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PROBLEMATIC STRUCTURES FROM THE EDIACARAN JODHPUR SANDSTONE, RAJASTHAN, INDIA AND THEIR POSSIBLE AFFINITY

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ABSTRACT

The Ediacaran Jodhpur Sandstone shows profuse development of megascopic noncarbonaceous bizarre structures. These are preserved as casts and moulds on the bedding surfaces of the sandstone in a shallow marine setting in moderate energy conditions. All finer details are missing except the gross morphology. These structures are in the form of filamentous tubes, nonseptate with branching pattern. The tubes have tapering ends with occasional swelling structures. Hook-shaped structures and also swelling structures are seen attached to the tubes. Organic and inorganic origin of these structures is discussed but organic origin is preferred. These structures are considered as body fossils and are put under algae and family *incertie sedis*. These unusual forms are named as *Vendophycus rajasthanensis, Vendophycus sursagarensis* and *Jodhpurophycus marwarensis*. It appears that these algal body fossils were growing as creepers slightly embedded within the microbial mats. They flourished at the upper few centimeters of the sandy substrate. The microbial mats gave stability to these forms and supplied nutrients. These algae grade structures lost their existence in the Cambrian either because of the appearance of the animal life which browsed upon them or due to some other unknown reasons.

Keywords: Jodhpur Sandstone, Marwar Supergroup, Ediacaran, noncarbonaceous megafossils, algal grade structure

INTRODUCTION

The megascopic nonvascular noncarbonaceous plants discovered from the Ediacaran Jodhpur Sandstone, Marwar Supergroup, western Rajasthan have been compared with Xanthophycean algae *Vaucheria* in morphological characters except variation in size by Kumar *et al.* (2009) and similar structures reported by Srivastava (2015) from the same horizon as sea weeds with red and green algal affinity. These need re-evaluation because both the reports have important implications for the evolution of nonvascular plants. Carbonaceous nonvascular megaplant fossils from the Neoproterozoic sediments are more or less all are related to carbonaceous films of varying shapes and sizes (Hofmann, 1992, Venkatachal *et al*., 1996; Xiao *et al*., 2002, Kumar and Srivastava, 2003; Dong *et al*., 2008; Yuan *et al*., 2011; Wang *et al*., 2011; Sharma and Shukla, 2012). In the present assemblage, the preservation of carbonaceous fossils is not recorded, because either the plants were not growing in such environments where sand was being deposited, or if present, they could not be preserved as they were oxidized due to higher porosity and permeability in the sand. In the absence of any organic matter associated with noncarbonaceous structures as is the case with the Jodhpur filaments, it is very difficult to decide whether the structures are fossils or nonfossils. The only available tool is the morphology of the structures. The Jodhpur filamentous tubes are straight to sinuous, nonseptate, megascopic, showing branching and tapering ends. Swelling or development of beads at some of the tapering ends as well as on the filamentous body is also seen. Such morphological structures may be compared with the thallus of nonvascular plants (Kumar *et al*., 2009). However, Srivastava (2015) compared these structures with sea weeds of green and red algal affinity and considered them representing a transitional phase of megascopic life proceeding from water to land without citing any valid reason. An attempt has been made in the present work to evaluate these problematic structures as fossils or non fossils or microbially induced sedimentary structures but there fossil origin is preferred.

GEOLOGICAL SETTING

The Jodhpur Sandstone is the youngest formation of the Jodhpur Group of the Marwar Supergroup, earlier referred to as the Trans-Aravalli Vindhyans (Fig.1). The Marwar Supergroup occupies a large area in the western Rajasthan in a desert setting with interspersed hillocks. In the eastern part of the Marwar Basin, the rocks are exposed on the surface, while in the western part the rocks are developed in the subsurface region where much of the information is based on the bore-hole data (Rastogi *et al*., 2005). The Marwar Supergroup unconformably overlies the Malani Igneous Suite and older metamorphic rocks (Pareek, 1981, 1984). They are unmetamorphosed and in general undeformed. In most of the areas, the rocks are horizontal or show very low dips. The lithology is represented by the sandstone, conglomerate, siltstone, dolostone, limestones and shales.

The Marwar Supergroup is subdivided into three groups; in the stratigraphic order these are the Jodhpur Group, the Bilara Group and the Nagaur Group (Pareek, 1981, 1984). Each group has been further subdivided into different formations (see Table 1). The Jodhpur Group has been subdivided by Pareek (1984) into the Pokaran Boulder Bed, the Sonia Sandstone and the Girbhakar Sandstone. However, Chauhan *et al*. (2004) have merged both the Sonia Sandstone and the Girbhakar Sandstone into the Jodhpur Sandstone.

