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ORIGINAL PAPER

Problematic fossils from the Palaeo-Neoproterozoic Vindhyan Supergroup, India

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Abstract Fossils of the Vindhyan Supergroup exhibit extensive diversity and variable biologic affinities represented by: bacteria, cyanobacteria, algae, fungi, acritarchs, metaphytes and metazoans (including members of the Ediacaran Fauna) and ranging from less than a micron to almost a metre in size. Besides identified fossils, a number of bizarre morphologies (due to deviation of morphology from conventional structures), present in various stratigraphic horizons, have been observed. It is very difficult to identify and decide their biologic affinities. In thin sections of Lower Vindhyan cherts, microfossils resembling lichen-like or fungal forms in which a sac encompassing a coiled filament may possibly indicate a symbiotic relationship, a *Volvox* colony-like structure and a vase-shaped body without an opening are unique. Among the carbonaceous fossils, very unusual and interesting fossil is a transparent disc comprising numerous appendages of an unidentified mesoscopic insect-like organism. Megascopic branching and associated *Grypania*-like structure is another form preserved as impression on micritic limestone. Petrographic thin sections of chert belonging to the Sirbu Shale Formation, exhibit presence of microscopic bizarre forms. The assemblage includes acritarchs and acanthomorphs of variable morphology and a dividing cell-like structure interpreted to be of rhodophycean affinity or a cleaving embryo of an animal affinity. Other peculiar morphologies among the carbonaceous fossils are: branched filaments that have attached sporangia-like vesicles, *Chuaria*-like body comprising cluster of very small-sized spheroids resemble scale-like structure, a chrysophycean alga or a multicellular tissue of a metaphyte. Another carbonaceous fossil represents a possible metazoan exhibiting an elongate body and a mid-gut-like structure or a Vaucheriacean alga. Although the biologic affinities of these bizarre forms can be a matter of debate, their biogenic nature is almost undoubted. The presence of such forms in the Vindhyans indicates advancement in morphology and a gradual evolution of life during the Palaeoproterozoic–Neoproterozoic period. In addition, presence of Ediacaran fossils in Bhander Group and large-sized acritarchs especially *Trachyhystrichosphaera* sp. in petrographic thin section of chert from the Sirbu Shale Formation, Bhander Group, Upper Vindhyans, suggests Ediacaran age as an upper age limit of the Vindhyan Supergroup.

Keywords Palaeoproterozoic · Neoproterozoic · Vindhyan Supergroup · Bizarre forms

Introduction

Palaeo-Neoproterozoic period lasted larger than the entire Phanerozoic Eon. During this interval, morphological diversity and turnover rates were low for early protistan evolution. In India, this is a period when Vindhyan sedimentation took place. The Vindhyan Supergroup, globally acknowledged as one of the best repository of the Proterozoic life, comprises exceptionally well-preserved fossils in basically three taphonomic windows. These are silicified microfossils in petrographic thin sections of chert, carbonaceous compressions on shales and moulds and casts on shale and sandstones. These are responsible for most of the preservation of nonbiomineralizing organisms in geological records. Based on available fossil record, bacterial,

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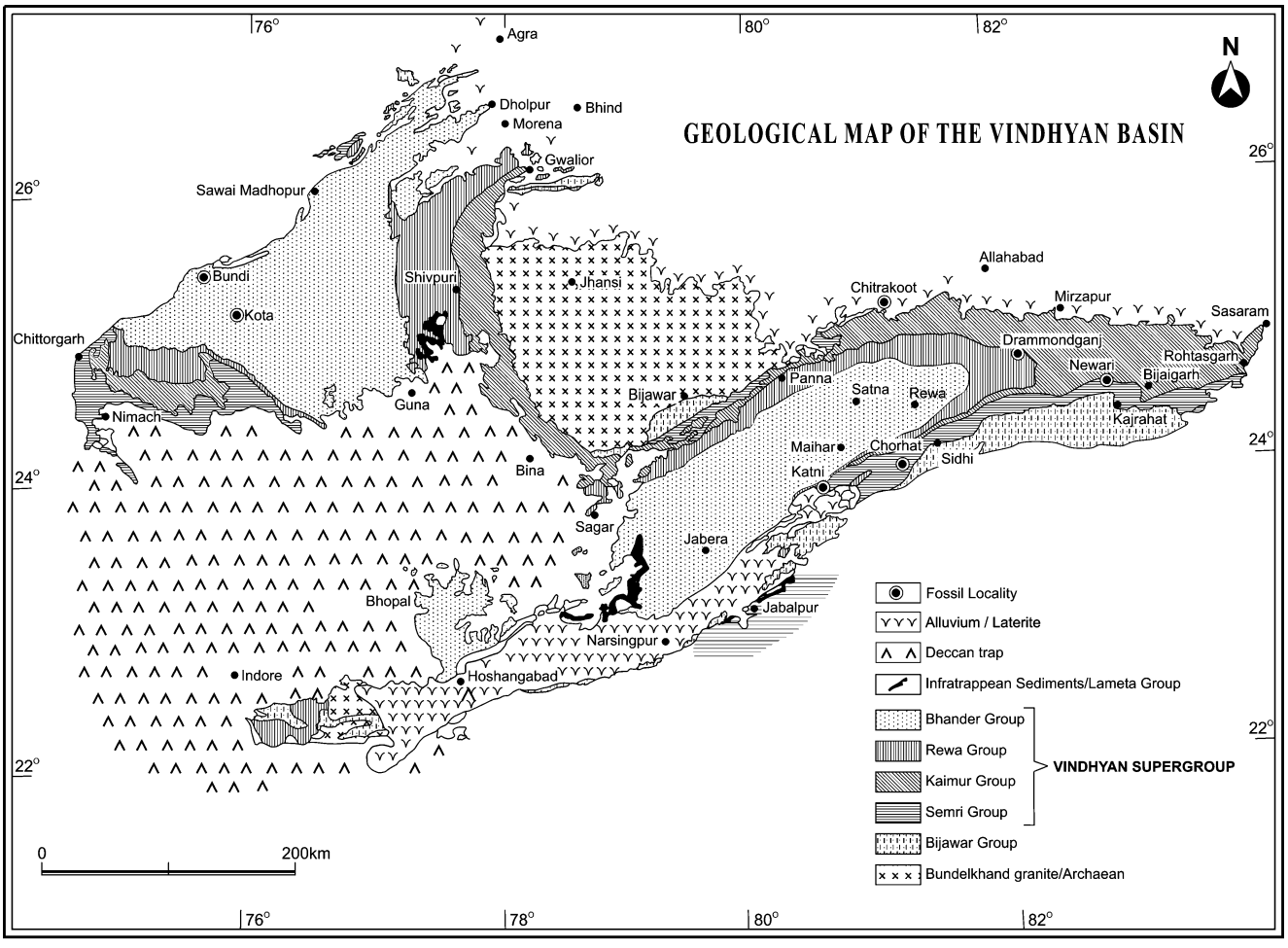
cyanobacterial, algal, fungal, acritarchean and Ediacaran affinities can be assigned to the Vindhyan fossil assemblage (see Kumar and Srivastava 1995, 1997, 2003; Rai et al. 1997; Sharma 2003, 2006; Srivastava 2002, 2004, 2005; Srivastava and Bali 2006; Venkatachala et al. 1996) exhibiting wide size range from micro megascopic level (from less than 1 μm to a meter-sized Ediacara fauna, Srivastava 2006, 2011). These fossils have potential to unravel the biodiversity and evolution of life in the Vindhyan Supergroup. Carbonaceous fossils from the Panna Shale (Rewa Group) interpreted as missing link between the evolution from micro to megascopic life (Srivastava 2004) and Ediacara fauna in the Bhander Group, Upper Vindhyans (De 2006; Srivastava 2006, 2011) are the supporting parameters for better understanding of Vindhyan evolutionary palaeobiology. Records of small shelly fauna by Azmi (1998), triploblastic animal traces by Seilacher et al. (1998) and an Ediacaran fossil record of *Spriggina* by Kathal et al. (2000) are still debatable, hence not included to draw any conclusion. Fossil records in geological formations form the basis to understand the evolution of life. Often these life forms become unavailable owing to hiatus or gap that interrupts at various geological intervals "This leads to wild speculations and bizarre interpretations".

