the *appearance* of *O. truncatum* favours a Late Neoproterozoic (ca. 750-650 Ma) age for the Kaimur and Rewa groups collectively. The absolute dating of the Rewa Group as 710-675 Ma (Srivastava & Rajagopalan, 1988) corroborates the above age inference.

The most important aspect of the Bhander Group assemblages is the abundance of different species of *Obruchevella*, viz. *O. valdaica, O. parva, O. delicata* and *O. parvissima*. Among these *O. valdaica* and *O. parva* appear in the upper parts of the Ganurgarh Shale, and become abundant in the overlying Nagod Limestone and Sirbu Shale. Similarly, *O. delicata, Lophosphaeridium* spp., *Cymatiosphaera* sp. and *Germinosphaera* spp. appear in the Nagod Limestone, and continue to occur in the Sirbu Shale. However, some Late Ediacaran-Early Cambrian marker taxa, viz. *Obruchevella parvissima*, *Dictyotidium* sp., *Cristallinium* sp. and small unidentifiable micrhystrids also make their appearance in the Sirbu Shale.

Although, the occurrence of *V. reticulatum, T. laufeldi* and *B. faveolata* suggests a Late Neoproterozoic (ca. 650-600 Ma) age for the Ganurgarh Shale, the appearence of various species of *Obruchevella* (*O. valdaica, O. parva*) in the upper part of the Ganurgarh Shale extends its age into the Early

PLATE 1 ⟶

Organic-walled microfossils from the Kajrahat Limestone (Mirzapur Subgroup). Specimen nos. 1-2 from the Barhi-Badanpur-Maihar outcrop section, 3-14 from the DMH-A well, CC-10 (3479-3483 m depth interval), representing the Kajrahat Limestone succession. Scale bar = 10 µm.

1, 2. *Leiosphaeridia crassa* (Naumova) Jankauskas. 1. S-5/1; EFR L 50. 2. S-5/1; EFR H 48/3.

3. *Leiosphaeridia tenuissima* Eisenack. CC-10, Seg. 3/5/1; EFR N 58.

4. *Leiosphaeridia asperata* (Naumova) Lindgren. CC-10, Seg.1/5/2; EFR F 25/4.

5. *Kildinosphaera chagrinata* Vidal in Vidal & Siedlecka. CC-10, Seg. 1/5/2; EFR P 65.

6. Opaque filament. CC-10, Seg. 1/5/1; EFR U 54.

7. *Siphonophycus robustum* (Schopf) Knoll, Swett & Mark. CC-10, Seg.1/5/2; EFR G 67/1.

8. *Tortunema pseudoseptata* (German) Butterfield, Knoll & Swett. CC-10, Seg. 1/5/2; EFR H 68/1.

9. An enlarged part of *T. pseudoseptata* in Fig. 8, showing incomplete transeverse septa on the filament. CC-10, Seg.1/5/2; EFR H 68/1.

10. *Siphonophycus kestron* Schopf. CC-10, Seg.1/5/2; EFR F 68/1.

11, 12. *Arctacellularia ellipsoidea* German. 11. CC-10, Seg.1/5/1; EFR Q 36/2. 12. CC-10, Seg.1/5/2; EFR G 28.

13. *Polythrichoides lineatus* (German) Knoll, Swett & Mark. CC-10, Seg.1/5/1; EFR G 42/3.

14. *Karamia segmentata* Jankauskas, Mikhailova & German. CC-10, Seg.1/5/2; EFR P 64.

PLATE 1

Ediacaran (ca. 590 Ma). The abundance of *Obruchevella* spp. in the Nagod Limestone, and the appearance of Late Ediacaran marker taxa, such as *O. delicata, L. tuncatum, L. rarum* and *Cymatiosphaera* sp., is suggestive of an Early Ediacaran age of the Nagod Limestone, and it appears that it may extend into the Late Ediacaran also. The persistence of these taxa in the Sirbu Shale, including the various species of *Obruchevella*, and the appearance of other Late Ediacaran and Early Cambrian marker taxa, viz. *Obruchevella parvissima, Dictyotidium* sp. *Cristallinium* sp. and unidentifiable small micrhystrids indicate a Late Ediacaran (ca. 560-544 Ma)-Early Cambrian age for the Sirbu Shale. But, the absence of specific Early Cambrian acritarch marker taxa, viz. *Comasphaeridium* spp., *Asteridium tornatum, Skiagia ciliosa, Fimbriaglomerella* spp., *Annulum squamaceum* and *Baltisphaeridium* spp. restricts the upper age limits for the Sirbu Shale to the Late Ediacaran of the Terminal Proterozoic.

CONCLUSIONS

1. The recovered organic-walled microfossil assemblages from Vindhyan sediments suggest that the Semri Group (Lower Vindhyan) ranges in age from Early Mesoproterozoic (Early Calymmian, ca. 1550 Ma) to Middle Neoproterozoic (Early Cryogenian, ca. 750 Ma). On the other hand, the Kaimur, Rewa and Bhander groups of the Upper Vindhyan succession range in age from Middle Neoproterozoic (ca. 750 Ma) to Terminal Proterozoic (Late Ediacaran, ca. 544 Ma).

2. Organic-walled microfossils of Early Cambrian aspect are not recorded in the Rohtas Subgroup, from which Azmi (1998) reported the occurrence of Early Cambrian small shelly microfossils and brachiopods. Even the sediments of the Bhander Group, representing the youngest lithounit of the Vindhyan succession, have not yielded any distinctive Early Cambrian organic-walled index microfossils.

3. The recent absolute age datings of the Deonar, Rampur and Rohtas formations of the Semri Group as old as ca. 1630-1599 Ma (Late Paleoproterozoic) need re-evaluation in the light of the record of the distinctive Middle Mesoproterozoic (ca. 1450-1350 Ma), latest Mesoproterozoic-Early Neoproterozoic (ca.1050-850 Ma) and Middle Neoproterozoic (ca. 850-750 Ma) organic-walled microfossil assemblages.

4. The age of the Vindhyan Supergroup appears to range from the Early Mesoproterozoic (ca. 1550 Ma) to Late Ediacaran (Terminal Proterozoic, ca. 544 Ma), and it does not encompass the Lower Paleozoic.

LIST OF TAXA

The organic-walled microfossil taxa, recognised and documented from the sediments of Vindhyan Supergroup, are listed below. Only the stratigraphic potential and age marker taxa, marked with asterisk (*), are described.

Acritarchs

Sphaeromorphs

Leiosphaeridia tenuissima Eisenack, 1958
L. asperata (Naumova, 1949) Lindgren, 1982
L. jacutica (Timofeev, 1966) Mikhailova & Jankauskas in Jankauskas, 1989
L. ternata (Timofeev, 1966) Mikhailova & Jankauskas in Jankauskas, 1989
L. crassa (Naumova, 1949) Jankauskas in Jankauskas, 1989
L. minutissima (Naumova, 1949) Jankauskas, 1989
* *L. kulgunica* Jankauskas, 1980b
Kildinosphaera chagrinata Vidal in Vidal & Siedlecka, 1983
K. verrucata Vidal in Vidal & Siedlecka, 1983
K. granulata Vidal in Vidal & Siedlecka, 1983
Gangasphaera bulbousus Prasad & Asher, 2001
* *Trachysphaeridium laminaritum* (Timofeev, 1966) Vidal, 1976a
* *T. laufeldi* Vidal, 1976a
T. levis (Lopukhin, 1972) Vidal, 1976a
Stictosphaeridium sinapticulum Timofeev, 1966
S. implexum Timofeev, 1966
* *Favososphaeridium favosum* Timofeev, 1966
* *Lophosphaeridium rarum* Timofeev, 1959
**Lophosphaeridium* sp. cf. *L. truncatum* Volkova, 1969

PLATE 2 ⟶

Organic-walled microfossils from the Deonar Formation (Chopan Porcellanite). Illustrated specimens from the Jhal-Bihara outcrop section (sample no. II/48C). Scale bar = 10μm.

1- 4. *Octoedryxium vindhyanense* sp. nov. 1. EFR T 67/3. 2. EFR U 42. 3. EFR T 65/3. 4. EFR W 64/2.
5. *Tappania tubata* Yin. EFR H 40/1.
6. *Tappania plana* Yin. EFR N 67.
7. *Satka squamifera* Pyatiletov. EFR T 58.
8. *Siphonophycus rugosum* (Maithy) Hofmann & Jackson. EFR G 39/4.
9. *Eomicrocystis elegans* Golovenok & Belova. EFR N 32/2.
10. *Leiosphaeridia tenuissima* Eisenack. EFR T 34/3.
11. *Leiosphaeridia asperata* (Naumova) Lindgren. EFR S 37.
12. *Polythrichoides lineatus* (German) Knoll, Swett & Mark. EFR T 50.
13. *Siphonophycus septatum* (Schopf) Knoll, Swett & Mark. EFR S 58.
14, 15. *Kildinosphaera granulata* Vidal in Vidal & Siedlecka. 14. EFR Q 47/3. 15. EFR K 30.
16. *Dictyosphaera* sp. EFR T 63/3.
17. *Synsphaeridium sorediforme* (Timofeev) Eisenack. EFR G 50/ 3.

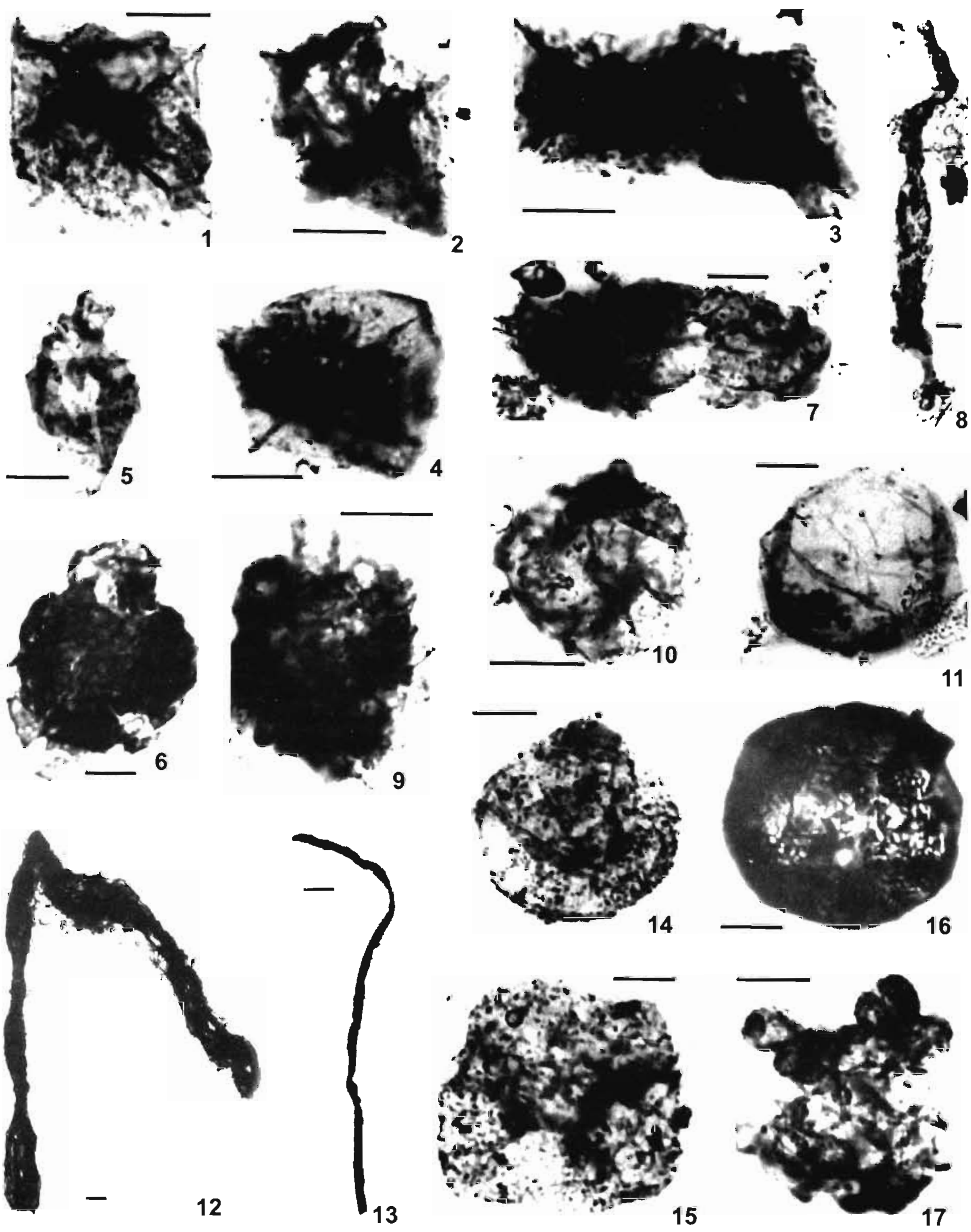

PLATE 2

Lophosphaeridium granulatus Maithy, 1975
L. jansoniusii Salujha *et al.*, 1971
Netromorphs
**Navifusa majensis* Pyatiletov, 1980
**N. segmentata* Prasad & Asher, 2001
N. granulata Prasad & Asher, 2001
N. actinomorpha (Maithy, 1975) Hofmann & Jackson, 1994
Acanthomorphs
**Tappania plana* Yin, 1997
**T. tubata* Yin, 1997
T. gangaei Prasad & Asher, 2001
**Vandalosphaeridium reticulatum* (Vidal, 1976) Vidal, 1981
V. varangeri (Vidal, 1976) Vidal, 1981
**Trachyhystrichosphaera truncata* German & Jankauskas in Jankauskas, 1989
**Germinosphaera unispinosa* Jankauskus, 1989
**G. bispinosa* Jankauskus, 1989
Pteromorphs
Pterospermopsimorpha insolita Timofeev, 1969
P. saccata Yin, 1987
**Simia annulare* (Timofeev, 1969) Mikhailova & Jankauskas in Jankauskas, 1989
Herkomorphs
**Cymatiosphaera* sp.
**Dictyotidium* sp.
**Cristallinum* sp. cf. C. *cambriense* (Slavikova, 1968) Vanguestaine, 1978
Polygonomorphs
**Octoedryxium vindhyanense* sp. nov.
**O. truncatum* (Rudavskaia, 1973) Rudavskaia in Jankauskas, 1989