The Marwar Supergroup unconformably overlies the Malani Igneous rocks which have been dated as 771±5 Ma by U-Pb method (Gregory *et al*., 2009). As such the rocks of the Marwar Supergroup have to be younger than 771 Ma. Recently, Kumar

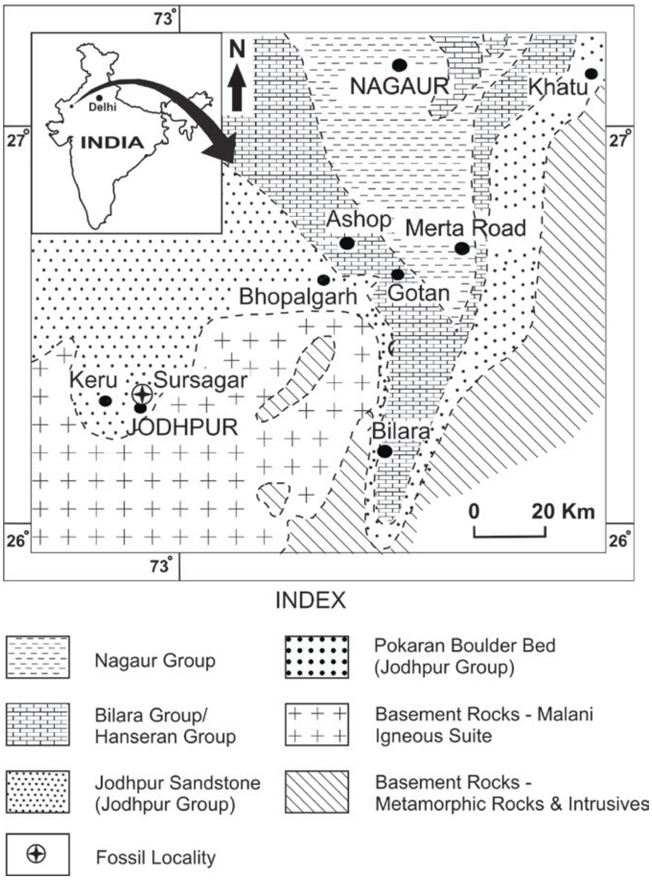


Fig. 1. Geological and location map of the Jodhpur area, western Rajasthan (after Pareek, 1984).

and Pandey (2008a, 2009) have reported Ediacaran body fossils *Aspidella, Hiemalora, Beltanelliformis minuta* and microbial mat structures *Arumberia banksi* and *Rameshia rampurensis* from the Jodhpur Sandstone and have assigned Ediacaran age to it. The Nagaur Sandstone of the Nagaur Group has yielded trilobite trace fossils represented by *Rusophycus* and *Cruziana*, body fossils of priapulid worms and an articulated "arthropod tergites" and on this basis the Nagaur Group has been assigned Lower Cambrian age (Kumar and Pandey, 2008b, 2010; Srivastava, 2012; Singh *et al*., 2013, 2014; Pandey *et al*., 2014; Ahmad and Kumar, 2014). The carbon isotope data of the carbonates of the Bilara Group supported that the Precambrian-Cambrian boundary should lie within the Bilara Group (Mazumdar and Bhattacharya, 2004). On the basis of acritarch study, Prasad *et al.* (2010) have suggested Precambrian/Cambrian boundary in the lower part of the Bilara Group. Thus, the available data favour an Ediacaran age to the Jodhpur Sandstone as it underlies the Bilara Group.

The fossiliferous Jodhpur Sandstone is represented by medium to fine-grained, light brown to brick-coloured sandstone, siltstone and brown coloured shale. A few conglomeratic horizons in the upper part are also present but the dominant lithology is the fine-grained sandstone. The middle part of the Jodhpur Sandstone (the Sonia Sandstone of Pareek, 1984) which has yielded the problematic structures shows excellent development of sedimentary structures indicating a shallow water marine environment of deposition. Parallel bedding with low angle discordances, mega cross bedding of both trough and planar types, small scale ripple bedding, wave and current ripples marks, interference ripples, starved ripples, salt pseudomorphs shale, mud cracks, etc are abundantly recorded. A variety of microbial mat structures and microbial mat mediated structures have been reported by Sarkar *et al*. (2008) and Kumar and Ahmad (2014). Chauhan *et al*. (2004) have suggested a beach-environment of deposition for the problematic structures bearing horizon. A generalized litholog of the Jodhpur Sandstone exposed in the Sursagar area is given in Fig. 2.