In Palaeo-Mesoproterozoic (1,700–1,000 Ma), eukaryotic microfossils were widespread but diversity (global) was low, while during Meso-Neoproterozoic=1,000–570 Ma; red, green algae and early animal forms diversified.

Apart from the identified fossil forms in the rocks of the Vindhyan Supergroup, there are number of unusual forms which exhibit uncommon and complex morphologies and are very difficult to compare with known fossil or extant forms of the plant or animal kingdom.

Geological setting

The Vindhyan Supergroup is about 4,000 m thick, mildly metamorphosed sedimentary succession distributed in Cen-



Geological map of the Vindhyan Basin (Simplified after Soni et al. 1987)

Fig. 1 General Geological Map of the Vindhyan Supergroup, simplified after Soni et al. 1987

tral India in a sickle shaped outcrop around Bundelkhand Granite, extending from Agra in northwest through south-eastern Rajasthan to eastward in Son Valley up to Sasaram in Bihar to Hoshangabad in south (Fig. 1) occupying an area of about 104,000 square km. The exposures occur in patches forming elevated hillocks and extended ridges on flat terrains in parts of Madhya Pradesh, Uttar Pradesh, Bihar and Rajasthan States. The Supergroup is subdivided in four groups viz. the Semri Group, the Kaimur Group, the Rewa Group and the Bhander Group (Auden 1933; Soni et al. 1987; Sastry and Moitra 1984; Prasad 1984). Each group is further divided into Formations and Members (see Table 1). Traditionally, the Semri Group is considered as Lower Vindhyans, whereas the other three groups are categorized among Upper Vindhyans. The overall lithology is represented by the sediments of calcareous, argillaceous and arenaceous facies (Fig. 2). The supergroup unconformably overlies the Bundelkhand (Granitic) Massif and slightly metamorphosed Bijawar Group ~2,500 Ma in age (Crawford and Compston 1970; Mandal et al. 2002).

Table 1 Generalised lithostratigraphy of the Vindhyan Supergroup. Stratigraphic units marked with asterisk are the reference units, from where samples have been collected for the present study

	Ganurgarh Shale
Bhander Group	Dholpura Shale*
	Balwan Limestone
	Maihar Sandstone
	Sirbu Shale*
	Bundi Hill Sandstone*
	Samaria Shale*
	Lakheri Limestone/Bhander Limestone*
	Ganurgarh Shale
Rewa group	Upper Rewa Sandstone
	Jhiri Shale
	Lower Rewa Sandstone
	Panna Shale*
Kaimur group	Dhandraul Quartzite
	Scarp Sandstone and Conglomerate
	Bijaigarh Shale
	Susnai Breccia
	Upper Quartzite
	Lower Quartzite
Unconformity	
Semri group	Rohtas Formation*
	Kheinjua Formation/Chorhat Formation*
	Porcellanite Formation
	Kajrahat Limestone
	Basal Formation
Unconformity	
Bijawar group	Phyllites