Coccoid Microfossils

Synaplomorphs
Eoentophysalis sp. cf. *E. belcherensis* Hofmann, 1976
Eoentophysalis sp.
Eosynechococcus moorei Hofmann, 1976
E. medius Hofmann, 1976
Sphaerophycus parvum Schopf, 1968
Eohyella dichotoma Green *et al.*, 1988
Tetraphycus acinulus Oehler, 1978
T. diminutivus Oehler, 1978
T. gregalis Oehler, 1978
**Eomicrocystis elegans* Golovenok & Belova, 1984
**E. malgica* Golovenok & Belova, 1986
**Bavlinella faveolata* (Schepeleva, 1962) Vidal, 1976a
Spumosina rubiginosa Andreeva, 1966
Symplassosphaeridium tumidulum Timofeev, 1959
Synsphaeridium sorediforme (Timofeev, 1959) Eisenack, 1965
Synsphaeridium gotlandicum Eisenack, 1958
**S. colonialica* Jankauskas, 1979b
**Satka squamifera* Pyatiletov, 1980

Filamentous Microfossils

Nematomorphs
Siphonophycus septatum (Schopf, 1968) Knoll *et al.*, 1991.
S. robustum (Schopf, 1968) Knoll *et al.*, 1991
S. rugosum (Maithy, 1975) Hofmann & Jackson, 1994
S. kestron Schopf, 1968
S. capitaneum Nyberg & Schopf, 1984
**Polythrichoides lineatus* (German, 1974) Knoll *et al.*, 1991
* *Karamia segmentata* Jankauskas *et al.*, 1989
Tortunema pseudoseptata (Germann, 1990) Butterfield *et al.*, 1994
Arctacellularia ellipsoidea German in Timofeev *et al.*, 1976
A. tetragonala (Maithy, 1975) Hofmann & Jackson, 1994
Oscillatoriopsis psilata Maithy & Shukla, 1977
Chlorogloeaopsis kanshiensis (Maithy, 1975) Hofmann & Jackson, 1994
C. contexta (German, 1976) Hofmann & Jackson, 1994
**Obruchevella valdaica* (Shepeleva ex Aseeva, 1974) Jankauskas *et al.* in Jankauskas, 1989

PLATE 3 ⟶

Organic-walled microfossils from the Koldaha Shale (Kheinjua Subgroup). Illustrated specimens from the Barhi-Badanpur-Maihar and the Jhal-Bihara outcrop sections, and the DMH-A well (1930-940 m depth interval), representing the Koldaha Shale succession. Scale bar = 10 μm.

1, 3, 4. *Tappania tubata* Yin. 1. DMH-A, 1390-95m/2 EFR G 72. 3. DMH-A, 1380-85m/1; EFR N 45. 4. DMH-A, 1450-55m/2; EFR N 56.
2, 5. *Tappania plana* Yin. 2. DMH-A, 1400-05m/2; EFR F 35/4. 5. DMH-A, 1380-85m/2; EFR F 40.
6. *Navifusa segmentata* Prasad & Asher. DMH-A, 1720-25m/1; EFR P 28.
7, 9. *Pterospermopsimorpha insolita* (Timofeev) Mikhailova. 7. DMH-A, 1675-80m/1; EFR F 63/1. 9. S-9/2; EFR O 65/2.
8. *Simia annulare* (Timofeev) Mikhailova & Jankauskas. S-8/C/1; EFR E 43/2.
10. *Navifusa majensis* Pyatiletov. DMH-A, 1205-10m/1; EFR N 44/1.
11. *Arctacellularia ellipsoidea* German. DMH-A, 1575-80m/1; EFR O 62/4.
12. *Arctacellularia tetragonala* (Maithy) Hofmann & Jackson. DMH-A, 1505-10m/2; EFR N 54.
13, 14. *Leiosphaeridia jacutica* (Timofeev) Mikhaylova & Jankauskas. 13. S-9/2; EFR S 64. 14. S-9/2; EFR K 47/1.
15. *Leiosphaeridia tenuissima* Eisenack. S-9/2; EFR U 41/4.
16. *Kildinosphaera chagrinata* Vidal in Vidal & Siedlecka. II/55D/7; EFR X 55/4.

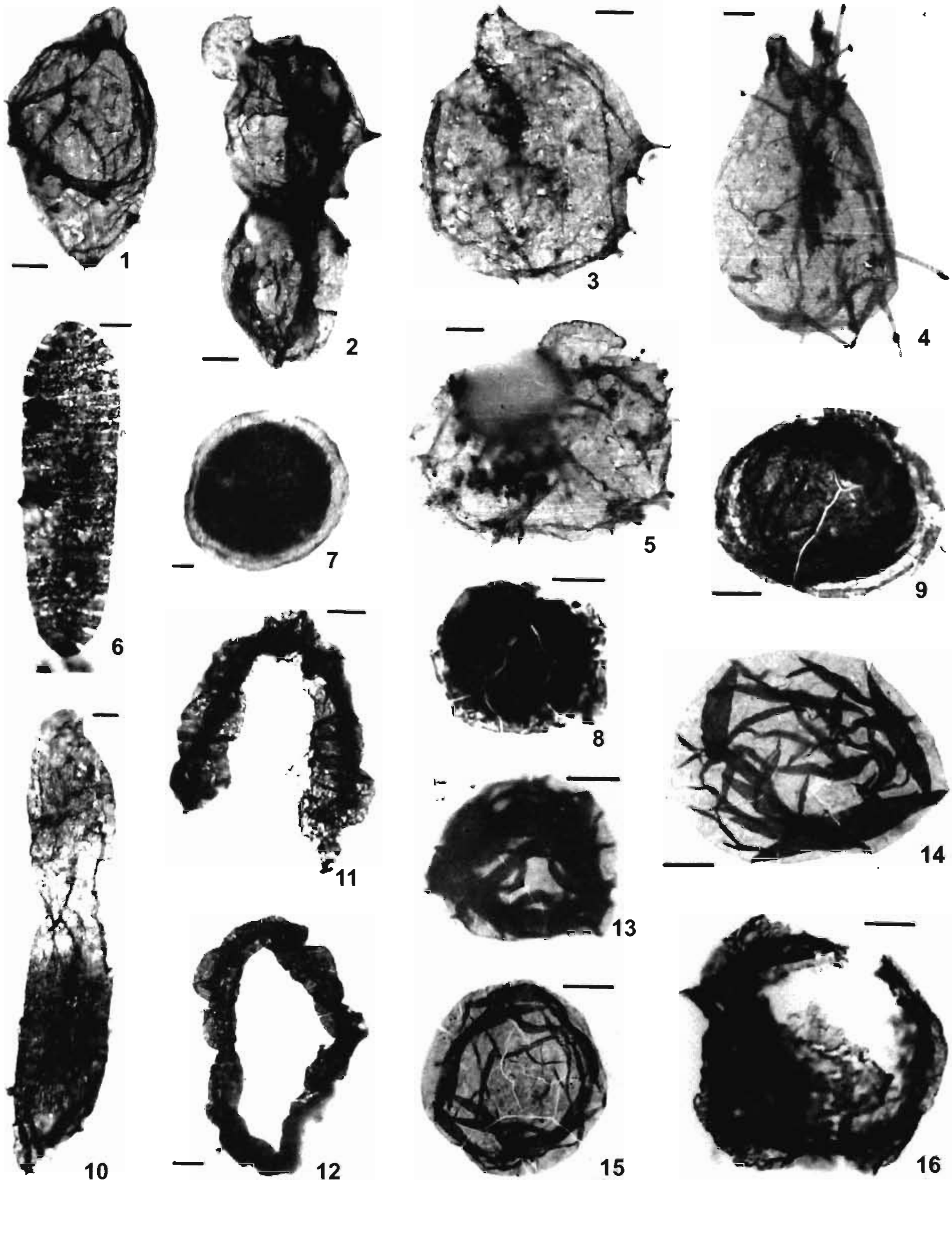

PLATE 3

**Obruchevella parva* Reitlinger, 1959
**Obruchevella delicata* Reitlinger, 1948
**O. parvissima* Song, 1984

Vase-shaped Microfossils

Melanocyrillium sp.

SYSTEMATICS

Group—ACRITARCHA Evitt, 1963

Subgroup—SPHAEROMORPHITAE Downie *et al.*, 1963

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

Type species—LEIOSPHAERIDIA BALTICA Eisenack, 1958.

LEIOSPHAERIDIA KULGUNICA Jankauskas, 1980b

(Pl. 5.14, 19)

Description—Vesicle sphaerical to subsphaerical, thin, single-walled; surface smooth to finely scabrate, with irregular folds. A distinct circular pylome (? excystment) present on the vesicle, having a narrow and thickened lip-like margin around the opening.

Dimensions—Vesicle diameter 36-70 μm, pylome diameter 13-15 μm.

Occurrence—*Leiosphaeridia kulgunica* appears in the Salkhan Limestone and ranges upto the Bhander Group in the Vindhyan basin. This species is mainly recorded from the Early to Middle Neoproterozoic sediments of Norway (Vidal & Knoll, 1983), Russian Platform (Jankauskas, 1980b) and China (Yin & Guan, 1999).

Genus—TRACHYSPHAERIDIUM Timofeev 1959 ex Timofeev, 1966

Type species—TRACHYSPHAERIDIUM ATTENUATUM Timofeev, 1959.

TRACHYSPHAERIDIUM LAMINARITUM (Timofeev, 1966) Vidal, 1976a

(Pl. 6.1; Pl. 8.11)

Description—Vesicle spherical, with thick vesicle- wall; surface ornamented by the sculptural elements of rugulae and alveoli. Sculptural elements coalesced, forming a pseudo-reticulate texture. Vesicle appears enclosed in thin and transparent envelope.

Dimensions—Vesicle diameter 37-52 μm.

Occurrence—This species appears in the Rampur Formation within Kheinjua Group and range upto the Sirbu Shale within the Bhander Group. Outside India, *T. laminaritum* is recorded from the Early to Late Neoproterozoic (ca 850-600 Ma) sediments of Sweden, Norway (Vidal, 1976a; Vidal & Knoll, 1983) and North China (Yin & Guan, 1999).

TRACHYSPHAERIDIUM LAUFELDI Vidal, 1976a

(Pl. 7.13; Pl. 11.8)

Description—Vesicle spherical, with thickened wall; surface ornamented by sparsely distributed sculptural elements of grana and echinae (small spines). A distinct, circular, rimmed opening present on the vesicle, opening often with a bulbous protrusion.

Dimensions—Vesicle diameter 44-50 μm, circular opening diameter 9-12 μm.

Occurrence—In Vindhyan Basin, this species appears in the Rampur Formation, and ranges upto the Sirbu Shale within the Bhander Group. *T. laufeldi* is recorded from the Early to Late Neoproterozoic (ca 850-600 Ma) sediments of Sweden and Norway (Vidal, 1976a; Vidal & Knoll, 1983) and North China (Yin & Guan, 1999).

Genus—FAVOSOSPHAERIDIUM Timofeev, 1966

Type species—FAVOSOSPHAERIDIUM SCANDICUM Timofeev, 1966.

FAVOSOSPHAERIDIUM FAVOSUM Timofeev, 1966

(Pl. 10.18)

PLATE 4 ⟶

Organic-walled microfossils from the Koldaha Shale (Kheinjua Subgroup). Illustrated specimens from the Barhi- Badanpur-Maihar and the Jhal-Bihara outcrop sections, and the DMH-A well (1930-940 m depth interval), representing the Koldaha Shale succession. Scale bar = 10 μm.