PROBLEMATIC STRUCTURES: NON-FOSSILS, NONVASCULAR PLANTS OR MICROBIALLY INDUCED SEDIMENTARY STRUCTURES (MISS)

The problematic structures are simply represented by morphology made up of sandstone and are found when the rock is split along the bedding planes. These structures are filamentous in nature and characterized by the following morphological features:

These are long, straight to sinuous, nonseptate, filamentous megascopic ribbon to tube-like structures preserved as epirelief on the bedding surface of medium to fine grained sandstone with maximum recorded length as 2.70 m and maximum recorded width as 7 cm. It is made up of more or less same material as that of the host rock but marked by a darker brown colour on

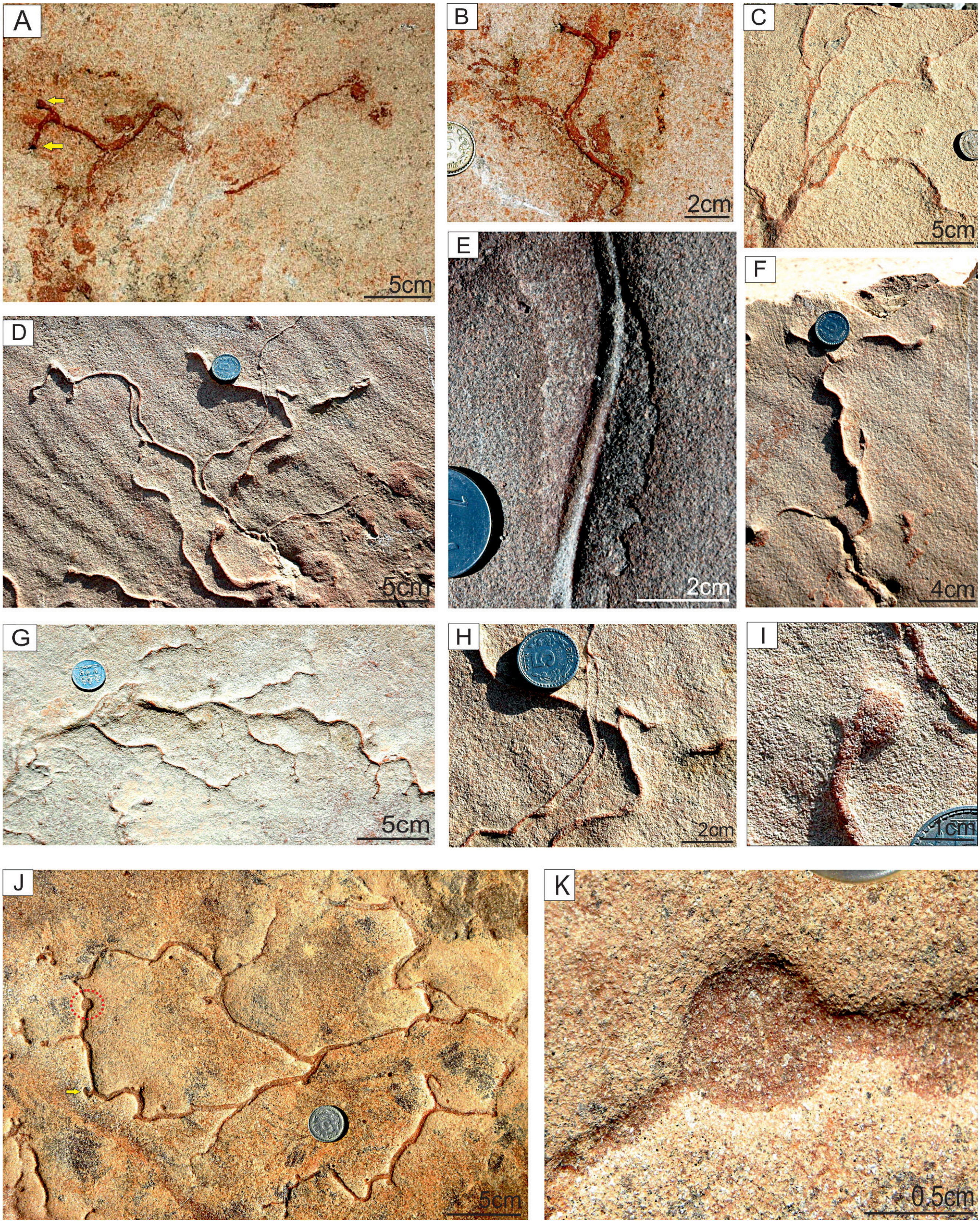
Table 1: Stratigraphic succession of the Marwar Supergroup (after Pareek, 1984 and Chauhan *et al*., 2004).