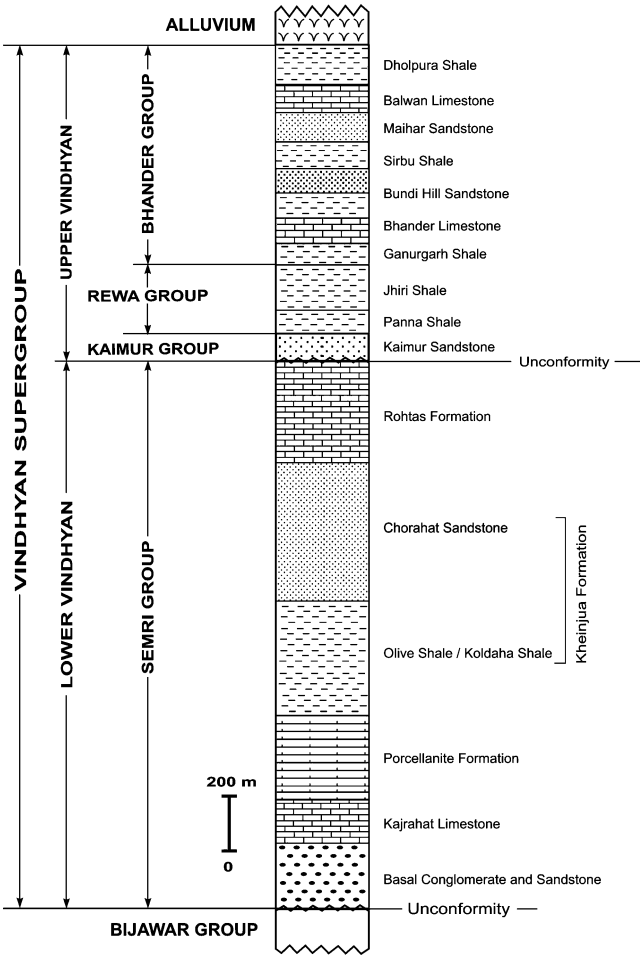


Fig. 2 Generalised lithostratigraphy of the Vindhyan Supergroup

Age

Age of the Vindhyan Supergroup is still a matter of debate. Conventionally, it is considered ranging between Palaeo-Neoproterozoic. Record of 1.1 Ga old triploblastic animal traces (Seilacher et al. 1998) from the Churhat Sandstone, Lower Vindhyans and small shelly fauna (earliest Cambrian in age) from the Rohtas Formation, Semri Group (Azmi 1998) suggested a far younger age than the traditional age assigned to the Vindhyan Supergroup. These findings created a hot debatable issue of abiotic origin of mentioned fossils (Brasier 1999; Kerr 2002; Morris et al. 1998; Hofmann 2005). The age, biogenicity and reproducibility of these fossils remained inconclusive, thus generated interest among bio and geochronologists to resolve the age and time for deep metazoan origin in the Vindhyan Supergroup. In recent years, a number of reports and substantial data for Vindhyan's age (based on different methodologies and parameters) are available as follows (see Ray 2006).