1. *Eosynechococcus moorei* Hofmann. S-8/C/1; EFR D 49/2.
2. *Tetraphycus diminutivus* Oehler. S-8/C/1; EFR V 34/2.
3, 4. *Sphaerophycus* sp. 3. S-9/2; EFR Q 44/3. 4. S-9/2; EFR S 70/4.
5. *Eomicrocystis elegans* Golovenok & Belova. S-9/2; EFR O 32.
6. *Eomicrocystis malgica* Golovenok & Belova. S-8/C; EFR S 66.
7. *Sphaerophycus parvum* Schopf. S-9/2; EFR L 73/1.
8. *Synsphaeridium sorediforme* (Timofeev) Eisenack. S-9/2; EFR O 43/2.
9. *Symplassosphaeridium tumidulum* Timofeev. S-8/C; EFR W 47/2.
10, 13. *Satka squamifera* Pyatiletov. 10. S-9/2; EFR P 63/1. 13. S-9/2; EFR L 61/1.
11, 15. *Satka colonialica* Jankauskas. 11. S-9/2; EFR M 74/3. 15. S-9/2; EFR Q 71.
12. *Leiosphaeridia jacutica* (Timofeev) Mikhailova & Jankauskas. S-9/2; EFR S 57/4.
14. *Kildinosphaera granulata* Vidal. S-9/2; EFR X 64/1.
16. *Leiosphaeridia crassa* (Naumova) Jankauskas. S-9/2; EFR Y 30.
17. *Leiosphaeridia tenuissima* Eisenack. S-8/A/1; EFR T 67/2.
18. *Lophosphaeridium granulatum* Maithy. S-8/C/2; EFR G 44/2.

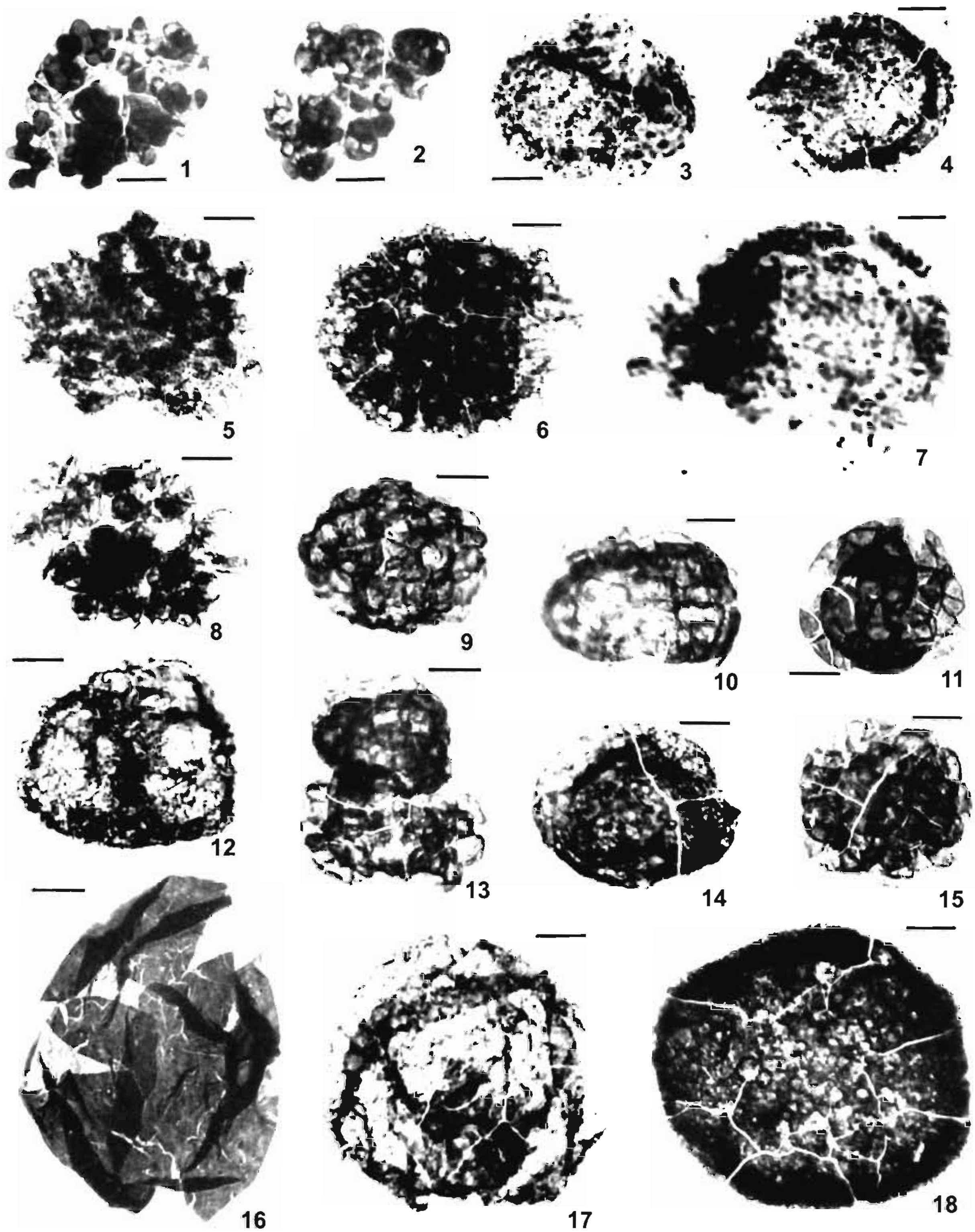

PLATE 4

Description—Vesicle spherical with oval outline, stout; surface covered with well-developed, irregular, microreticulated networks. Vesicle associated with irregular thin folds.

Dimensions—Vesicle diameter 102-120 μm.

Occurrence—This species appears in the Nagod Limestone within the Bhander Group and ranges upto the Sirbu Shale. *F. favosum* is recorded from the Late Neoproterozoic to Terminal Proterozoic sediments of Sweden and Norway (Vidal & Knoll, 1983).

Genus—LOPHOPSPHAERIDIUM Timofeev, 1959 ex Downie, 1963

Type species—LOPHOSPHAERIDIUM RARUM Timofeev, 1959

LOPHOPSPHAERIDIUM RARUM Timofeev, 1959

(Pl. 10.9, 10)

Description—Vesicle subspherical to subtriangular, thick-walled; vesicle surface ornamented by the closely placed small solid tubercles and spines with pointed ends.

Dimensions—Vesicle diameter 40-44 μm, tubercles 2 μm long.

Occurrence—*L. rarum* appears rarely in the Nagod Limestone and persists in the Sirbu Shale. This taxon is very common in the Early and Middle Cambrian sediments with earliest records from the latest Ediacaran-Early Cambrian (Volkova, 1968; Downie, 1974).

LOPHOPSPHAERIDIUM sp. cf. **L. TRUNCATUM** Volkova, 1969

(Pl. 10.8, 14)

Description—Vesicle spherical, thick-walled, become subtiangular to quadrangular due to compressions; surface ornamented by sparsely distributed well-developed small solid tubercles.

Dimensions—Vesicle diameter 42-46 μm, tubercles 2-3 μm long.

Remarks—The Vindhyan specimens are larger in size, and tubercles are sparsely distributed. So, these specimens are compared with the *L. truncatum,* and not assigned to it.

Occurrence—This species appears rarely in the Nagod Limestone and persists in the overlying Sirbu Shale within the Bhander Group. *L. truncatum* is a common element of Cambrian acritarch assemblages with its earliest records from the Early Cambrian (Volkova *et al.,* 1979; Knoll & Swett, 1987; Moczydlowska, 1991).

Subgroup—NETROMORPHITAE Downie, Evitt & Sarjeant, 1963

Genus—NAVIFUSA Combaz, Lange & Pansart, 1967

Type species—NAVIFUSA NAVIS Eisenack, 1938.

NAVIFUSA MAJENSIS Pyatiletov, 1980

(Pl. 3.10; Pl. 5.15; Pl. 7.1, 8)

Description—Cylindrical, nonseptate, longitudinally elongate (naviform) vesicle, tapers at both the longitudinal ends with rounded tips. Vesicle-wall smooth, often associated with thin folds, folds generally running parallel to the long axis of the vesicle.

Dimensions—Vesicle 50-225 μm (length) x 27-40 μm (breadth).

Occurrence-In Vindhyan basin, *N. majensis* shows the restricted occurrence within the Kheinjua Subgroup with its appearance in the Koldaha Shale and disappearance in the upper part of the Rampur Formation. Elsewhere, its earliest records are known from the Middle to Late Mesoproterozoic

PLATE 5 ⟶

Organic-walled microfossils from the Salkhan Limestone (Kheinjua Subgroup). Illustrated specimens from the Jhal-Bihara outcrop section, and the DMH-A well (940-780 m depth interval), representing the Salkhan Limestone. Scale bar = 10 μm.

1, 2. *Satka squamifera* Pyatiletov. 1. II/55-G10; EFR T 37/1. 2. II/55-G10; EFR L 48.
3. *Symplassosphaeridium tumidulum* Timofeev. II/55-G10; EFR F 31.
4. *Eomicrocystis elegans* Golovenok & Belova. DMH-A, 930-35m/1; EFR F 61/1.
5. *Eomicrocystis malgica* Golovenok & Belova. DMH-A, 930-35m/1; EFR P 28.
6. *Eoentophysalis belcherensis* Hofmann. II/55-G10 ; EFR H 34/3.
7. *Tetraphycus gregalis* Oehler. II/55-G10 ; EFR U 57/2.
8. *Leiosphaeridia asperata* (Naumova) Lindgren. II/55-G10; EFR K 47/1.
9. *Simia annulare* (Timofeev) Mikhailova & Jankauskas. II/55-G10; EFR R 42.
10, 11. *Tappania plana* Yin. 10. DMH-A, 930-35m/1; EFR N 43/4. 11. II/55-G 10; EFR O 29/3.
12. *Siphonophycus robustum* (Schopf) Knoll, Swett & Mark. DMH-A, 930-35m/1; EFR R 32/3.
13 *Stictosphaeridium sinapticulum* Timofeev. II/55-G10; EFR K 40.
14, 19. *Leiosphaeridia kulgunica* Jankauskas. 14. II/55-G10; EFR R 32/3. 19. II/55-G10; EFR D 62.
15. *Navifusa majensis* Pyatiletov. DMH-A, 870-75m/1; EFR N 35/1.
16. *Navifusa segmentata* Prasad & Asher. DMH-A, 800-05m/1; EFR G 37.
17. *Pterospermopsimorpha insolita* Timofeev. DMH-A, 855-60m; EFR O 47.
18. *Leiosphaeridia crassa* (Naumova) Jankauskas. II/55-G10; EFR L 34/2.

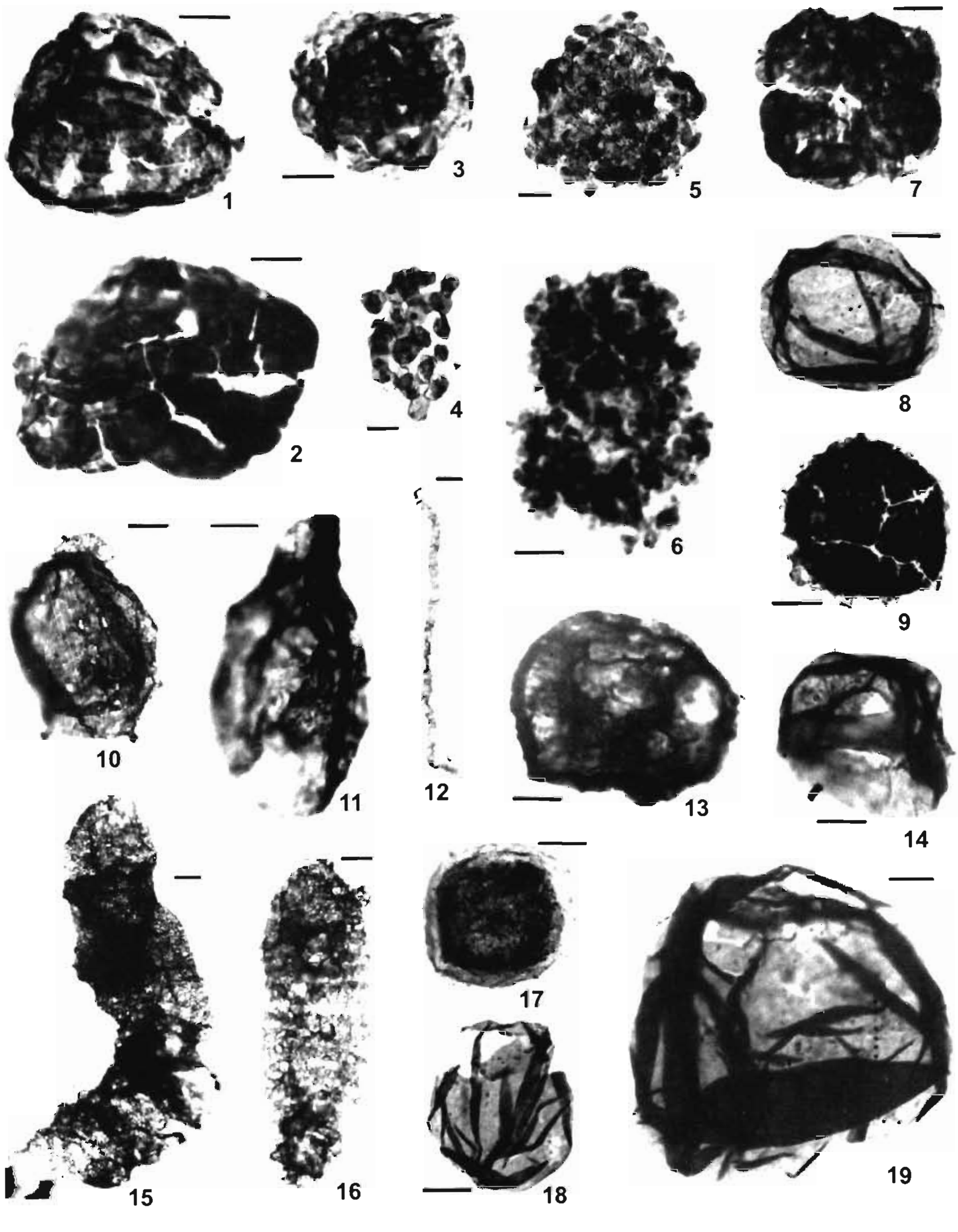

PLATE 5

sediments (Hofmann & Jackson, 1994; Prasad & Asher, 2001) and range upto the Early Neoproterozoic (Jankauskas, 1980b).