	Supergroup	Group	Formation
← Late Neoproterozoic to Early Cambrian →	Marwar Supergroup ↑↓	Nagaur Group (75-500 m)	Tunklian Sandstone
			Nagaur Sandstone
		Bilara Group (100-300 m)	Pondlo Dolomite
			Gotan Limestone
			Dhanapa Dolomite
		Jodhpur Group (125-240)	Jodhpur Sandstone
			Pokaran Boulder Bed
	~~Unconformity ~~~~~~~~~~~~~~~~		
		Basement	Malani Igneous Suite / Metamorphites

EXPLANATION PLATE I

Plant fossils of the Jodhpur Sandstone, Sursagar area, Jodhpur, western Rajasthan. A) The holotype of ***Vendophycus rajasthanensis*** showing thallus with swollen tips referred as beads, arrow marks the beads. B) Close up view of (A) showing the swollen part at the tip. C) Development of microbial mat over the thallus of plant fossil on the bedding surface. D) ***Vendophycus rajasthanensis*** showing thallus with smooth wall preserved on the top of the rippled surface of the medium grain sandstone. E) Thallus preserved as hollow tube. F) Development of thallus showing fertile structures at their tips as beads. G) Branching pattern of ***Vendophycus rajasthanensis*** seen on the bedding surface. H) Figure shows overlapping of thallus as well as splitting tendency of thallus. I) Magnified view of (D) showing well developed fertile structure (oogonia). J) Figure shows well developed thallus with antheridia marked by arrows. K) Close up view of J (marked by dotted circle) showing *cf.* developing synzoospore.

Plate I



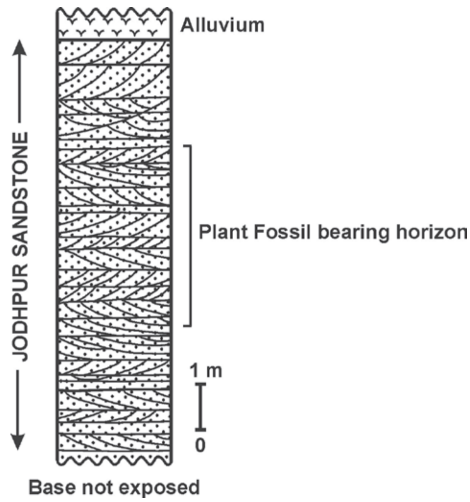


Fig. 2. Litholog of the fossil-bearing horizon, Sursagar mine area, Jodhpur, western Rajasthan.

the weathered surface and light brown colour on fresh surface.

The ribbon/tube-like structures show branching and tapering.

The filament splits into two and then joins again.

Bead-like structures are seen on main filamentous body as well as at the tips.

In some cases the structure is made up of relatively finer material in comparison to the host rock.

These structures show bulbous or hook like structures attached to the main tube or filament.

Tube-like feature also shows hollow nature with well developed walls.

Presently, there are only two studies available regarding the these problematic structures, one by Kumar *et al.* (2009) and the other by Srivastava (2015), though earlier possibly comparable structures were also reported by Kumar *et al*. (1997) as inorganic secondary fillings and rill marks. Both the studies have indicated plant affinity. Kumar *et al*. (2009) have considered these structures as Xanthophycean algae while Srivastava (2015) has suggested a red and green algal affinity and considered them as sea weeds. Can these morphologies be produced by any inorganic process and, if so, what are the possible ways to produce such complicated morphologies? There are two possibilities; they may represent sandstone dykes/sills or diagenetic structures or they represent biogenic structures. In the Sursagar mines, the transverse sections to the bedding planes can be searched at many places as there are many available areas and sections where bedding planes can be studied in detail. No where could one find any evidence for the presence of sandstone dykes and sills in the middle part of the Jodhpur Sandstone. Moreover the interwoven nature of tube like structures at many places rules out the possibility of these structures being sandstone dykes. They cannot represent a diagenetic feature as its synsedimentary nature can be inferred from the fact that a thin microbial mat in the form of small blisters referred to as a microbial mat *Rameshia rampurensis* (see Kumar and Pandey, 2008a) has also engulfed these tubes. This is possible only, when the tubes were already existing before the development of the microbial mats. Moreover, no calcareous mineral has been detected in thin sections which might represent a diagenetic material. These structures are made up of the similar material as that of the host rock. Thus, the possibilities of its being a primary inorganic sedimentary structure as well as secondary diagenetic structures are ruled out. If biogenic, these structures may belong either to plant kingdom or they may represent animal body fossils or trace fossils. On the basis of morphology, it is not comparable to any animal body fossil or trace fossil. Its morphology is also not comparable to any microbial mat induced sedimentary structures including synaeresis cracks (MISS; see Schieber *et al*., 2007). No comparable structures have been noted in either modern microbial mat or ancient rocks. In support of its nonvascular plant origin only the morphology can be used as there is no other parameter available for any scrutiny. With mould and cast preservation in sandstones no details are preserved. The following points can be cited in support of nonvascular plant origin:

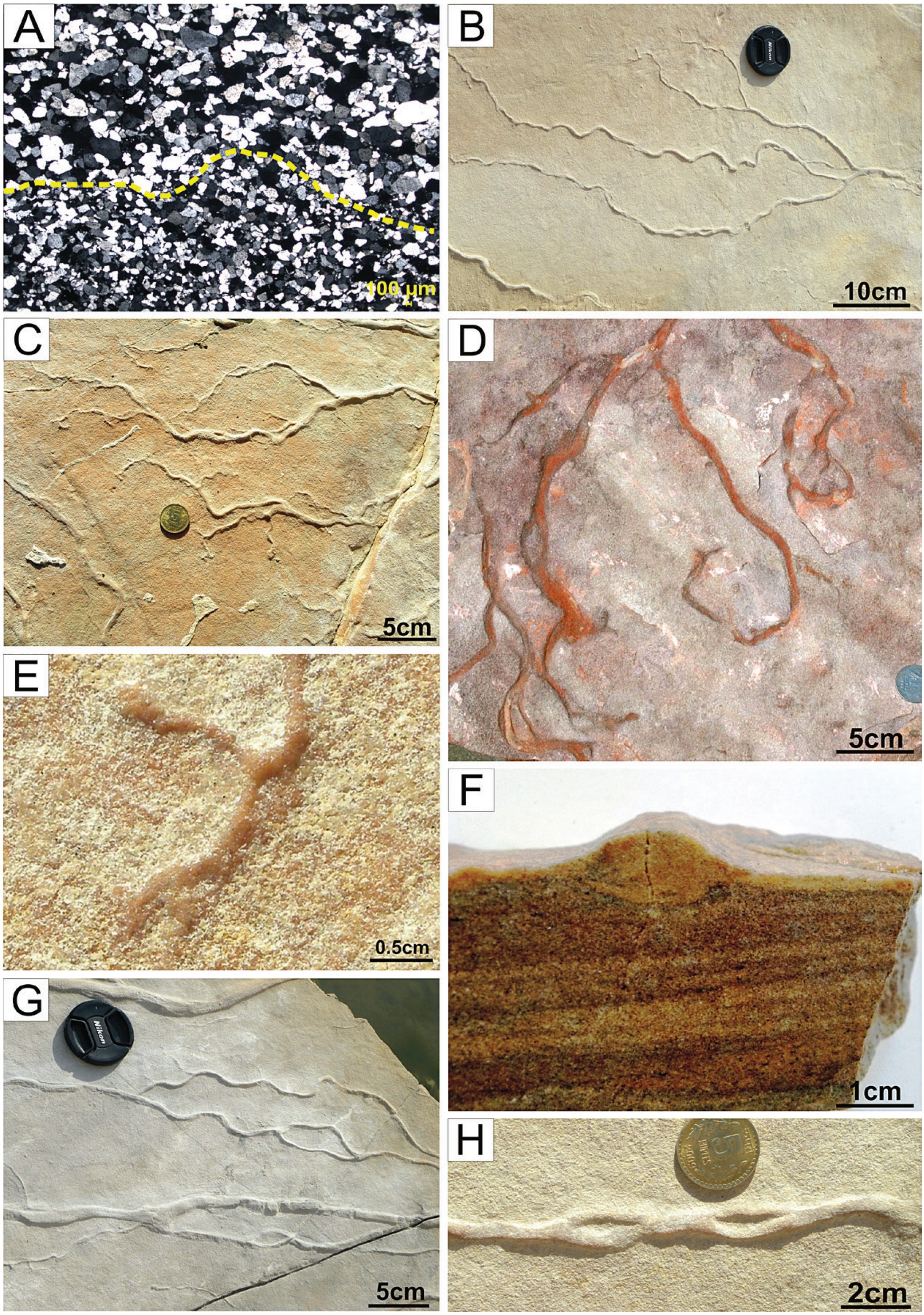
1. The structure is represented by a filamentous tube which is comparable to a thallus. It is nonseptate with smooth margins and has a tapering ends. It appears as a hollow tube with thin walls.
2. Branching is prominently seen in the tubes.
3. In the middle part of the tubes, swelling is seen. No other details are visible and only morphological comparison can be made. It can simply inferred as a germinating cell comparable to fertile structure in the living *Vaucheria.*
4. Presence of swelling at the end of the thallus as well as on the thallus is an important characteristic morphological feature which is prominently developed at different places. As mentioned earlier, no morphological details are seen except gross outline and only morphological similarity can be helpful in suggesting its role. It is definitely attached to the main body of the tube and cannot be taken as floating structure or even a concretionary or diagenetic structure. Apparently, it looks comparable to oogonia (sporangium) of a living nonvascular plant (Pl. I, fig. K; Pl. III, fig. G, marked by arrow "b").
5. The hook-shaped structures present at the margins of the thallus can be compared with antheridium in extant algae. The antheridia are curved, sickle-shaped cylindrical tube generally found along with oogonia in modern-day *Vaucherian* algae (Robin South and Whittick, 1987). The problem with this suggestion is again the non availability of any other parameter to prove this. Only suggestions can be made.