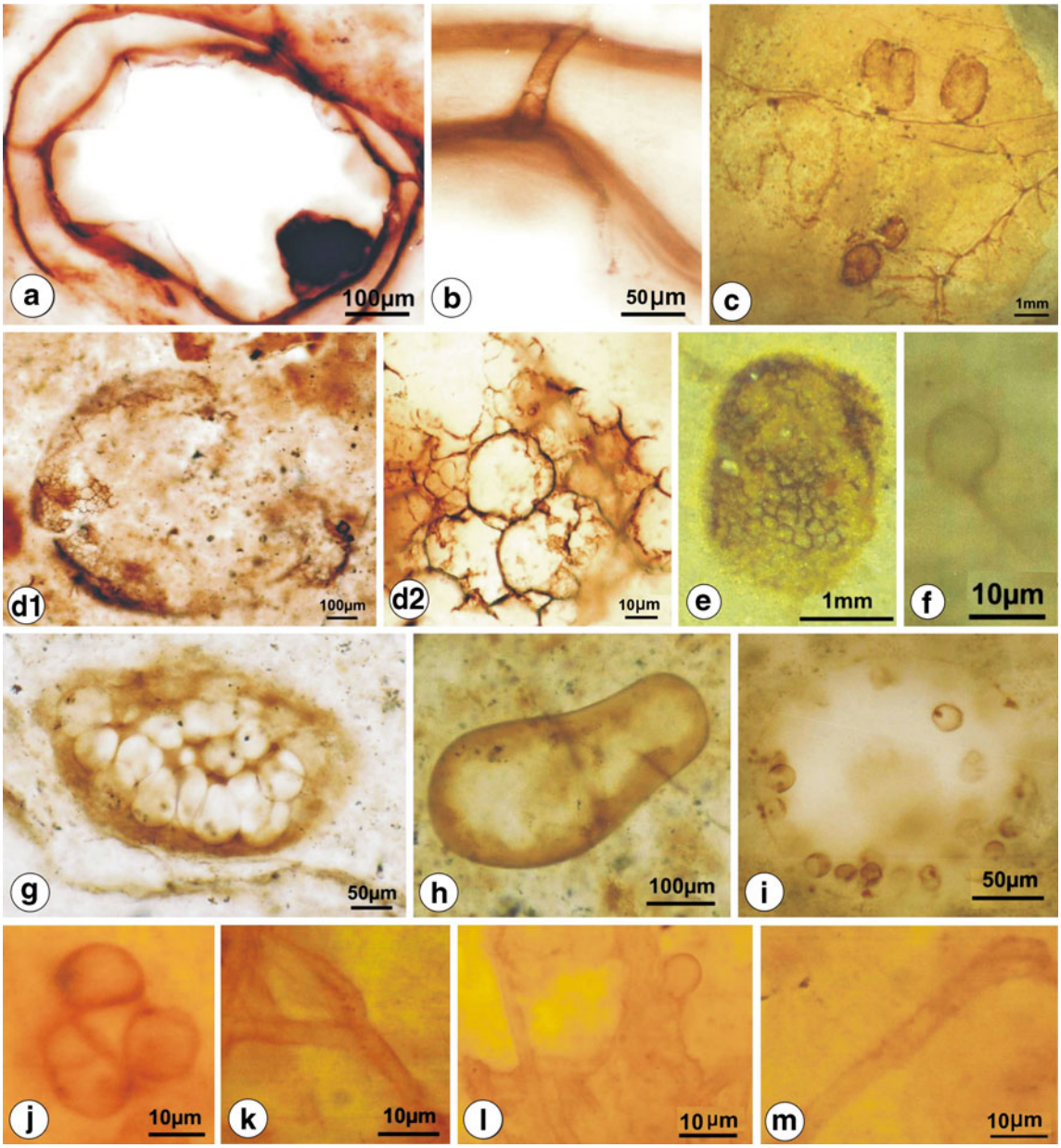


Fig. 3 Problematic forms of the Vindhyan Supergroup, microfossils in petrographic thin sections of chert, megascopic carbonaceous compressions in shale and megascopic impressions in limestone samples. *A*, *B* Large sized *Trachyhystrichosphaera* sp. Slide No. BN-3, Co-ordinates 18.7/68.9, Sirbu Shale Formation, Bhander Group, Rajasthan. *C* Branched filaments with attached vesicles, sample No. LK-mg1.6, Dholpura Shale, Uppermost Vindhyans, Rajasthan. *D1*, *D2* Large-sized ornamented acritarch or a resting zygote-like structure, Slide No. BN-5, 22.4/72.3, Sirbu Shale Formation, Bhander Group, Rajasthan. *E* Carbonaceous discs or *Chuaria*-like vesicle encompassing cluster of small spheroids or a scale-like structure of a metazoan/metaphyte, Sample No. Kp-6, Dholpura Shale, Uppermost Vindhyans, Rajasthan. *F* Lichen-like symbiotic/parasitic form, a cell with string-like structure or a flagellated fungi. Slide No. SBO-H, Co-ordinates-16.3/84.2, Kheinjua Formation, Semri Group, Lower Vindhyans. *G* Dividing cells within an enclosing sheath-like structure, *Paratetraphycus*, *Tetrasporangia* or a binary division stage of an early cleaving metazoan embryo, Slide No. BN-6, Co-ordinates, 27.0/67.5, Sirbu Shale Formation, Bhander Group, Rajasthan. *H* Vase-shaped microfossil without an opening, Slide No. Bu-17, Coordinates-25.2/68.8, Sirbu Shale Formation, Bhander Group, Rajasthan. *I Volvox* colony like microfossil, Slide No. Bundi-14, Co-ordinates-9.5/84.0, Sirbu Shale Formation, Bhander Group, Rajasthan. *J* Multilobed sporangia-like structure, supporting fungal affinity, Slide No. SBO-H, Co-ordinates 6.8/83.8, Kheinjua Formation, Semri Group, Lower Vindhyans. *K* Branched filament supporting fungal affinity, Slide No. SBO-H, Coordinates 5.9/83.2, Kheinjua Formation, Semri Group, Lower Vindhyans. *L* Resting Sporangia-like structure comparable to *Chytridiomycota*, Slide No. SBO-H, Co-ordinates 12.8/83.4, Kheinjua Formation, Semri Group, Lower Vindhyans. *M* Bulb-shaped closed end of a filament supporting fungal affinity, Slide No. SBO-H, Co-ordinates 14.5/82.2, Kheinjua Formation, Semri Group, Lower Vindhyans

- Pb–Pb zircon (SIMS), Mandal et al. 2002 for (Granitic) Basement rocks ~2,492±10 Ma
- Pb–Pb isochron, Sarangi et al. 2004 for Kajrahat Limestone ~1,721±90 Ma
- Rb/Sr for Glauconite (Chitrakut, Semri Grp.), Kumar et al. 2001 ~1,504–1,409 Ma
- U–Pb–Zr (TIMS) Rampur Shale, Rasmussen et al. 2002 ~1,599±8 Ma
- (SHRIMP) Rampur Shale, Ray et al. 2002 ~1,628± 8 Ma
- Pb–Pb isochron, Rohtasgarh Limestone, Ray et al. 2003 ~1,601±130 Ma
- Rb–Sr, Kaimur Group, Maihar, Kumar et al. 2001 >1,067 Ma
- *Chuaria–Tawuia,* Jhiri Shale, Rewa Grp, Rai et al. 1997 1,100–700 Ma
- *Chuaria–Tawuia,* Bhander Limestone, Kumar and Srivastava 1997 1,100–700 Ma
- *Chuaria–Tawuia,* Dholpura Shale, Bhander Grp. Srivastava 2002 Upper Riphean
- Sr–Sr, Lakheri Limestone (Rajasthan), Ray et al. (2003) ~650 Ma

Vindhyan's fossil profile

The overall Vindhyan's life can be represented by the presence of bacterial, cyanobacterial, algal, fungal, acritarchean and Ediacaran fossils. Like other parts of the world, Meso-Proterozoic fossil record is rather poor in comparison to the Neoproterozoic. The bizarre forms of the entire Vindhyan Supergroup are as follows:

Lichen-Like Symbiotic and Endophytic Association, Kheinjua Formation, Semri Group

Description Small-sized coccoids of 8–10 μm with a string like structure, cluster of coccoids (Fig. 3j) resembling multi-lobed sporangia, branched filaments of 2–3 μm width (Fig. 3k), filaments with bulb- shaped closed ends (Fig. 3m) and resting sporangia attached to irregular fungal hyphae like structure similar to the *Chytridiomycota* (Fig. 3l). In addition, vesicle like structure of 14–20 μm diameter, encompassing *Obruchevella* like filament within it and attachment of this vesicle to irregular hyphae like structure (Fig. 4-i-1, i-2). Number of such forms are many (8–10), but the level of preservation is not very good (Figs. 3 f, j–m, 4i-1, i-2).

Discussion The fossils are reported from the petrographic thin sections of chert of the Kheinjua Formation, Son Valley (~1,600 Ma old) Semri Group. The association of coccoids with fungal hyphae was interpreted as symbiotic Yuan et al. (2005) from the 600 Ma old phosphorite of the Doushantou Formation, China. Corsetti et al. (2003) reported complex biota from Neoproterozoic, Kingston Peak Fm, USA. The Vindhyan record of symbiotic association or a lichen-like association from the Kheinjua Formation, Lower Vindhyans must be the earliest record of Proterozoic Era. Presence of flagellated fungi and multi-lobed sporangia-like structures (Fig. 3f, j) support fungal affinity. It can be speculated that these early events or association may have occurred long before the colonization of land and vascular plants in a shallow marine ecosystem, where a large number of free living cyanobacteria, algae and fungi were living in close association; considered to be a necessary step in the evolution of symbiosis. Filaments interpreted to be fungal hyphae occur in lichen-like association with clusters of coccoidal, probably cyanobacterial unicells (Fig. 3j). Fungal interpretation is based on a combination of characters like: dichotomous branching (Fig. 3k), pyriform/bulb-shaped terminals of filaments (Fig. 3m), absence of sheaths and narrow diameters.