NAVIFUSA SEGMENTATA Prasad & Asher, 2001

(Pl. 3.6; Pl. 5.16; Pl. 7.10, 16)

Description—Cylindrical, septate, longitudinally elongate (naviform) vesicle, tapers at both the longitudinal ends with rounded tips. Vesicle-wall smooth to scabrate, divided into a number of rectangular chambers or segments by the transeverse striations or grooves, vesicle often associated with irregular thin folds.

Dimensions—Vesicle 66-150 µm (length) x 11-36 µm (breadth).

Occurrence—In Vindhyan basin, *N. segmentata* shows the restricted occurrence within the Kheinjua Subgroup. It appears in the Koldaha Shale and disappears at the upper boundary of the Rampur Formation. This species was originally recorded from the Middle Mesoproterozoic (ca. 1350 Ma) sediments (Bahraich Group) of Ganga Basin (Prasad & Asher, 2001). Later on, Yin and Yuan (2002) recorded this species from the Late Mesoproterozoic (ca. 1200-1100 Ma) Beidajian Formation (Ruyang Group), Shanxi, China and cosidered it as Middle to Late Mesoproterozoic age-potential taxa.

Subgroup—ACANTHOMORPHITAE Downie *et al.*, 1963

Genus—TAPPANIA Yin, 1997

Type species—TAPPANIA PLANA Yin, 1997.

TAPPANIA PLANA Yin, 1997

(Pl. 2.6; Pl. 3.2, 5; Pl. 5.10, 11; Pl. 6.11)

Description—Acanthomorph acritarch, vesicle subspherical, oval to broadly elliptic, with a prominent, neck-like trapezoid extension (projection) on one side of the vesicle, having a fimbriate distal margin. Vesicle bears irregularly distributed, hollow, heteromorphic, conical to tubular processes; processes distally tapering as accumulate, truncate to furcate ends.

Dimensions—Vesicle diameter 50-90 µm.

Occurrence—In the Vindhyan basin, *T. plana* appears in the Deonar Formation and persists in the overlying Koldaha Shale, Fawn Limestone and disappears in the Rampur Formation. The earliest record of *T. plana* is from the late Early Mesoproterozoic (ca. 1450 Ma) sediments of central Australia (Zang & Walter, 1989), and abundantly occurs in Middle and Late Mesoproterozoic sediments of China and India (Yin, 1997; Prasad & Asher, 2001).

TAPPANIA TUBATA Yin, 1997

(Pl. 2.5; Pl. 3.1, 3, 4; Pl. 6.12, 13)

Description—Acanthomorph acritarch, vesicle subspherical to oval, with a prominent, apically neck-like tubular projection /extention. Surface bears well developed, irregularly distributed hollow, often long, heteromorphic, conical to tubular processes that distally taper as accumulate, truncate to furcate ends with often darkened mass.

Remarks—The apically neck-like projection/extension on one side of the vesicle in *T. tubata* is elongate tubular, whereas trapezoid in *T. plana*.

Dimensions—Vesicle diameter 40-80 µm.

Occurrence—*T. tubata* appears in the Deonar Formation and persists in the overlying Koldaha Shale, Fawn Limestone and disappears in the upper parts of Rampur Formation. Its oldest record is from the late Early Mesoproterozoic (ca, 1450 Ma) sediments of central Australia (Zang & Walter, 1989), and occurs quite abundantly in Middle to Late Mesoproterozoic (ca. 1350-1050 Ma) sediments of China and India (Yin, 1997; Prasad & Asher, 2001).

Genus—VANDALOSPHAERIDIUM Vidal, 1981

Type species—VANDALOSPHAERIDIUM RETICULATUM (Vidal) Vidal, 1981.

VANDALOSPHAERIDIUM RETICULATUM (Vidal) Vidal, 1981

(Pl. 6.5, 6; Pl. 9.23; Pl. 11.12, 13)

Description—Vesicle large, spherical to subspherical. Vesicle surface ornamented with numerous regularly arranged, short processes; processes support outer membrane of the vesicle.

PLATE 6 ⟶

Organic-walled microfossils from the Rampur Formation (Kheinjua Subgroup). Illustrated specimens from the Jhal-Bihara outcrop section, and the DMH-A well (780-620 m depth interval), representing the Rampur Formation. Scale bar = 10 µm.

1. *Trachysphaeridium laminaritum* (Timofeev) Vidal. II/168/1; EFR,G 66/3.
2. *Leiosphaeridia asperata* (Naumova) Lindgren. II/168/2; EFR V 69/2.
3. *Trachyhystrichosphaera truncata* German & Jankauskas in Jankauskas. II/168/2; EFR W 57/1.
4. *Gangasphaera bulbousus* Prasad & Asher. II/168/1; EFR P 48/3.

5, 6. *Vandalosphaeridium reticulatum* (Vidal) Vidal. 5. II/168/1; EFR T 66/2. 6. II/168/1; EFR D 51.

7. *Vandalosphaeridium varangeri* (Vidal) Vidal. II/168/1; EFR O 47/3.

8, 9, 10. *Melanocyrillium* sp. 8. II/168/1; EFR J 57. 9. II/168/2; EFR K 71/4. 10. II/168/1; EFR H 62/1.

11. *Tappania plana* Yin. II/168/1; EFR L 48/4.
12. *Tappania* sp. cf. *T. tubata* Yin. II/168/2; EFR J 66/4.
13. *Tappania tubata* Yin. II/168/1; EFR J 34.

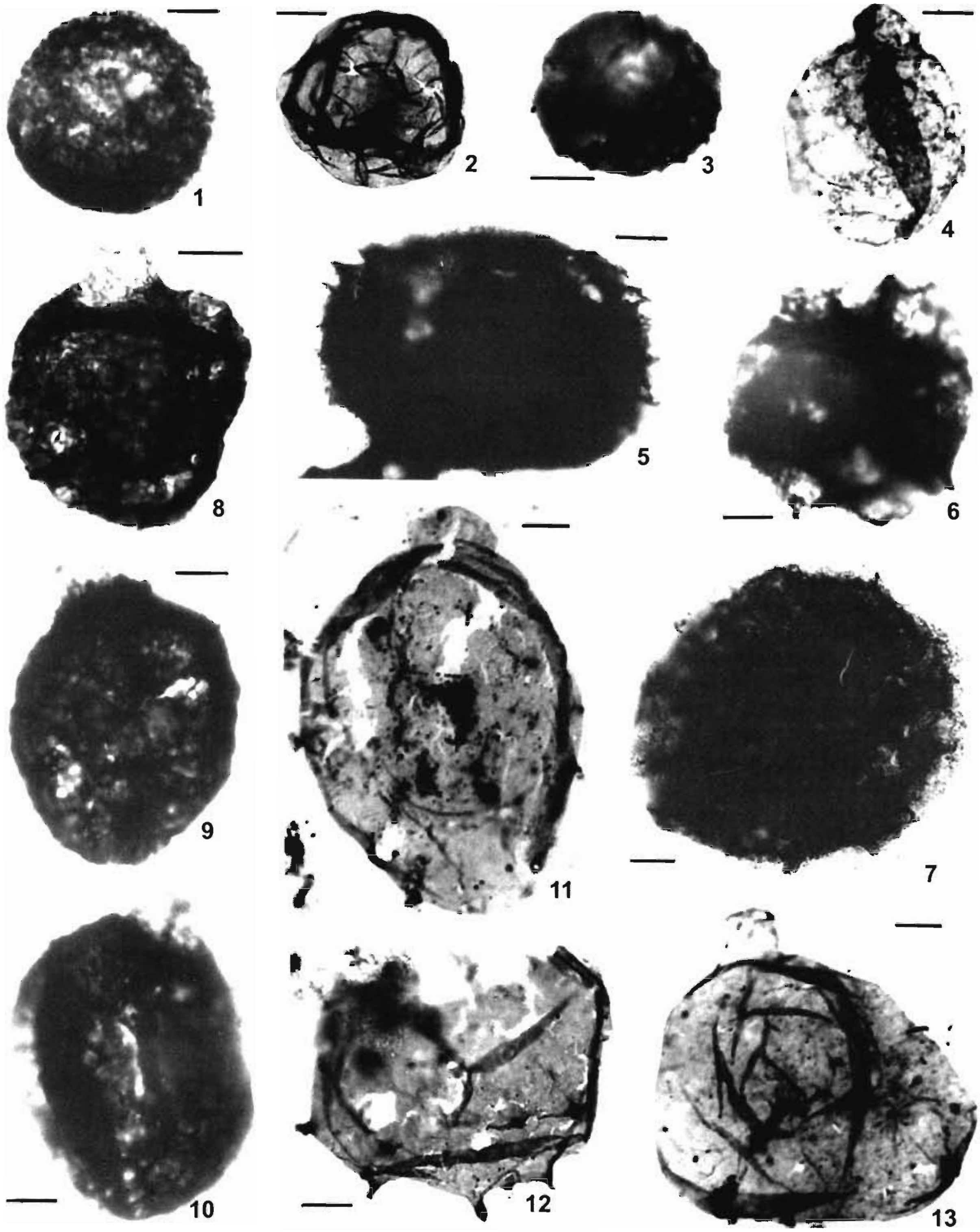

PLATE 6

Dimensions—Vesicle diameter 51-70 μm, processes 3-5 μm long.

Occurrence—This species appears in the Rampur Formation and occurs rarely upto the Sirbu Shale. The earliest record of this species is from the Middle Neoproterozoic sediments of Sweden and Norway (Vidal & Knoll, 1983), and is an important element of the Late Neoproterozoic assemblages (Knoll, 1996).

Genus—TRACHYHYSTRICHOSPHAERA German in Timofeev *et al.*, 1976 emend. German & Jankauskas in Jankauskas, 1989

Type species—TRACHYHYSTRICHOSPHAERA AIMIKA German in Timofeev *et al.,* 1976.

TRACHYHYSTRICHOSPHAERA TRUNCATA German & Jankauskas in Jankauskas, 1989

(Pl. 6.3)

Description—Vesicle spherical and thick, single layered with chagrinate surface. Vesicle bears sparsely distributed short, spine-like processes that communicate with the vesicle.

Dimensions—Vesicle diameter 30-35 μm, processes 2-3 μm long.

Occurrence—This species occurs rarely in the Rampur Formation of the Semri Group. This species is originally recorded from the Early Neoproterozoic (ca. 1000-900 Ma) Lakhanda Formation of eastern Siberia (German in Timofeev *et al.,* 1976). This species is also known to occur in the Late Neoproterozoic and Terminal Proterozoic sediments of Siberia (Jankauskas, 1989) and India (Prasad & Asher, 2001).

Remarks—Butterfield *et al.* (1994), in their emendation, suggested that the *T. truncata* is an entirely a distinct taxon, and does not fit into the circumscription of *Trachyhystrichosphaera*. However, at present, this specimen is placed under the *T. truncata* German and Jankauskas.

Genus—GERMINOSPHAERA Mikhailova, 1986 emend. Butterfield in Butterfield *et al.*, 1994

Type species—GERMINOSPHAERA BISPINOSA Jankauskas, 1989.

GERMINOSPHAERA UNISPINOSA Jankauskas, 1989

(Pl. 10.3; Pl. 11.1, 2)

Description—Vesicle spherical to subspherical, single layered. Vesicle wall scabrate to granulate, often with irregular folds. A long single prominent process emerges from one end of the vesicle; process broad at base, distally tapers into a pointed end, process not communicating with the vesicle.

Dimensions—Vesicle diameter 30-36 μm, process 9-65 μm long.

Occurrence—*G. unispinosa* appears in the Nagod Limestone and become common in the overlying Sirbu Shale. Although the earliest records of this species are from the Early Neoproterozoic sediments in eastern Officer Basin, Australia (Zang, 1995), it is quite common in the latest Neoproterozoic and Terminal Proterozoic sediments of Svalbard (Butterfield *et al.,* 1994), China (Yin & Wang, 1990) and India (Prasad & Asher, 2001).