All these features support the conclusion that these structures show morphologies comparable to the nonvascular plants and hence they can be assigned to plant kingdom. The

EXPLANATION OF PLATE II

Vendophycus sursagarensis reported from the Jodhpur Sandstone, Sursagar area, Jodhpur, western Rajasthan. A) Photomicrograph showing the contact of the host rock (Quartz arenite) with the thallus of the plant fossil. The dotted line marks the contact; The upper part represents the host rock and the lower part the thallus B) Well developed branching pattern in the thallus; C) View of the thallus showing regular pattern of branching; D) The holotype of ***Vendophycus sursagarensis*** showing branching pattern, swollen structure and splitting in thallus; E) Swollen structure seen at the tip of the thallus; F) Elliptical size of the thallus in cross sectional view, preserved in sandstone and G-H) Typical characteristic feature of splitting of the thallus at middle part of thallus.

Plate II



consistency in the morphology observed at different places also supports this conclusion. However, it is not possible to suggest any affinity to living plants as there is no way to prove the comparison with *Vaucheria* as has been done by Kumar *et al.* (2009) or any other genus of Xanthophyceae as size is the main obstacle for comparison, one is microscopic and the structures under discussion are megascopic. Srivastava (2015) has identified the Jodhpur structures as red and green algae on the basis of her recognition of terminal and lateral sporangia, dichotomous branching, bladder, scale and spine-like leaves, stolons or leafless stems, horizontally creeping rhizomes, hold-fasts, carpospores and lignin-like structures and compared them with earliest land plants. The problem with her approach is that here comparison of these structures with modern plants is very subjective and speculative. Because of this reason these nonvascular plants are grouped under the family incertie sedis. It is contended that these nonvascular plants developed in the Ediacaran period with unique morphological characters which cannot be compared with living nonvascular plants.

DESCRIPTION OF ENIGMATIC FORMS

Three forms have been described from the Jodhpur Sandstone which belong to two genera and three species. These nonvascular plant fossils are recorded only in the Sursagar area, which is about 8 km NNE of Jodhpur city. These fossils can be studied in the different mine pits where about up to ca.15 m thick section of the middle part of the Jodhpur Sandstone is exposed. The GPS value of fossil-bearing horizon is N26^{o} 20.007' and E72^{o} 59.76'. Since the rocks are more or less horizontal, the bedding planes can be searched for these structures. These are preserved as moulds and casts on the bedding planes of the light brown coloured, fine to medium-grained sandstone. The fossils are marked by the relatively darker colour in comparison to the host rock on the exposed bedding surfaces (Pl. II, fig. F). But in the fresh sections, they are also of lighter colour. Petrographic investigation reveals the grain size disparity between the host rock and thallus (Pl. II, fig. A). All the samples have been deposited in the Museum of the Geology Department, University of Lucknow, Lucknow.

Family Incertie sedis

Genus ***Vendophycus*** n. gen.

(*Type Species*: *Vendophycus rajasthanensis* n. sp.)

Locality: Sursagar mines, Jodhpur area, Rajasthan

Lithology: Fine to medium grained sandstone; middle part of the Jodhpur Sandstone (Sonia Sandstone of Pareek, 1984)

Derivation of name: The new genus is named after the ‘Vendian’ stage denoting the age of the Jodhpur Sandstone.

Generic diagnosis: Filamentous, nonseptate, hollow, large cylindrical and tubular body. Generally preserved as cast, rarely as mould. Filament generally straight to sinuous with thin wall surface and smooth margins, filament width varies from 0.3 to 7.0 cm (Pl. I, figs. D, G; Fig. 3B). Filament freely branched with acute angle, tapering or forming globular body of 0.4 to 3 cm at tips. Filament generally interwoven with tendency to break or split. Midway swelling in tube is also seen. Occasionally small curved bodies are preserved on the filament.