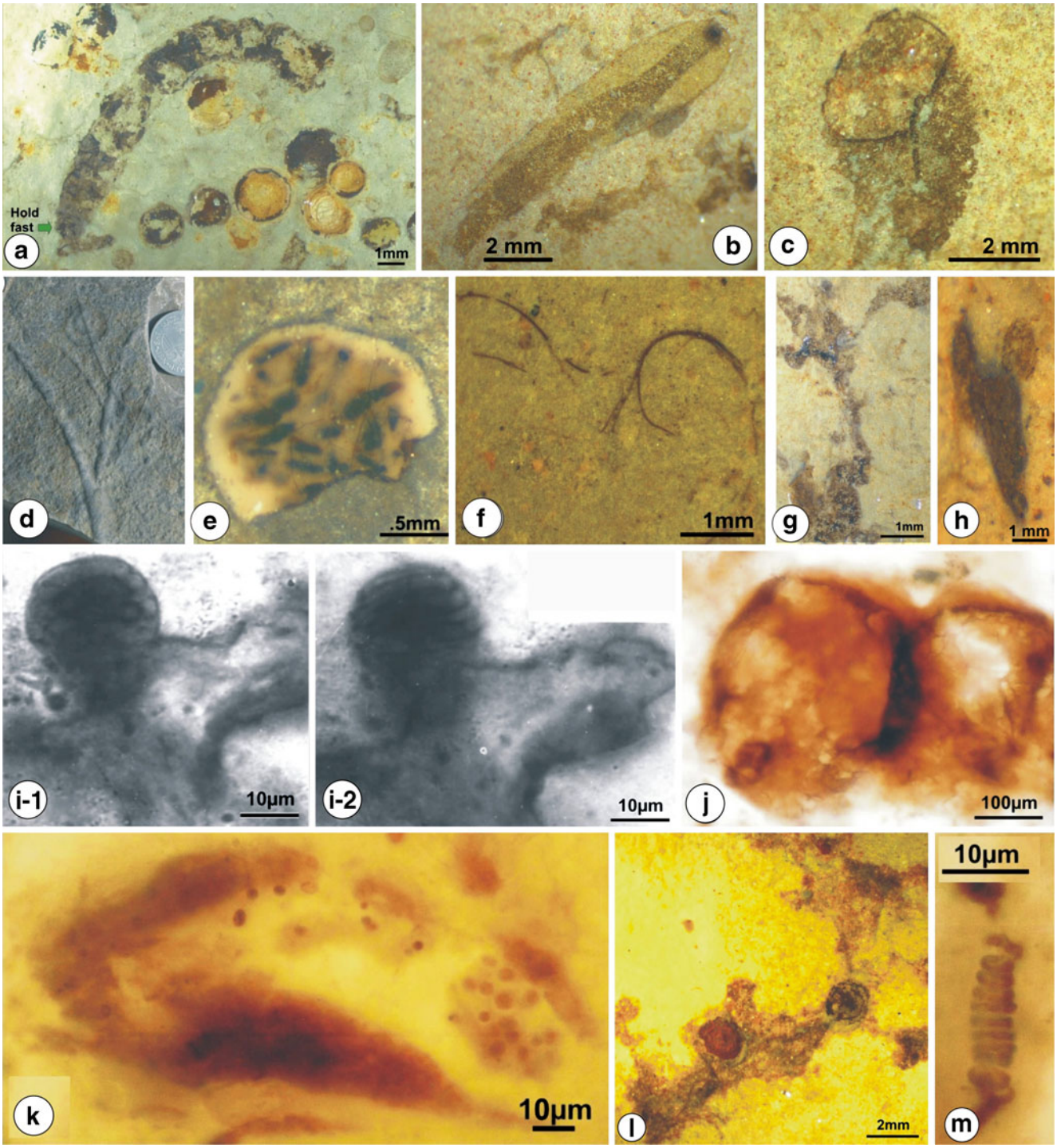
Association of *Chuaria* with irregular hyphae-like structures, Dholpura Shale, Bhander Group, Uppermost Vindhyans, Rajasthan

Description Chuaria like morphologies of 1.5–2.0 mm in diameter with well preserved folds and concentric markings are entrapped within irregular fungal hyphae-like mesh spread all over the bedding surface. Branching like structures are also present among these hyphae (Fig. 4l).

Discussion The modern marine fungi (mostly ascomycetes) also exhibits a wide range of interaction with cyanobacteria, chlorophytes, phaeophytes and rhodophytes. These interactions can be loose lichenoidal association with microscopic photobionts or mycophycobiosis with macroscopic algae or an obligate lichen association as shown by the present specimens of *Chuaria*-like objects, where they are embedded in a spongy irregular mesh-like structure (Fig. 4l).

Chuaria arranged as beaded spheroids in an elongated vesicle, Sirbu Shale, Bhander Group, Upper Vindhyans

Description An elongated, compressed and slightly curved tube like carbonaceous vesicle (length—11.2 mm, width—1.4 mm, single specimen) with impressions of *Chuaria*-like structures arranged in a beaded manner preserved on bedding surface. Adjacent to this structure, a number of spheroids (11 in number) assignable to *Chuaria* are scattered. Elongated vesicle is tapered at one end with an attachment structure of a thin, slightly undulating plate



(length measured 2.2 mm, thickness—.4 mm) at an angle of 80° with the vesicle giving an appearance of a hold-fast (Fig. 4a).

Discussion Present specimen gives an impression that a number of *Chuaria*-like forms are arranged in a row enclosed within an elongated tube like vesicle. *Chuaria* are arranged in a beaded manner resembling a bean/pea-like structure. There is a possibility that the specimen belongs to *Vaucherian* affinity. Presence of a hold-fast-like structure also suggests rhodophycean algal affinity. *Bangiomorpha* displays 3-D preservation of outer and inner walls, whereas cyanophycean filament with sheath generally show 3-D preservation of sheath, but partial or complete collapse of the cells inside (Bartley 1996; Knoll et al. 2006).

◀ **Fig. 4** Problematic forms of the Vindhyan Supergroup, microfossils in petrographic thin sections of chert, megascopic carbonaceous compressions in shale and megascopic impressions in micritic limestone samples. *A* Carbonaceous disc or *Chuaria*-like spheroids arranged within a tubular sac/vesicle-like structure, Sample No. DulMg/1.5, Sirbu Shale Formation, Bhander Group, Central India. *B* Carbonaceous megafossil comparable to Pre-Ediacaran metazoan or an alga-like morphology, Sample No. Rj-1, Samria Shale Formation, Bhander Group, Rajasthan. *C* Carbonaceous megafossil comparable to Pre-Ediacaran metazoan, Sample No. Rj-1, Samria Shale Formation, Bhander Group, Rajasthan. *D* Megascopically branched filamentous alga in association with *Grypania*-like fossil form, Sample No. Roh-1, Rohtas Formation, Semri Group, Lower Vindhyan. *E* Compressed disc encompassing numerous appendages of some insect-like mesoscopic organisms, Sample No. Roh-4, Rohtas Formation, Semri Group, Lower Vindhyan. *F* Very thin carbonaceous thread-like filaments showing branching, Sample No. Kat-th-4, Rohtas Formation, Semri Group, Lower Vindhyan. *G* Bryophyte plant-like carbonaceous fossils, Sample No. Lk-6, Dholpura Shale, Uppermost Vindhyans, Rajasthan. *H Eopalmaria* or *C. stipitata*-like multicellular algae or a bryophyte, Sample No. Lk-3 Dholpura Shale, Uppermost Vindhyans, Rajasthan. *I-1*, *I-2* Lichen-like symbiotic/parasitic or an endophytic association of a microscopic spheroidal vesicle encompassing *Obruchevella*-like filament, Slide No. SBO-H, Co-ordinates 13.8/84.2, Kheinjua Formation, Semri Group, Lower Vindhyans. *J* Cleaving-embryo or a large-sized dividing cell-like unit of some alga, resembling to some extent with *Paratetraphycus*, *Megasphaera*, Slide No.BN-1, Co-ordinates-27.0/73.9, Sirbu Shale Formation, Bhander Group, Rajasthan. *K* Multicellular alga like microfossil, Slide No. Bundi-4, Co-ordinates-15.5/70.1, Sirbu Shale Formation, Bhander Group, Rajasthan. *L* Carbonaceous disc or *Chuaria* embedded within a mesh of irregular hyphae-like structure, inclining towards fungal affinity. Slide No. Dulmsh-1, Sirbu Shale Formation, Bhander Group, Central India. *M* Very small-sized *Obruchevella*, in thin sections of chert, Slide No. Bundi-14, Co-ordinates-9.4/73.8, Sirbu Shale Formation, Bhander Group, Rajasthan