GERMINOSPHAERA BISPINOSA Jankauskas, 1989

(Pl. 11.3)

Description—Vesicle spherical, thin, single layered; vesicle surface psilate to scabrate, with numerous irregular folds. A single long process emerges from one end of the vesicle, witout communicating with the vesicle; process broad at base, distally bifurcates into the two 6-9 μm long proccesses, each processes distally pointed with closed ends.

Dimensions—Vesicle diameter 30-36 μm, processes 10-15 μm long.

Occurrence—In the Vindhyan Basin, this species rarely

PLATE 7 ⟶

Organic-walled microfossils from the Rampur Formation (Kheinjua Subgroup). Illustrated specimens from the Jhal-Bihara section, and the DMH-A well (780-620m depth interval), representing the Rampur Formation. Scale bar = 10μm.

1, 8. *Navifusa majensis* Pyatiletov. Fig. 1, II/168/1; EFR N 58/1. Fig. 8, DMH-A, 680-85m/1; EFR V 56/4.

2, 3, 5. Budding leiosphaerids. 2. II/168/2; EFR L 31. 3. II/168/2; EFR W 43/3. 5. II/168/2; EFR T 60/1.

4. *Eomicrocystis malgica* Golovenok & Belova. II/168/2; EFR P 31.

6, 11. *Satka colonialica* Jankauskas. 6. II/168/2; EFR B 60/2. 11. II/168/2; EFR D 52/1.

7. *Chlorogloeaopsis kanshiensis* (Maithy) Hofmann & Jackson. II/168/1; EFR N 63/2.

9. *Chlorogloeaopsis contexta* (German) Hofmann & Jackson. DMH-A, 690-95m/1; EFR V 54/3.

10, 16. *Navifusa segmentata* Prasad & Ashaer. 10. DMH-A, 640-45m/2; EFR U 33/3. 16. DMH-A, 680-85m/2; EFR H 28/2.

12. *Satka squamifera* Pyatiletov. II/168/2; EFR O 72/1.

13. *Trachysphaeridium* sp. cf. *T. laufeldi* Vidal. II/168/2; EFR V 50.

14. *Stictosphaeridium implexum* Timofeev. II/168/2; EFR S 35.

15. *Arctacellularia tetragonala* (Maithy) Hofmann & Jackson. DMH-A, 690 -95m/1; EFR W54.

17. *Siphonophycus rugosum* (Maithy) Hofmann & Jackson. II/168/1; EFR F69/4.

18. *Kildinosphaera granulata* Vidal in Vidal & Siedlecka. II/168/2; EFR M47/3.

19. *Kildinosphaera verrucata* Vidal in Vidal & Siedlecka. II/168/1; EFR S 29/4.

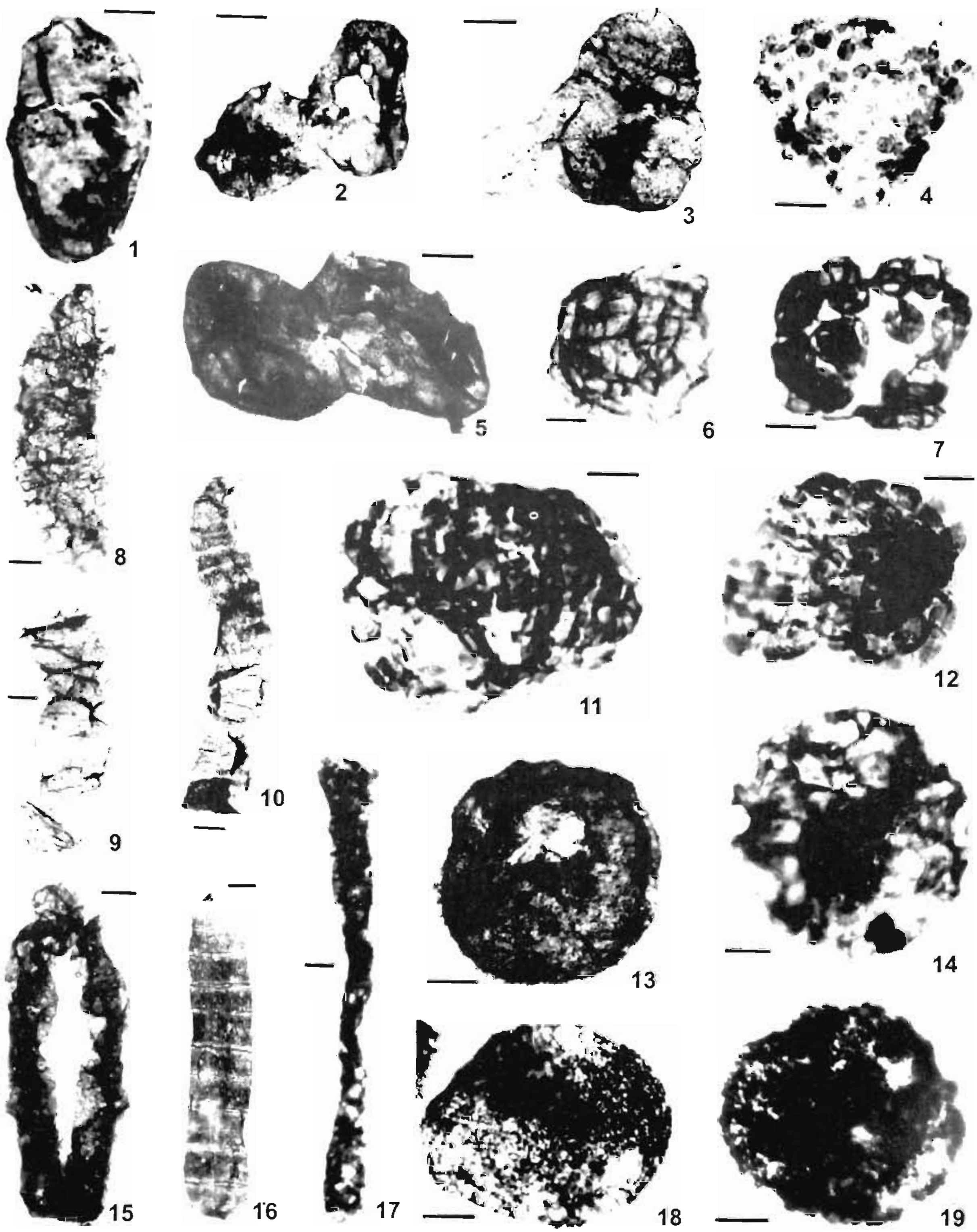

PLATE 7

occurs in the uppermost lithounit of the Vindhyan Supergroup within the Sirbu Shale. Although, its earliest records are from the Early Neoproterozoic (Jankauskas, 1989), it is quite common in the Late Neoproterozoic and Terminal Proterozoic sediments (Butterfield *et al.*, 1994).

Subgroup—PTEROMORPHITAE Downie *et al.*, 1963

Genus—SIMIA Mikhailova & Jankauskas in Jankauskas, 1989

Type species—SIMIA ANNULARE (Timofeev, 1969) Mikhailova & Jankauskas in Jankauskas, 1989.

SIMIA ANNULARE (Timofeev, 1969) Mikhailova & Jankauskas in Jankauskas, 1989

(Pl. 3.8; Pl. 5.9)

Description—Vesicle small, spherical to subsphaerical, double-walled; inner part comparatively dark and thickened, appears enveloped by a thin outer transparent layer; outer layer slightly extends beyond the vesicle periphery, showing a narrow peripheral transparent rim.

Dimensions—Vesicle diameter 30-36 µm.

Discussion—*Simia* and *Pterospermopsimorpha* are similar in morphology. However, the outer transparent layer in *Simia* completely envelops the vesicle; whereas, a narrow transparent zone is formed around the vesicle peripheral margins in *Pterospermopsimorpha*.

Occurrence—In the Vindhyan basin, *Simia annulare* appears in the Koldaha Shale and persists in the overlying Fawn Limestone and Rampur Formation. It disappears in the upper parts of the Rohtas Subgroup. Its oldest record is from the Middle Mesoproterozoic (ca, 1350 Ma) sediments of India (Prasad & Asher, 2001), and very common in the Late Mesoproterozoic to Late Neoproterozoic sediments (Samuelsson *et al.*, 1999; Yin & Guan, 1999).

Subgroup—HERKOMORPHITAE Downie, Evitt & Sarjeant, 1963

Genus—DICTYOTIDIUM Eisenack 1955 emend. Staplin, 1961

Type species—DICTYOTIDIUM DICTYOTUM Eisenack, 1938.

DICTYOTIDIUM sp.

(Pl. 11.4-7)

Description—Spharical to subspherical globular vesicle, single layered; vesicle surface divided into a number of irregular reticulate campi, ridges thin and low, lacunal areas polygonal.

Dimensions—Vesicle diameter 27-57 µm.

Comparison—The Vindhyan specimens of *Dictyotidium* differ from the known species of this genus in being smaller in size and having low ridges. So, these specimens are identified as the *Dictyotidium* sp., rather assign it to the species.

Occurrence—This form is recorded rarely in the Sirbu Shale. The earliest records of *Dictyotidium* are from the Early Cambrian sediments (Volkova *et al.*, 1979; Moczydlowska, 1991), and common constituents of the Middle and Late Cambrian assemblages.

Genus—CYMATIOSPHAERA Wetzel, 1933

Type species—CYMATIOSPHAERA RADIATA Wetzel, 1933.

CYMATIOSPHAERA sp.

(Pl. 10.17; Pl. 11.18)

Description—Vesicle subspherical with polygonal outline; central body indiscernible, a relatively darkened polygonal area present at the center of the vesicle. Vesicle

PLATE 8 →

Organic-walled microfossils from the Rohtas Subgroup. Illustrated specimens from the Jhal-Bihara outcrop section, and the DMH-A well (625-575 m depth interval), representing the Rohtas Subgroup. Scale bar = 10 µm.

1. *Oscillatoriopsis* sp. DMH-A, 625-30m/1; EFR J 63/3.
2. *Bavlinella faveolata* emend. Schepeleva Vidal. II/388/1; EFR F 45.
3. *Symplassosphaeridium tumidulum* Timofeev. II/388/2; EFR L 43/4.
4. *Stictosphaeridium sinapticulum* Timofeev. II/388/1; EFR X 55/4.
5. *Stictosphaeridium implexum* Timofeev. II/388/1; EFR G 49.
6. *Satka squamifera* Pyatiletov. DMH-A, 565- 570m/1; EFR P 67/3.
7. *Satka colonialica* Jankauskas. II/388/2; EFR P 70.
8. *Lophosphaeridium jansoniusii* Salujha, Rehman & Arora. DMH-A, 565- 570m/1; EFR T 57/2.
9. *Leiosphaeridia asperata* (Naumova) Lindgren. II/388/2; EFR N 56.
10. *Kildinosphaera granulata* Vidal. II/388/2; EFR U 60/1.
11. *Trachysphaeridium laminaritum* (Timofeev) Vidal. II/388/1, EFR S 32/1.
12. *Kildinosphaera verrucata* Vidal in Vidal & Siedlecka. II/388/2; EFR G 48/2.
13. *Pterospermopsimorpha saccata* Yin. II/388/1; EFR M 32/1
14. *Karamia segmentata* Jankauskas, Mikhailova & German. DMH-A, 650-55/2m; EFR W 46.
15. *Oscillatoriopsis psilata* Maithy. DMH-A, 625- 30m/1; EFR J 38/2.

16, 17. *Leiosphaeridia tenuissima* Eisenack. 16. II/388/1; EFR V 23/2. 17. II/388/2; EFR V 24/2.