Remarks: The nonvascular plant has morphology comparable to *Vaucheria* except the dimensions (Kumar *et al*., 2009). It is an unusual comparison as the *Vaucheria* is a microscopic form, whereas the present fossil is megascopic one, and hence this comparison does not hold well and appears inappropriate. Because of this reason, the present genus is not assigned to any extant form and, hence, put under the family incertie sedis. The filament is described as thallus, and swelling tips or beads as oogonia. The curved structure attached to the thallus has been identified as antheridium. Midway swelling in tube is compared with synzoospore (Pl. I, fig. K). Presence of oogonia, synzoospore and antheridium are mere suggestions on the basis of morphological similarity and mode of occurrence but there is no way to prove it. Midway swelling in the filament can be compared with the synzoospore. Figure C of Pl. I depicts the development of microbial mat over the thallus on the rippled bedding surface confirming the synsedimentary nature of the thallus. The frequency of branching and presence of bead-like structure is less in *Vendophycus* in comparison to *Jodhpurophycus.*

Vendophycus rajasthanensis n. sp.

(Pl. I, figs. A-K; Fig. 3, B)

Holotype: Sample no. SK-15

Paratypes: Sample no. SS/SK-10, 11, 12, 13

Locality: Sursagar mines, Jodhpur, Rajasthan

Lithology: Fine grained to medium grained sandstone.

Derivation of name: The species is named after “Rajasthan” state in western India, from where it is being reported for the first time.

Species diagnosis: It is generally preserved as cast on the bedding surface and less commonly as mould. It is represented by filamentous form which is large in size and made up of nonseptate cylindrical and tubular body (Pl. I, figs. A, B), straight to sinuous with smooth margins (Pl. I, fig. D, G) freely branched with tapering ends. Branching generally makes an acute angle, but at right and obtuse angles also present (Pl. I, fig. F, G). Interwoven nature of the filaments is occasionally seen. The length of the thallus is up to 44 cm (N=35) while the width of the filament varies from 0.3 to 1.5 cm. If the tubular filament is thin, it shows smooth upper surface and is circular to elliptical in cross-section, but in thicker filaments striations are seen on the surface of the filament wall and it is compressed or flattened (Pl. I, fig. C). The filaments appear to be hollow with a thin wall (P1. I, fig. E). It shows a tendency to break or split with smooth margin in the middle part of the thallus (Pl. I, fig. D). Overlapping of filament is also observed (Pl. I fig. H). Tip

EXPLANATION OF PLATE III

Plant fossil ***Jodhpurophycus marwarensis*** reported from the Jodhpur Sandstone, Sursagar area, Jodhpur, western Rajasthan. A) ***Jodhpurophycus marwarensis*** showing shrub-like profuse branching with abundance of bead like structure on the thallus preserved on the top of the bedding plane; B) Figure shows hollow depressions in the middle of the thallus, marked by the arrow; C) Excellent preservation of fertile structures (oogonia) closely attached with the thallus; D) Closely attached bead like structure at the wall of thallus with bulbous tip; E) Close up view of the thallus showing closely attached beads making the outer wall serrated which is marked by the arrow; F) The holotype of ***Jodhpurophycus marwarensis*** showing development of thallus with well preserved beads as fertile structures. Arrows mark the structure and G) Magnified view of fertile parts of plant; antheridia and oogonia are marked by the arrows “a” and “b” respectively.