Large-sized *Trachyhystrichosphaera*, a possible fungi, Sirbu Shale, Bhander Group, Upper Vindhyan

Description A large-sized spheroidal vesicles 480–615 μm in diameter (three specimens), double/triple walled, folded where vesicle wall is collapsed. Inner wall bears five to six tubular hollow processes that regularly, extend outward from the inner wall. Intracellular mass is prominent and about 100 μm in diameter. Processes are cylindrical and exhibit almost uniform width; they are 30–65 μm in length and 10–12 μm in width (Fig. 3a, b).

Discussion Trachystrichosphaera aimica erected by Timofeev et al. (1976) had no outer membrane or wall in vesicle. Knoll (1984) erected new species *T. vidalii*, from the Hunnberg Formation, where very thin outer membrane is present. In Vindhyan specimens, the outer and inner walls of vesicles are quite robust. This feature may be governed by the taphonomy. Morphologically *T. vidalii* is one of the most complex acritarch known from the Precambrian rocks. According to Knoll (1984), it is a confirmed eukaryote. According to Corsetti et al. (2003), *Trachyhystrichosphaera* and *Tappania* are possibly of fungal affinity. Presence of open ended, unbranched, tubular processes and absence of excystement structures, conspicuously large and variable central vesicle support their affinity towards fungi. It is considered as a Neoproterozoic age marker form (Butterfield and Rainbird 1998; Sergeev 1999, 2006; Yan et al. 2007). Size acquired by the Vindhyan form support Ediacaran as an upper age limit of Vindhyans, as in Cambrian period, size of acanthomorphs reduced markedly at global level (Huntley et al. 2006).

Cf-Tetrasporangia/Paratetraphycus or an animal embryo *Tianzhushania* (?), Sirbu Shale Formation, Bhander Group, Upper Vindhyans

Description Clusters of 16 cell-like units are closely packed in a mucilaginous sheath like structure in petrographic thin section of chert. The diameters of the individual unit vary between 35 and 48 μm. Y-shaped triple junction is seen in few spheroids. In other specimen (Fig. 4j), a large-sized (>700 μm) dividing unit has double-walled margins and very prominent median dividing plane. A specimen exhibiting exceptionally large size (1,020 μm), polyhedral ornamented surface exhibits partly preserved outer membrane (Figs. 3, d1, d2, g, 4j).

Discussion Size and arrangement of spheroids with Y-shaped triple junction suggests successive binary division, as shown by the early cleavage stage of a metazoan embryo (Xiao 2002). However, in thin section study, it is difficult to decide a T- or a Y-shaped junction, as it depends on plane through which the thin section is made. *Tetrasporangia* in Floridiophycideae (Dixion 1974) is the widely distributed form of sporangia in which meiosis resulted in formation of tetraspores. *Paratetraphycus* of red algal affinity also exhibits sheath enclosing large-sized tetraspores (Sergeev and Joo 2006). These are the other probable affinities of this particular specimen. The fossil evidences suggest that red algae are more primitive than the green algae. These Proterozoic tetrahedral tetrads, as well as certain unicells would appear best assigned to the present division. Specimen shown in Fig. 4j resembles to some extent with two-celled stage of a cleaving animal embryo *Tianzhushania* (Yin et al. 2004). Butterfield (2001) reported *Bicamera stigmata*, a large-sized dividing unicell with undulose shared wall, which was interpreted as a possible monosporangium of bangiophyte alga, in which cells divide to produce a diad, with characteristically curved shared wall. The specimen may also represent a spheroidal microfossil *Megasphaera ornata* (Yin et al. 2004). Other specimen shown in Fig. 3d1, d2 may be a large-sized acritarch assignable to Oömorph in which a unique egg-shaped vesicle commonly shows heavy ornamentation at one end.

There is also a possibility that the specimen may represent a resting zygote of an animal embryo preserved within a cover.

A multicellular alga like morphology, from thin section of chert from the Sirbu Shale Formation, Upper Vindhyans

Description Cluster of small-sized (5–7 μm diameter), granular/psilate spheroids with or without an enveloping sheath occur within a loosely packed cloudy mucilaginous sheath like structure. Maximum length and width is 185 and 75 μm respectively (single specimen; Fig. 4k).

Discussion Cluster of psilate spheroids are present with an enveloping sheath like structure around individual cell like unit placed within a mucilaginous mass. Individual unit without sheath gives the appearance of *Melasmatosphaera*, a form genera of cyanophycean affinity. Present morphology may incline towards multicellular algal affinity. As far as comparison of this form with other fossil forms is concerned, it is difficult to find any nearest analogue.

A large vesicle encompassing nucleated spheroids, Sirbu Shale Formation, Bhander Group, Upper Vindhyans and Rajasthan

Description A smooth and thin walled vesicle (in thin section of chert) exhibiting diameter of 205 μm, encompassing in it a number of nucleated cell like units with diameter ranging in size from 10–12 μm. Intracellular mass is eccentrically located. Single specimen traced (Fig. 3l).

Discussion In general appearance, the present specimen resembles with *Volvox* colony. Presence of *Volvox*-like organism in Upper Vindhyans, indicative of an initiation of colonial origin of multicellularity, where many single-celled organisms produce colonies, which share the same genetic code. It is believed that within these colonies or hollow spheres, a division of labour was achieved by cell differentiation. Individual nucleated cell-like unit resembles well with *Glenobotrydion* and *Gloeodiniopsis*, which are very common genera of Proterozoic time. However, their presence within a transparent large-sized vesicle is a unique feature, deviating from a normal morphology, hence placed among bizarre forms.