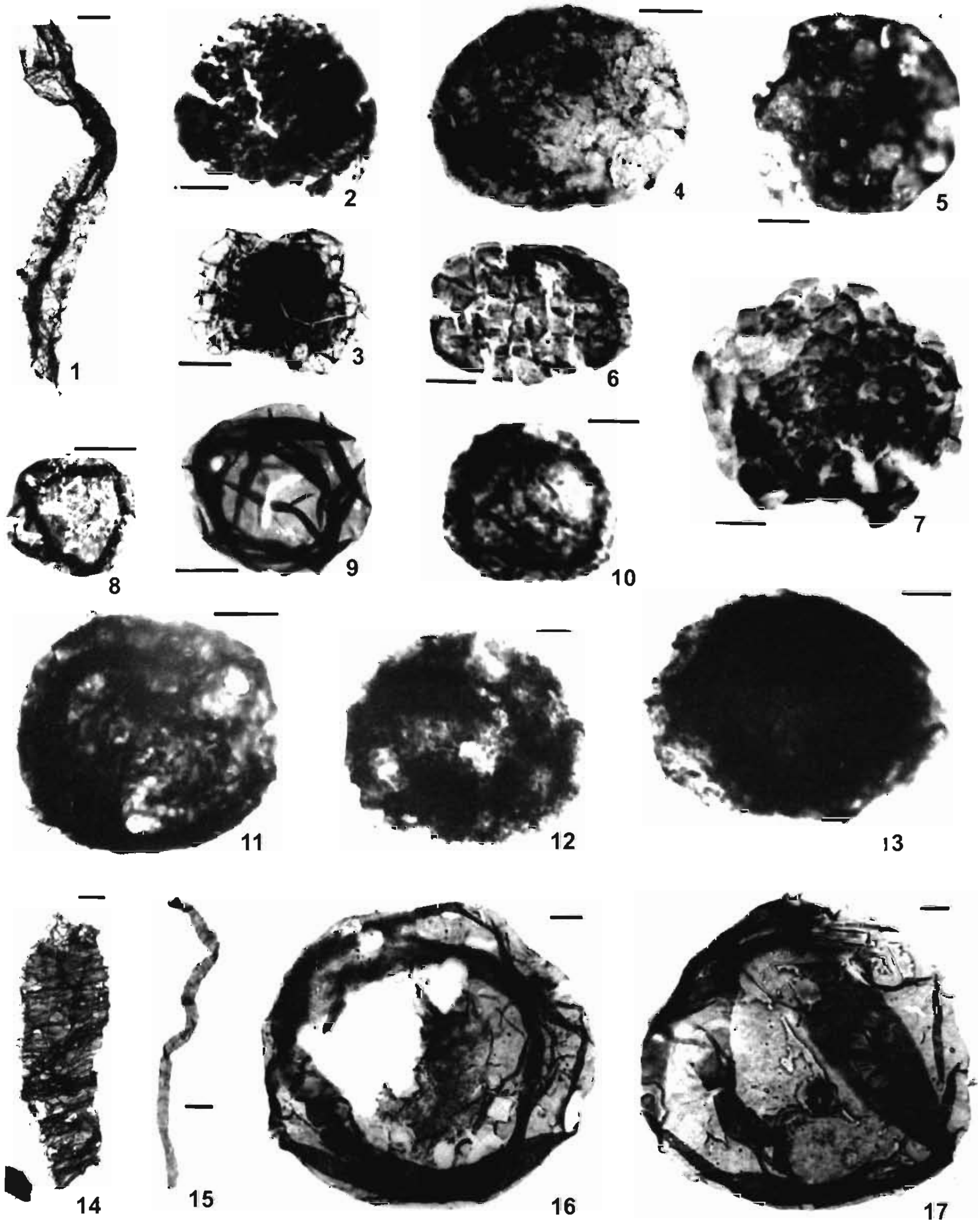

PLATE 8

surface divided into a number of distinct well-developed polygonal chambers (campi); campi separated by raised thickened, and granulated muri (ridges).

Dimensions—Vesicle diameter 78-84 µm.

Comparison—The Vindhyan specimens of *Cymatiosphaera* differ from the known species of this genus in being the bigger in size and having very thick ridges. These specimens are identified as the *Cymatiosphaera* sp. rather assign it to the species level.

Occurrence—This species appears in the Nagod Limestone, and continues to occur in the Sirbu Shale. The earliest records of *Cymatiosphaera* are from the Early Cambrian (Volkova *et al.*, 1979; Moczydlowska, 1991).

Genus—CRISTALLINIUM Vanguestaine, 1978

Type species—CRISTALLINIUM CAMBRIENSE (Slavikova, 1968) Vanguestaine, 1978.

CRISTALLINIUM sp. cf. **C. CAMBRIENSE** (Slavikora) Vanguestaine, 1978

(Pl. 11.17)

Description—Vesicle polyhedral with polygonal outline. Vesicle surface divided into a number of polygonal chambers (campi) by thin and slightly raised muri (ridges); ridges adorn by small coni and cristae.

Dimensions—Vesicle diameter 63-78 µm.

Comparison—The Vindhyan specimens of *Cristallinium* comparable with the *C. cambriense* (Slavikora) Vanguestaine (1978) in its morphology and ornamentation. However, the campi are not distinct as in the case of *C. cambbriense.*

Occurrence—This species appears in the Sirbu Shale and rarely occurs in this formation. The earliest records of *Cristallinium camabriense* are from the Early Cambrian sediments and forms important constituents of the early and middle Cambrian assemblages (Volkova *et al.*, 1979; Moczydlowska, 1991).

Subgroup—POLYGONOMORPHITAE Downie *et al.*, 1963

Genus—OCTOEDRYXIUM Rudavskaia, 1973 emend. Vidal, 1976a

Type species—OCTOEDRYXIUM TRUNCATUM Rudavskaia, 1973 emend. Rudavskaia in Jankauskas, 1989.

OCTOEDRYXIUM VINDHYANENSE sp. nov.

(Pl. 2.1-4)

Holotype—Pl. 2, fig.1; slide no. II/48C/5B /1; T67/3 (England Finder); size 24 x 24 µm.

Locus typicus—Jhal- Bihara section, Son valley (eastern Madhya Pradesh), India.

Stratum typicum—Deonar Formation, Semri Group (Lower Vindhyan).

Age—Early to Middle Mesoproterozoic.

Etymology—Vindhyan, refers to the hill ranges in the Northern India, on which the name "Vindhyan Basin" is derived.

Diagnosis and description—Vesicles octahedral, side margins straight to convex, often undulated (due to presevational compression); longitudinal width 17-24 mm, transeverse width 17-34mm; holotype (Pl. 2.1) measures 24 x

PLATE 9 ⟶

Organic-walled microfossils from the Kaimur and Rewa groups. Taxa in figs. 1-17 the from the Kaimur Group (DMH-A, 575- 480 m depth interval); Taxa in figs.18-26 from the Rewa Group of the Barhi-Badanpur-Maihar section, and the DMH-A well (480-320 m depth interval). Scale bar = 10 µm.

Kaimur Group :

1, 3. *Leiosphaeridia minutissima* (Naumova) Jankauskas. Fig.1, DMH-A, 520-25m/2; EFR V 44/3. Fig. 3, DMH-A, 520-25m/2; EFR J 26.

2. *Leiosphaeridia asperata* (Naumova) Lindgren. DMH-A, 520-25m/1; EFR Q 45.

4, 5. *Symplassosphaeridium tumidulum* Timofeev. Fig. 4, DMH-A, 520-25m/1; EFR N 36. Fig. 5, DMH-A, 570-75m/2; EFR M 57.

6, 7. *Bavlinella faveolata* emend. Schepeleva Vidal. 6. DMH-A, 520-25m/1; EFR U 37.

8, 9. *Synsphaeridium sorediforme* (Timofeev) Eisenack. 8. DMH-A, 520- 25m/1; EFR P 52/2. 9. DMH-A, 515-20m/2; EFR E 58/3.

10, 11. *Leiosphaeridia crassa* (Naumova) Jankauskas. 10. DMH-A, 535- 40m/1; EFR R 51/4. 11. DMH-A, 520-25m/1; EFR F 27/2.

12. *Kildinosphaera chagrinata* Vidal in Vidal & Siedlecka. DMH-A, 535-40m; EFR K 48.

13, 14. *Synsphaeridium gotlandicum* Eisenack. 13. DMH-A, 520-25m/2; EFR T 63/3. 14. DMH- A, 520-25m/2; EFR U 48.

15. *Synsphaeridium* sp. DMH-A, 535-40m/2; EFR U 41.

16. *Pterospermopsimorpha saccata* Yin. DMH-A, 520-25m/1; EFR G 35.

17. *Kildinosphaera granulata* Vidal in Vidal & Siedlecka.DMH-A, 500-505m;EFR P44.

Rewa Group :

18, 22. *Synsphaeridium sorediforme* (Timofeev) Eisenack. 18. RP-1/1; EFR U 55/2. 22. RP-1/1; EFR S 68/1

19. *Leiosphaeridia asperata* (Naumova) Lindgren. RP-1/2; EFR Q 40.

20. *Octoedryxium truncatum* Rudavaskaia emend. Rudavaskaia in Jankauskas. RP-1/1; EFR W 40.

21. *Synsphaeridium gotlandicum* Eisenack. RP-1/1; EFR N 33.

23. *Vandalosphaeridium reticulatum* (Vidal) Vidal. RP-1/2; EFR K 64/1.

24. *Bavlinella faveolata* Schepeleva emend. Vidal. RP-1/2; EFR X 59/2.

25. *Leiosphaeridia jacutica* (Timofeev) Mikhailova & Jankauskas. RP-1/1; EFR U 29.

26. *Pterospermopsimorpha saccata* Yin. DMH-A, 325-330m; EFR O 55/2.

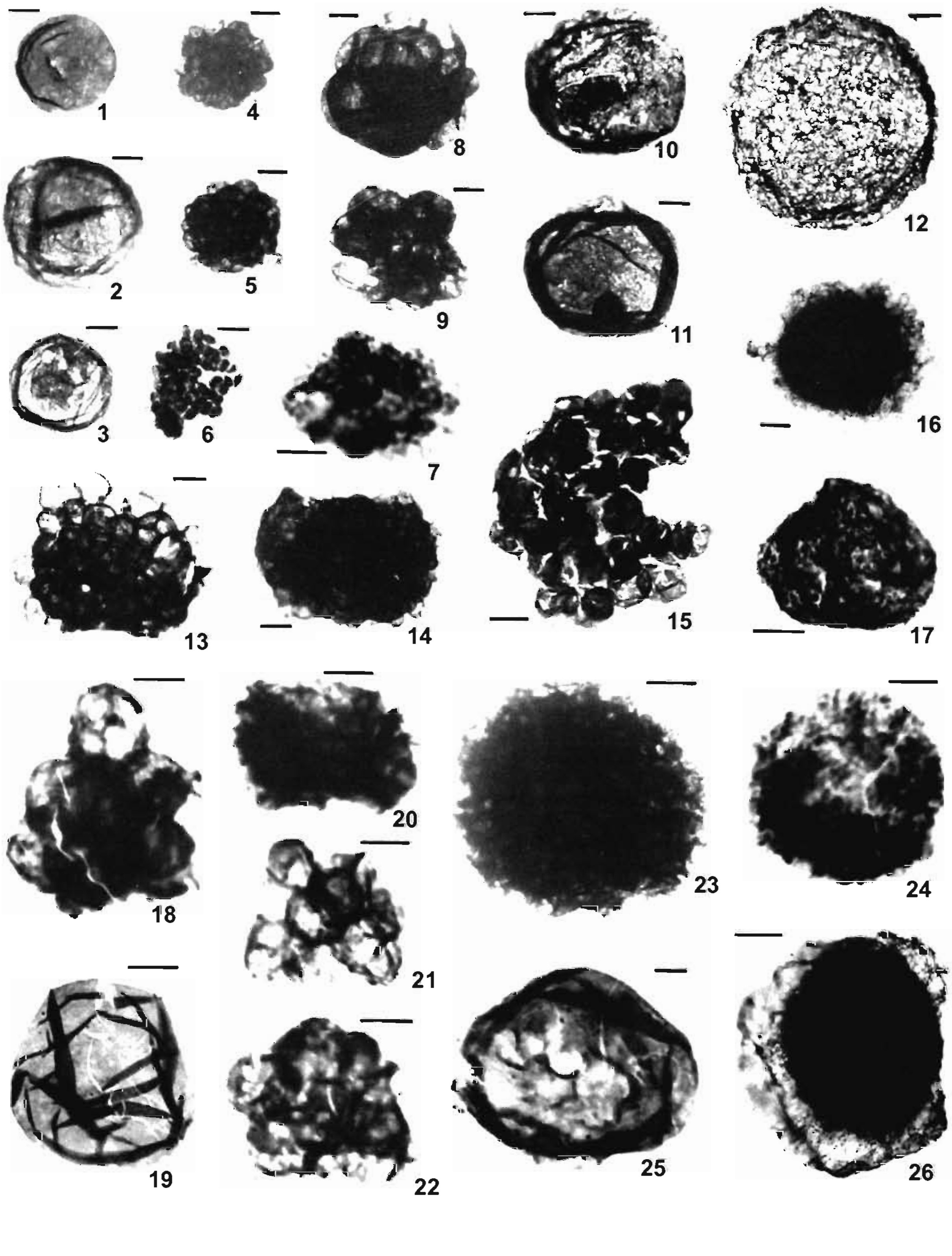

PLATE 9

24 mm. Vesicle surface granulate; joints of the faces raised, developed into swollen ridges or protuberances, protuberances often projected beyond the vesicle margins, showing processes.

Comparison—Octoedryxium vindhyanense sp. nov. differs from the type species *O. truncatum* Rudavskaia, 1973 emend. Rudavskaia, 1989 (in Jankauskas, 1989), in having granulate vesicles and being relatively smaller in size.

Occurrence—This species occurs abundantly in the Deonar Formation and within Kheinjua Subgroup, continues to occur rarely in the overlying Koldaha Shale and disappears in the upper part of Koldaha Shale.

OCTOEDRYXIUM TRUNCATUM Rudavskaia, 1973 emend. Rudavskaia in Jankauskas, 1989

(Pl. 9.20)

Description—Vesicles octahedral, sides straight to convex; longitudinal width 35-37 mm, transeverse width 24-27 µm. Vesicle surface granulate; joints of the faces raised, developed into poorly defined swollen ridges or protuberances.

Comparison—The present specimen closely compares with *O. truncatum* emend. Rudavskaia, 1973 Rudavskaia (in Jankauskas, 1989). The other species of this genus, viz. *O. vindhyanense,* recovered from the Semri Group in Vindhyan Basin, differs in having granulate vesicles and being relatively smaller in size.