Discs comprising segmented body and appendage-like structures, Rohtas Formation, Semri Group, Lower Vindhyans

Description Discs of .5–1.5 mm in diameter occurring on bedding surface of micritic limestone. The discs are transluscent and comprised of objects resembling segmented bodies and appendages of very small-sized insect-like structures. Disc diameter vary between 0.3 and 0.5 mm, three samples traced with different levels of preservation (Fig. 4e).

Discussion The specimens in first glance give the appearance of fossils in amber. As far as affinity of these fossils is concerned, it is very difficult to say anything. However, morphology suggests a possibility that the structures represent some mesoscopic metazoans, comprising segmented body and appendage-like structures.

Megascopic dichotomous branching in association with *Grypania*-like object, Rohtas Formation, Semri Group, Lower Vindhyans

Description Impression of a dichotomously branched plant fossil, occurring in association with *Grypania*-like object preserved on bedding plane of a limestone bed. Maximum and minimum diameters of the branch are 1.5 mm and 1.0 cm, respectively. Single specimen was recovered in both hypo and epirelief. Maximum length of branch is 9 cm. Width of spire in *Grypania*-like structure is 1.8 cm (Fig. 4d).

Discussion Megascopic algae is already reported from the Semri Group, like *Grypania Chuaria, Tawuia, Vendotaenia* etc. (Kumar 2001; Srivastava and Bali 2006; Sharma 2006; Sharma and Shukla 2009). Beautifully preserved branching at such megacopic scale has not yet been recorded. A megascopically branched algal thallus *Konglingiphyton* also exhibits comparable morphology, except hold-fast structure reported from the China, which was considered as the first erect plant that broke the dominance of flat lying microbial mats (Menge et al. 1995). These are of ecological and environmental significance as they could raise the photosynthetic efficiency and the free oxygen level in atmosphere and hydrosphere. Macroscopic algae are, therefore, a treasure for elucidating the earlier evolution of life (Menge et al. 1995).

Megascopic-branched filaments with attached vesicles, Dholpura Shale, uppermost Vindhyans, Rajasthan

Description Well-preserved branched filaments of 0.3–0.5 mm diameter, repeated lateral branching, two vesicles attached to these branches, among which one vesicle exhibits excystment. Attachment structure is very clear in present specimen. Diameters of vesicles vary between 1 and 2 mm (four vesicles). All these features are preserved on bedding surface of shale (Fig. 3c).

Discussion Preservation of these samples is exceptional; branching is very clear, excystment in vesicle is undoubted. Morphological features suggest Vaucheriacean affinity for these fossils; however, no such fossil has so far been reported from any Proterozoic sequence of the world.

An erect plant like fossil, Dholpura Shale, Bhander Group, Uppermost Vindhyan, Rajasthan

Description An erect plant-like megascopic carbonaceous fossil exhibiting sporangia-like features; maximum length of whole plant measured is 7 mm, maximum diameter of sporangia like structure is 1.5 mm, diameter and length of setae-like structure is .25 and 1.5 mm, respectively. Rhizoid or hold-fast-like structures are also seen, although preservation of these features is not very good (Fig. 4g).

Discussion The morphological features of present form suggest bryophytic affinity to some extent. Presence of structures resembling sporangia and setae along with rhizoids or hold-fast are the supporting features. Differentiation of thalli into hold-fast and vegetative parts like sporangia and setae also resemble with *Konglingiphyton*-like fossil form of China (Menge et al. 1995). However, evidences are not conclusive as the complete morphology is represented by a single specimen.

Chuaria-like vesicle with cluster of small spheroids or a scale-like feature within a spheroidal carbonaceous fossil

Description Small-sized carbonaceous sub-spherical vesicle of 2.0 mm diameter, encompassing a cluster of about 40 very small, closely packed spheroids (two specimens). Diameter of these small cell-like units ranges between 0.1 and 0.2 mm (Fig. 3e).

Discussion Morphology of present form resemble to some extent with scale fossil *Chilodictyon* (a microfossil of 15–18 μm in diameter) reported from 700–600 Ma old Tindir Group, Canada, interpreted to have affinity with Chrysophyte algae, a member of *Chromalveolate* clade. Since the present form is megascopic, there is always a possibility of getting megascopic analogue of any microscopic form. Allison and Hilgert (1986) reported scale microfossils from Early Cambrian of Canada. There is a possibility that the specimen may represent a sheath encompassing numerous cell-like units of a multicellular tissue of a metaphyte. Although presence of cell tissue in Precambrian carbonaceous compressions are rare, they have been reported only from the phosphorites and siliceous rocks, like 900 Ma old *Bangiophyte* colonies from Somerset Island in northern Canada and Doushantou Formation of South China.

Pre-Ediacaran metazoan or a metaphyte (?), Bhander Group, Upper Vindhyan

Description There is an elongated body of 7 mm in length and 2.5 mm in width, tapered at one end with an opening-like structure seen at broader end. A median gut-like structure, comparatively darker in colour, is running along its whole length (single specimen; Fig. 4b, c).

Discussion As far as affinity of this form is concerned, it is very difficult to decide whether it belongs to a plant or an animal kingdom. There is a possibility that the form represents a metazoan, in which opening-like structure is its mouth and median dark structure running along its length is its median gut. There is also a possibility that the specimen is a Voucheriacean alga or a benthic plant body with hold-fast-like structure. Another specimen with conical hollow body with a well-preserved rim-like structure and a loop like string may also represent a possible metazoan fossil of unknown affinity (Fig. 4c).

Very thin thread-like carbonaceous filaments, Rohtas Formation, Semri Group, Lower Vindhyans

Description Smooth, straight or curved, at places branched, thin thread-like filamentous structures on bedding surface of micritic limestone. Diameter of filaments vary between 0.2 and 0.3 mm; they are not visible with naked eye. Length varies between 3 and 12 mm (Fig. 4f).

Discussion In comparison to the present forms, *Chambalia minor*, reported by Kumar and Srivastava (2003), from the Bhander Group, Central India is larger in size, which is visible by the naked eye. Moreover, branching has not been reported in any specimen of *C. minor*, which is a very prominent in case of the present form. *Vendotaenia* also exhibits larger dimensions in comparison to present forms. It is, therefore, categorized among problematic forms.