Occurrence—O. truncatum appears in the Panna Shale (Rewa Group) and rarely occurs in the overlying Ganugarh Shale and Nagod Limestone units of the Bhander Group. The earliest records of *O. truncatum* are from the Late Neoproterozoic Middle Visingksö Beds, Sweden (Vidal, 1976a; Vidal & Knoll, 1983), and ranges upto Terminal Proterozoic (Knoll, 1996).

Phylum—CYANOPHYTA Stainer *et al.,* 1978

Class—COCCOGONEAE Thuret, 1875

Order - CHROOCOCCALES Wettstein, 1924

Family—CHROOCOCCALES Nageli, 1849

Genus—EOMICROCYSTIS Golovenok & Belova, 1984

Type species—EOMICROCYSTIS ELEGANS Golovenok & Belova, 1984.

EOMICROCYSTIS ELEGANS Golovenok & Belova, 1984

(Pl. 2.9; Pl. 4.5; Pl. 5.4)

Description—Spherical to subspherical colony, consisting 16 to 35 numbers of loosely packed, small, rounded to sphaeroidal cells with 3-6.5 µm diameter.

Dimensions—Colony diameter 28-56 µm.

Occurrence—In Vindhyan Basin, *E. elegans* appears in the Deonar Formation, become abundant in the Kheinjua Subgroup and disappears in the upper part of the Rohtas Subgroup. Its earliest records are from the Early Mesoproterozoic sediments (Peat *et al.,* 1978; Horodyski, 1980), and abundant in the Middle to Late Mesoproterozoic and Early Neoproterozoic sediments (Hofmann & Jackson, 1994; Jankauskas, 1989).

EOMICROCYSTIS MALGICA Golovenok & Belova, 1986

(Pl. 4.6; Pl. 5.5; Pl. 7.4)

Description—Spherical to subspherical colony, with 16 to 45 numbers of tightly packed small globoidal cells of 2-4 µm diameter. Cells appear embedded in the thin mucilaginous matrix.

Dimensions—Colony diameter 28-56 µm.

Occurrence—In Vindhyan Basin, *E. malgica* appears in the Deonar Formation, become abundant in the sediments of

PLATE 10 ⟶

Organic-walled microfossils from the Ganurgarh Shale and the Nagod Limestone (Bhander Group). Illustrated specimens from the Barhi-Badanpur-Maihar section, and the DMH-A well (depth interval 320-165m -Ganurgarh Shale; 165-105 m-Nagod Limestone). Scale bar = 10 µm.

Ganurgarh Shale :

1. *Oscillatoriopsis psilata* Maithy & Shukla. DMH-A, 215-20m/2; EFR G 61/1.
4. *Obruchevella parva* Reitlinger. DMH-A, 165-70m/1; EFR T 34/3.
5. *Obruchevella valdaica* (Shepeleva ex Aseeva) Jankauskas, Mikhailova & German. DMH-A, 165-70m/2; EFR O 37/3.
15. *Leiosphaeridia asperata* (Naumova) Lindgren. DMH-A, 215-20m/1; EFR J 43.

Nagod Limestone :

2. *Chlorogloeaopsis kanshiensis* (Maithy) Hofmann & Jackson. DMH-A, 150-55m/2; EFR T 33/3.
3. *Germinosphaera unispinosa* Jankauskas. DMH-A, 115-20m/1; EFR S 56/4.
6. *Obruchevella valdaica* (Shepeleva ex Aseeva) Jankauskas, Mikhailova & German DMH-A, 150-55m/2; EFR T 40.
7, 11. *Obruchevella delicata* Reitlinger. 7. DMH-A, 150-55m/1; EFR K 27. 11. DMH-A, 150-55m/2; EFR M 69.
8, 14. *Lophosphaeridium* sp. cf. *L. truncatum* Volkova. 8. IV/625B; EFR O 55/4. 14. IV/ 613/1; EFR T 50/4.
9, 10. *Lophosphaeridium rarum* Timofeev. 9. IV/625B; EFR S 68. 10. DMH-A, 150 -55m/1; EFR R 38.
12. *Obruchevella parva* Reitlinger. DMH-A, 150-55m/1; EFR K 42.
13. *Kildinosphaera chagrinata* Vidal in Vidal & Siedlecka. IV/625B; EFR O 68.
16. *Leiosphaeridi jacutica* (Timofeev) Mikhaylova & Jankauskas. DMH-A, 110-15m/1; EFR L 44.
17. *Cymatiosphaera* sp. DMH-A, 150-55m/2; EFR K 51.
18. *Favososphaeridium favosum* Timofeev. DMH-A, 115-20m/1, EFR O 64.

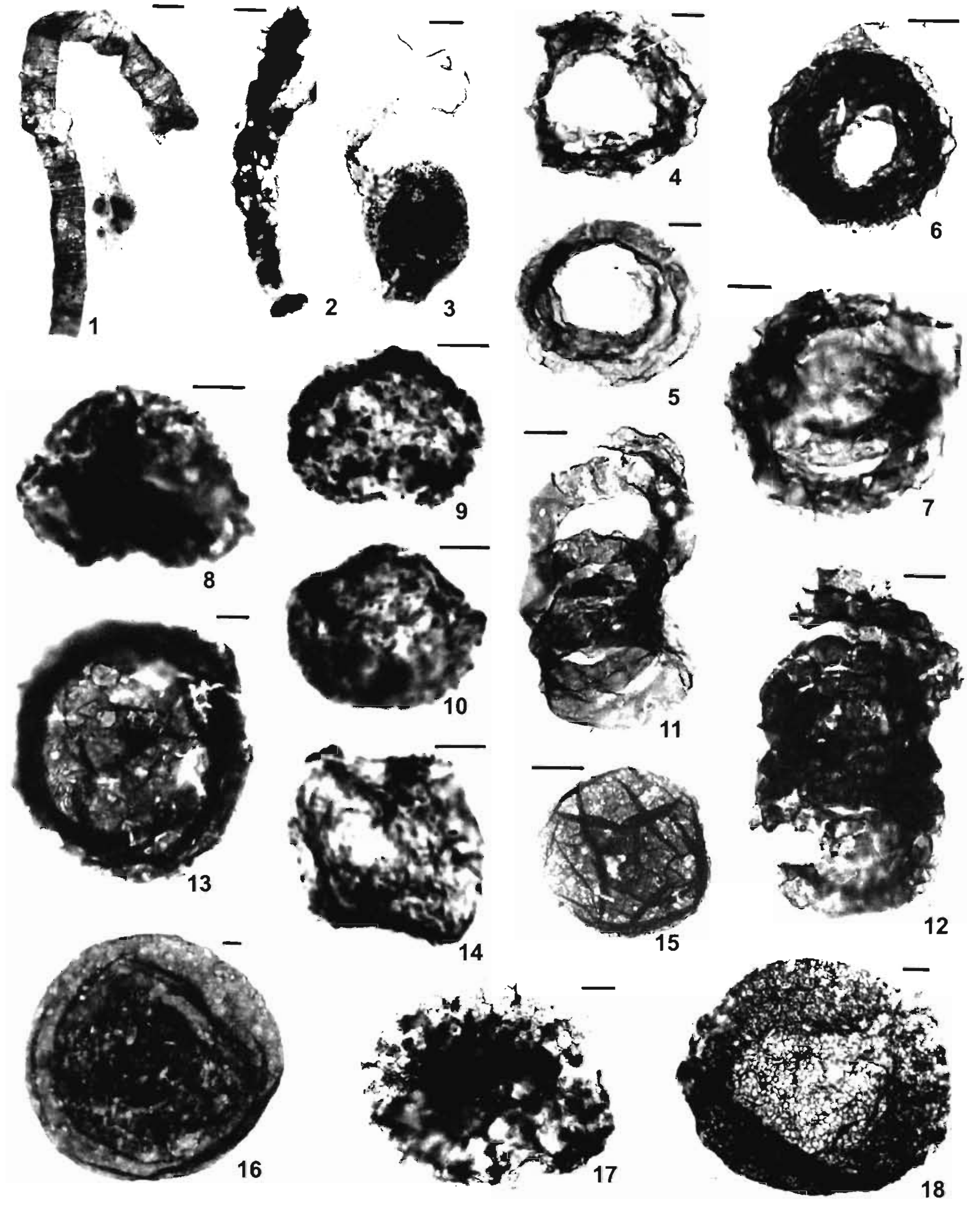

PLATE 10

Kheinjua Group and disappears in the upper part of the Rohtas Subgroup. Its earliest records are from the Early Mesoproterozoic sediments (Peat *et al.*, 1978; Horodyski, 1980) and very common in the Middle to Late Mesoproterozoic and Early Neoproterozoic sediments (Hofmann & Jackson, 1994; Jankauskas, 1989).

Genus—BAVLINELLA Schepeleva, 1962 emend. Vidal, 1976a

Type species—BAVLINELLA FAVEOLATA Schepeleva, 1962 emend. Vidal, 1976a.

BAVLINELLA FAVEOLATA Schepeleva, 1962 emend. Vidal, 1976a

(Pl. 8.2; Pl. 9.6, 7, 24)

Description—Spherical to subspherical globular colony, consisting of large number of tightly to packed, very small globoidal cells of 1.5 to 2.5 µm diameter. Cells appear embedded in the thin mucilaginous matrix.

Dimensions—Colony diameter 32-40 µm.

Occurrence—*B faveolata* appears in the Rampur Formation in Kheinjua Subgroup and occurs rarely in all the overlying formations of the Vindhyan Supergroup. Its earliest record is from the Early Neoproterozoic (ca. 900-800 Ma) Veteranen Group, Spitsbergen (Knoll & Swett, 1985) and is very common elements of Late Neoproterozoic and Terminal Proterozoic organic-walled microfossil assemblages (Vidal & Knoll, 1983).

Genus—SATKA Jankauskas, 1979b

Type species—SATKA FAVOSA Jankauskas, 1979b.

SATKA COLONIALICA Jankauskas, 1979b

(Pl. 4.11, 15; Pl. 7.6, 11; Pl. 8.7)

Description—Spherical to subspherical colonies, cluster of 3-4 colonies very common; each colony consisting of numerous, generally 16-40 in number, closely packed cell-like polygonal to subpolygonal units of 4 to 6 µm diameter.

Dimensions—Colony diameter 32-56 µm.

Occurrence—In Vindhyan Basin, *S. colonialica* appears in the Deonar Formation, become abundant in the sediments of Kheinjua Group and disappears in the upper part of the Rohtas Subgroup. Its earliest records are from the Early Mesoproterozoic (ca. 1450-1400 Ma) sediments of Roper Group, central Australia (Peat *et al.*, 1978) and Lower Belt Supergroup, Montana (Horodyski, 1980). This species is very common in the Late Mesoproterozoic sediments (Hofmann & Jackson, 1994) and become rare in Early to Middle Neoproterozoic (ca. 900-750 Ma) sediments (Knoll & Swett, 1985).

SATKA SQUAMIFERA Pyatiletov, 1980

(Pl. 2.7; Pl. 4.10, 13; Pl. 5.1, 2; Pl. 7.12; Pl. 8.6)

Description—Colonies oval to elliptic, flattened, mostly elongate; cluster of 2-3 colonies very common; each colony consisting of numerous closely packed cell-like subpolygonal units of 4 to 6 µm size. Individual unit packaged in a distinct belt-like rows transeverse to the longer axis of the colony.

Dimensions—Colony diameter 35-65 µm.

Occurrence—*S. squamifera* appears in the Deonar Formation, become abundant in the Kheinjua Subgroup and disappears in upper part of the Rohtas Subgroup. Its earliest records are from the Early Mesoproterozoic (ca. 1450-1400 Ma) sediments of Roper Group, central Australia (Peat *et al.*, 1978) and Lower Belt Supergroup, Montana (Horodyski, 1980). This species is very common in the Late Mesoproterozoic sediments (Jankaukas, 1979a, 1980a; Hofmann & Jackson, 1994; Prasad & Asher, 2001) and shows rare occurrence in the Early and Middle Neoproterozoic (ca. 900-750 Ma) sediments (Knoll & Swett, 1985).

PLATE 11 ⟶

Organic-walled microfossils from the Sirbu Shale (Bhander Group) Illustrated specimens from the Barhi- Badanpur -Maihar section, and the DMH-A well (105-00 m depth interval), representing the Sirbu Shale succession. Scale bar = 10 µm.