Carbonaceous fossil with budding/feather-like structure, Sirbu Shale Formation, Bhander Group, Upper Vindhyans, Rajasthan

Description An elongated, more or less triangular or cuneiform carbonaceous film or thalli with two small spherical bud-like structures giving it forked appearance at the broader end. Maximum length of triangular structure is 6–8.5 mm, maximum width measured is 2 to 3 mm (two specimens; Fig. 4h).

Discussion In general morphology, present form shows some resemblance with *Eopalmaria prinstina* Yan (1995)

or *Changchengia stipitata* (Sharma 2006). The difference in present form is the shape of bud-like structures with reticulate ornamentation. There is a possibility that the present form belongs to some other unknown biologic affinity. In general, the morphology also suggests bryophyte affinity for this particular form.

Vase-shaped microfossils with and without an opening, Sirbu Shale Formation, Bhander Group, Upper Vindhyans, Rajasthan

Description Flask or vase-shaped body is preserved in petrographic thin section of Sirbu chert. Long diameter 450 μm and short axis is 225 μm. Vesicle is truncated at one end (Fig. 3h).

Discussion Prior to this report, well-preserved vase-shaped microfossils were not recorded from any Vindhyan assemblage. Fossils with opening are many, but very few specimens have been traced without an opening but a perfect vase-shaped body. The specimens are well preserved and being reported from petrographic thin section of chert. Both these forms, though differ in size, exhibit comparable morphology. Moreover, these have been recorded from the same stratigraphic unit i.e. the Sirbu Shale Formation. There is thus a possibility that both forms belong to a common biologic affinity, which may be an algae or metazoans. They seem to be a good example of sequential representation of evolution from micro-megascopic life.

Discussion and conclusion

The fossil assemblage comprised of bizarre forms of the Vindhyan Supergroup suggests that:

- Life during Vindhyan sedimentation was complex, advance and highly diversified. The fossil profile of the Vindhyan Supergroup can be represented by cyanobacterial (most dominating community), bacterial, algal, fungal acritarchean (Kumar and Srivastava 1995, 1997, 2003; Rai et al. 1997; Sharma 2003, 2006; Srivastava 2002, 2004; Srivastava and Bali 2006; Venkatachala et al. 1996), pre-metazoan and Ediacaran communities (De 2006; Srivastava 2006, 2011; Srivastava and Tewari 2011).
- In general, Palaeoproterozoic acritarchs are simple spheroids with occasional median split, enveloping sheaths or surface ornamentation, whereas during Mesoproterozoic, they exhibit pores in vesicle walls and multicellular structures at both micro- and megascopic levels.
- Vindhyan acritarchs exhibit significant change in the Cryogenian (850–630 Ma) period. Morphological disparity as well as global taxonomic diversity decreased significantly during this time. Large and complex acanthomorphs are few in number (Srivastava 2009).
- Presence of mesoscopic carbonaceous fossils from the Mesoproterozoic Panna Shales, Rewa Group, Upper Vindhyans (Srivastava 2004) interpreted as intermediate forms or a missing link between the evolution from micro- to megascopic life and complex morphologies (bizarre forms) of present paper open a new window in Proterozoic evolution. Present paper is a step ahead in the direction of evolutionary palaeobiology of the Vindhyan Supergroup.
- *Grypania* is broadly distributed by ca 1,400 Ma and appears to be unaccompanied by other multicellular macroscopic fossils (Butterfield 2000). In contrast, the Vindhyan Supergroup exhibits presence of *Grypania* accompanied by (megascopic eukaryotic branched alga) and a number of multicellular macroscopic fossils (Fig. 4d).
- Presence of *Chuaria–Tawuia* during Mesoproterozoic are simple, in Neproterozoic they exhibit complex morphologies like, *Chuaria* with cluster of small spheroids (Fig. 3e), with intracellular mass, with enveloping sheath and with spine like processes and other complex morphologies.
- Presence of large-sized (>600 μm) acanthomorph *Trachyhystrichosphaera* sp. (Fig. 3a, b) in Sirbu Shale, Bhander Group, suggests Ediacaran age as the upper age limit of the Vindhyan Supergroup because *Trachyhystrichosphaera* is considered to be an index fossils for latest Proterozoic (Butterfield and Rainbird 1998; Srivastava 2009). During the Cambrian, size of the acanthomorphs markedly reduced globally (Huntley et al. 2006).
- Presence of large-sized *Trachystrichosphaera* along other supporting evidences viz. lichen-like fossils may confirm the existence of organic forms with fungal affinity in the Vindhyans.
- Multicellularity, sexuality and animal affinity at both micro- and megascopic levels seem to have been established during the sedimentation of Neoproterozoic, Bhander Group. Presence of fossils represented by chlorophycean, rhodophycean and Ediacaran affinities are found to have evolved during Vindhyans.
- Presence of Ediacara Fauna in Upper Vindhyans (De 2006; Srivastava 2006, 2009) support its Ediacaran age as the upper age limit for the Vindhyan Supergroup.
- Large-spiked/process-bearing acritarchs and multicellular organisms without skeletons were found in the Partatak Formation, Spitsbergen, Vindhyan Supergroup,

India and Doushantou Formation, China. These complex and peculiar microfossils formally united into the groups of acanthomorphs, herkomorphs and heterogenous group including green algae, dinoflagellates and other protists and metazoans.

- The outbreak of the spiked/acanthomorphs reflects a transition from Early Precambrian biosphere dominated by morphologically simple prokaryotes to the Neoproterozoic biosphere dominated by eukaryotic, advanced organisms (Sergeev et al. 2002).
- Since typical Cambrian fossils have so far not been recorded from the Vindhyan Supergroup (except Azmi's controversial Small Shelly fauna), Precambrian age is strongly recommended for the Vindhyan Supergroup.
- Microfossils, comparable in morphology to animal embryo to some extent, red algal forms or carbonaceous megafossil interpreted as pre-metazoan animal and record of Ediacaran fauna would be significant evidences for metazoan evolution in Vindhyans at micro- and megascopic level.
- Striking similarity in morphology of the vase-shaped microfossils and *Tawuia* (carbonaceous macrofossil) suggest animal affinity for *Tawuia* and may help in establishing the sequential representation of evolution from micro to megascopic animal life.
- Different modes of occurrence in case of *Chuaria*, strongly support variable affinities for this morphotaxa. Bud-like outgrowth in *Chuaria* and its occurrence in irregular mesh of hyphae-like structures are the evidence suggesting its fungal affinity in the Vindhyan assemblage.

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