1, 2. *Germinosphaera unispinosa* Jankauskas. 1 DMH-A, 15-20m/1, EFR N 43. 2. DMH-A, 75-80m/1, EFR Q 37/2.
3 *Germinosphaera bispinosa* Jankauskas. DMH-A, 15-20m/1; EFR R 52/2.
4,5,6,7. *Dictyotidium* sp. 4. V-4/3, EFR O 67/3. 5. V-63/1, EFR V 64/3. 6. V-4/3, EFR N 72/3. 7 DMH-A, 150-55m/1, EFR K 31/3.
8. *Trachysphaeridium laufeldi* Vidal. DMH-A, 75-80m/1, EFR P 70/4.
9. *Obruchevella parva* Reitlinger. DMH-A, 75-80m/2; EFR Q 65.
10. *Obruchevella parvissima* Song. DMH-A, 15-20m/1; EFR R 51/2
11 *Obruchevella delicata* Reitlinger. DMH-A, 20-25m/1, EFR Q 29/2.
12, 13. *Vandalosphaeridium reticulatum* (Vidal)Vidal. 12. DMH-A, 15-20m/1; EFR O 60. 13. DMH-A, 15-20m/1, EFR D 51/4.
14. *Chlorogloeaopsis contexta* (German) Hofmann & Jackson. DMH-A, 100-105m/1; EFR W 49.
15. *Kildinosphaera verrucata* Vidal in Vidal & Siedlecka. DMH-A, 75-80m/1, EFR H 43/4..
16. *Leiosphaeridia asperata* (Naumova) Lindgren. DMH-A, 75-80m/2; EFR P 64.
17. *Cristallinium* sp. cf. *C. cambriense* (Slavikova) Vanguestaine. V/4; EFR Q 62/2.
18. *Cymatiosphaera* sp. V-4/3; EFR V 67/4.

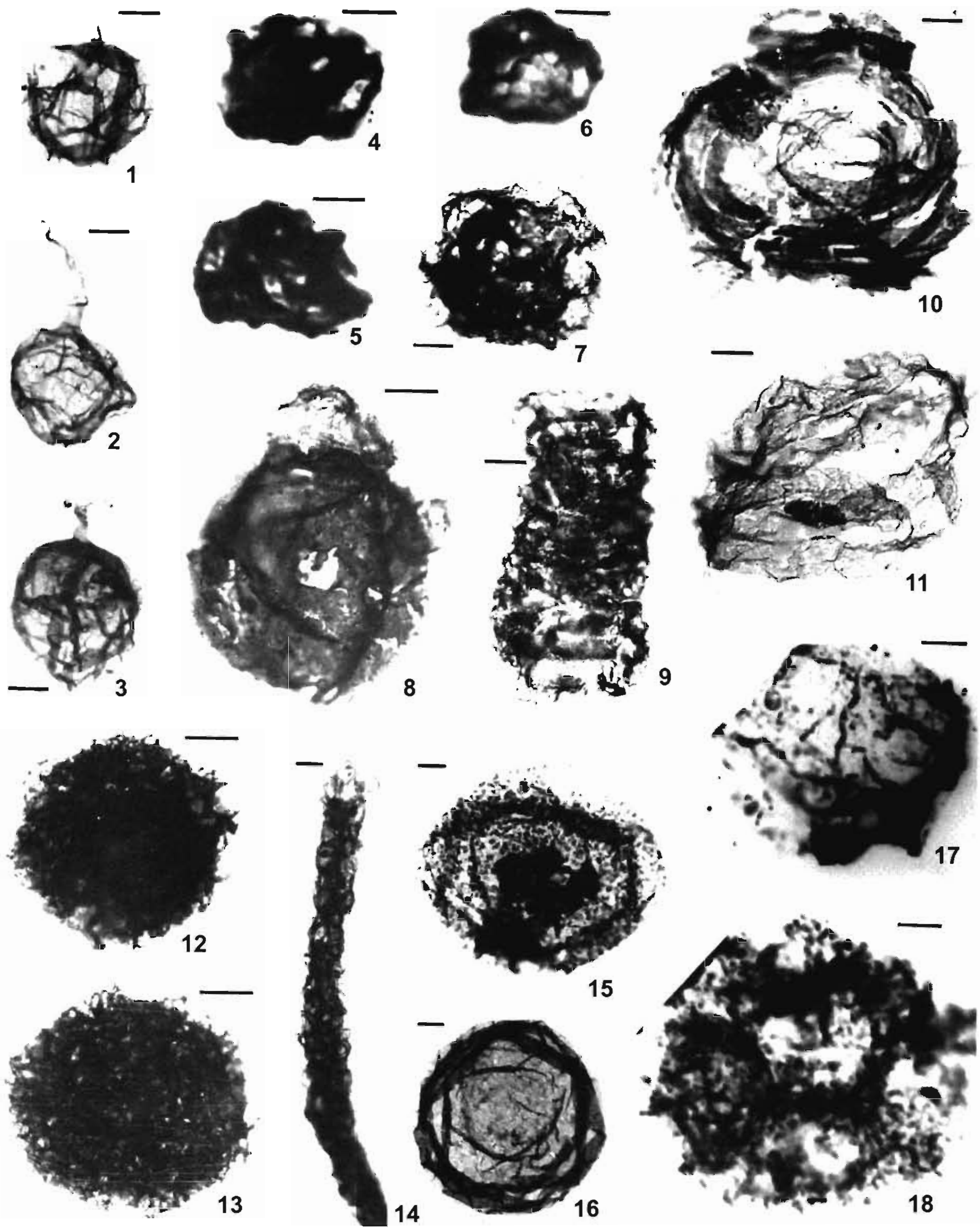

PLATE 11

Class—HORMOGONEAE Thuret, 1875
Order—OSCILLATORIALES Elenkin, 1949

Family—OSCILLATORIACEAE Dumortier ex Kirchner, 1900

Genus—OBRUCHEVELLA Reitlinger, 1948

Type species—OBRUCHEVELLA DELICATA Reitlinger, 1948.

OBRUCHEVELLA VALDAICA (Shepeleva, 1974 ex Aseeva, 1974) Jankauskas, Mikhailova & German, 1989 in Jankauskas, 1989

(Pl. 10.5, 6)

Description—Helically coiled, long, aseptate filamentous microfossils, compressed, with subcircular to oval outline; comprising tightly wound coils (helices) of almost uniform diameter. Helices (spiral coils) tightly concentric, compressed, without any gaps between the successive helics; central portions of the coiled mass generally missing.

Dimensions—Coil (helix) diameter 42-60 µm, filament diameter 5-9 µm.

Remarks—*O. valdaica* is distinguished from other species of *Obruchevella* by its compressed and tightly concentric coils (helices) without any gaps between the successive whorls.

Occurrence-In Vindhyan Basin, *O. valdaica* appears in the basal part of Bhander Group within the Ganurgarh Shale, and shows common occurrence in the overlying Nagod Limestone and the Sirbu Shale. This species is abundantly recorded from the Ediacaran (Vendian) sediments of Russian Platform (Aseeva, 1974; German *et al.,* 1989) and elsewhere (for details Mankiewicz, 1992). Although, this species is also recorded from Late Mesoproterozoic sediments (Hofmann & Jackson, 1994; Samuelsson *et al.,* 1999; Prasad & Asher, 2001), but its abundance in Terminal Proterozoic is well established.

OBRUCHEVELLA PARVA Reitlinger, 1959

(Pl. 10.4, 12; Pl. 11.9)

Description—Helically coiled, long filamentous microfossils, with subcircular to oval helices (spiral coils). Whorls with tightly to loosely wound helices (coils) of uniform halix diameter, 7-10 helices very common; filament with cross-partitions, dividing the filaments in a number of small rectangular compartments..

Dimensions—Helix diameter 45-60 µm, filament diameter 5-10 µm.

Remarks—*O. parva* is distinguishable from the other species of the *Obruchevella* in having little loosely wound helices (coils) than the *O. valdaica,* and comparatively tight helices than the *O. delicata.* Filament bears cross-partitions, and diameter varies between 5-10 µm.

Occurrence—In Vindhyan Basin, *O. parva* appears in the Ganurgarh Shale within the Bhander Group, shows abundance in the Nagod Limestone and the Sirbu Shale. *O. parva* is regarded as the Ediacaran (Vendian)-Early Cambrian marker microfossil. It is abundantly recorded in the Ediacaran (Vendian) sediments from a number of localities, and observed to appear in the Early Ediacaran and disappears in Early Cambrian (for details Mankiewicz, 1992).

OBRUCHEVELLA DELICATA Reitlinger, 1948

(Pl. 10.7, 11; Pl. 11.11)

Description—Hilically coiled, long filamentous microfossils, with broad filament diameter (12-16 µm); comprising well defined, subcircular to oval, loosely wound helices (coils). Helices of uniform helical diameter, successive helices widely separated; 5-7 whorls very common.

Dimensions—Helix diameter 45-66 µm, filament diameter 12-16 µm.

Remarks—*O. delicata* is distinguishable from other species of *Obruchevella* in having loose wounds, well defined and widely separated successive whorls and filament diameter varies between 12-16 µm.

Occurrence—*O. delicata* appears abundantly in the Nagod Limestone within the Bhander Group and very common in the overlying Sirbu Shale. This species is abundantly recorded from the Late Ediacaran (Vendian) and Early Cambrian sediments, and observed to appear in the Late Ediacaran and ranges upto Early Ordovician (for details Mankiewicz, 1992).

OBRUCHEVELLA PARVISSIMA Song, 1984

(Pl. 11.10)

Description—Helically coiled, filamentous microfossils, with very narrow filament; comprising a number of loosely wound helices of varying diameter; successive heices closely coiled.

Dimensions—Coil (helix) diameter 35-52 µm; filament diameter 3-5 µm.

Remarks—*O. parvissima* is distinguishable from the other species of *Obruchevella* in having loosely wound, closely placed successive whorls and very narrow filament diameter between 3-5 µm.

Occurrence—In Vindhyan Basin, *O. parvissima* occurs rarely in the Sirbu Shale within the Bhander Group. It is originally recorded from the Early Cambrian (Meishucunian) sediments of Yunnan, China (Song, 1984).

Genus—POLYTHRICHOIDES German, 1974

Type species—POLYTHRICHOIDES LINEATUS German, 1974 emend. Knoll *et al.*, 1991

POLYTHRICHOIDES LINEATUS German, 1974 emend. Knoll *et al.*, 1991

(Pl. 1.13; Pl. 2.12)

Description—Elongate fragments of tubular filamentous aggregates, comprising a number of longitudinally aligned, closely placed, non-septate, narrow filaments, showing a twisted rope-like feature; individual filaments parallel orientation, showing a longitudinally striated aspect; aggregates without sheath

Dimensions—Fragment length 180-385 μm, filament diameter 1-2 μm.

Occurrence—In Vindhyan Basin, *P. lineatus* occur abundantly in Kajrahat Limestone and rarely present in the Deonar Formation. This form is very common in the Mesoproterozoic sediments of China (Yin & Yuan, 2002), Canada (Hofmann & Jackson, 1994) and Zaire (Maithy, 1975) and also very frequent in the Neoproterozoic sediments of Siberia (German, 1974) and Svalbard (Knoll *et al.*, 1991).

Genus—KARAMIA Kolosov, 1984

Type species—KARAMIA SEGMENTATA Jankauskas, Mikhailova & German, 1989.

KARAMIA SEGMENTATA Jankauskas, Mikhailova & German, 1989

(Pl. 1.14)

Description—Elongate, ? non-septate filament, composed of a number of transverse to slightly oblique grooves or striations, that divide the filament into a number of segments. Apparently looks like a narrow, non-septate filament, with tight coiling.

Dimensions—Filament length 180-230 μm, filament diameter 66 μm.

Occurrence—In Vindhyan Basin, *K. segmentata* is very common in the Kajrahat Limestone and rarely present in the Deonar Formation. This form is rarely recorded from the Middle to Late Mesoproterozoic sediments of Canada (Hofmann & Jackson, 1994) and Early Neoproterozoic sediments of Russian Platform (Jankauskas *et al.*, 1989).

Vase-shaped Microfossils

Genus—MELANOCYRILLIUM Bloeser, 1979 ex Bloeser, 1985

Type species—MELANOCYRILLIUM HEXODIADEMA Bloeser, 1979.

MELANOCYRILLIUM sp.

(Pl. 6.8-10)

Description—Vesicle flask-shaped, oval to elliptic in outline; vesicle surface dark and thickened, with granulate to echinate ornamentation. One side of the vesicle abruptly tapers to form a neck-like narrow tubular extention; extension with a distinct opening at distal end.

Dimensions—Vesicle length 38-55 μm, width 36-52 μm; neck-like extension length 7-12 μm.

Occurrence—The recovered specimens broadly comparable with the vase-shaped microfossils referable to *Melanocyrillium* Bloeser (1985). However, these specimens differ with typical *Melanocyrillium* in having narrow tubular neck and much smaller in size with irregular shape; whereas in *Melanocyrillium* neck is wide. So, the Vindhyan specimens of the vase-shaped microfossils are provisionally referred to as the *Melanocyrillium* sp.

REPOSITORY

The slides, examined for organic-walled microfossils from outcrop as well as subsurface (DMH-A well) sections of the Vindhyan Basin from Madhya Pradesh, are preserved in the Repository Section of the Palynology Laboratory (Geology Division) at the KDM Institute of Petroleum Exploration, ONGC, Dehradun (India) with registration No. KDMIPE/ PALY/ 2004/ BP/ VINDHYAN-M.P. The desired outcrop slides can be retrieved by traverse name and sample nos. (like Jhal-Bihara Tr., II/5-D), and the subsurface slides by the well name (DMH-A) with respective depth intervals (like 450-455m). The illustrated taxa are located by England Finder References (EFR J50/2), mentioned against each forms.

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