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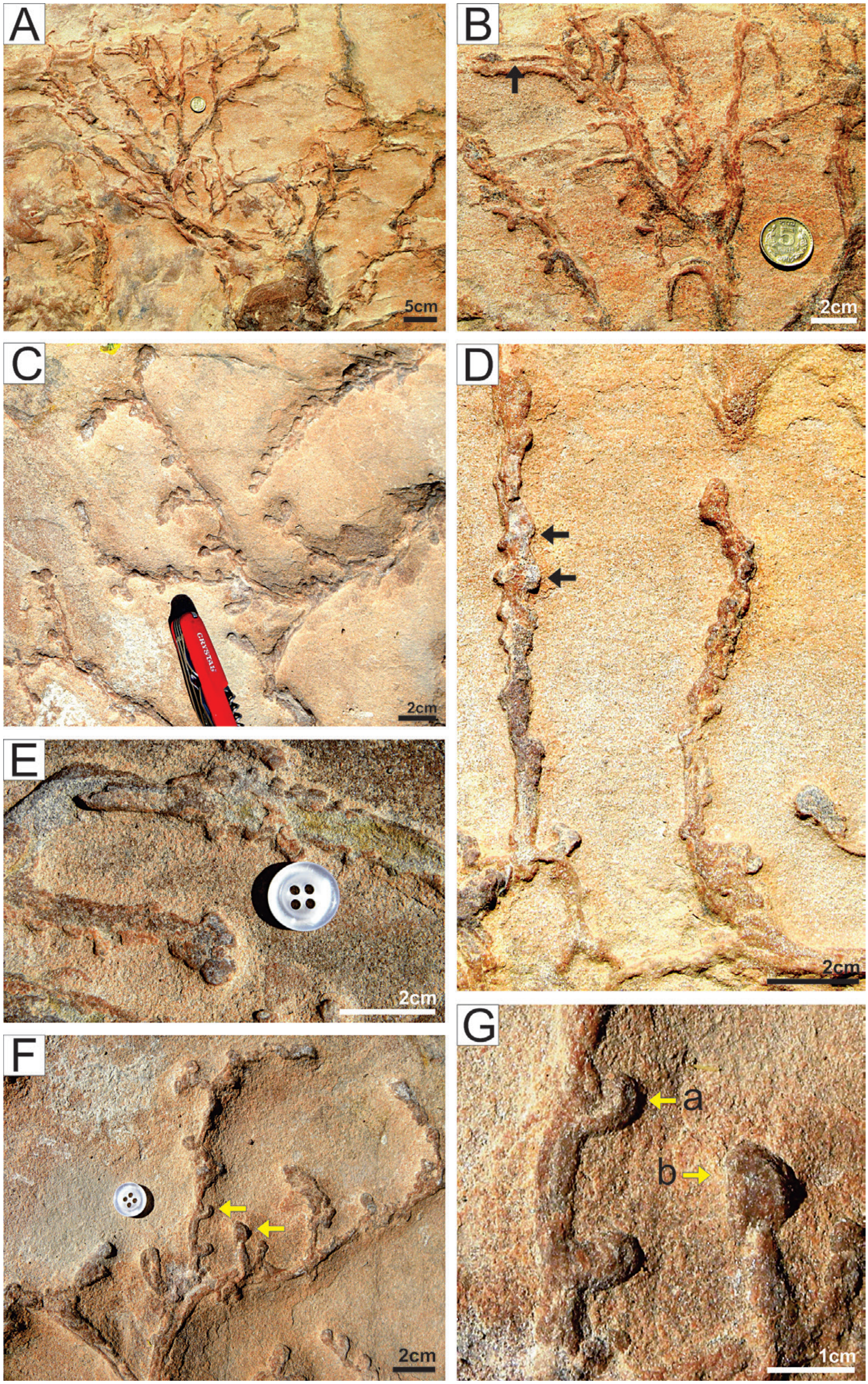
Plate III



of the filaments is either tapering or becomes swollen, forming a circular, globular or elliptical body (Pl. I, figs. I, J). The mean diameter of the globular bodies is 1.6 cm (N=20).

*Remarks***:** It is characterized by many swellings at the end of the filament tips, whereas they are very few in *V. sursagarensis* and swellings are smaller in size.

Vendophycus sursagarensis n. sp.
(Pl. II, figs. A-H; Pl. IV, figs. A-C; Fig. 3 A)

Holotype: Sample no-SS/SK-16

Paratypes: Sample no-VS/C 1-4

Locality: Sursagar mines, Jodhpur, Rajasthan

Lithology: Fine to medium grained sandstone

Derivation of name: The species is named after the locality Sursagar, near Jodhpur Township from where it is reported for the first time.

Species diagnosis: It is preserved as cast on the bedding surface and rarely within the bed. It shows filamentous morphology with nonseptate, cylindrical and tubular in outline and having a straight to sinuous and smooth margin. It is freely branched (Pl. II, figs. B, C) with tapering ends. Interwoven nature of the filaments is also seen (Pl. II, figs. B, C). The maximum width of the filament is up to 7 cm (Pl. IV, fig. A, see the area marked by dotted circle). The maximum length recorded is 270 cm (Pl. IV, fig. A). Branching occur at acute angle (Pl. II, fig. D) and also sometime at right angle (Pl. II, fig. E). The filament bifurcates at a mean angle of 56^{o} (N=8). The maximum elevation of the filament from the bedding surface is 1.4 cm (N=10). Bifurcation on an average is after a length of 35 cm (N=15). If the tubular filament is thin, it shows smooth upper surface and is circular to elliptical in cross-section, but in the thicker thallus it is compressed or flattened with striation on the surface. The thallus is curved and smooth walled (Pl. II, fig. F). It shows a tendency to break or split in the middle (Pl. II, figs. G, H). Very few swollen tips are seen with diameter ranging from 2 to 3 mm with mean value of 2 mm (N=10) (Pl. II, fig. E).

Remarks: The difference between the two species of the genus *Vendophycus* is that in the *V. sursagarensis* the swollen tips are very few and rare, while in the *V. rajasthanensis* they are common and the swellings are relatively larger in size. The size of *V. sursagarensis* is also larger in comparison to *V. rajasthanensis*.

Family Incertie sedis
Genus ***Jodhpurophycus* n. gen.**
(Type Species: *Jodhpurophycus marwarensis* n. sp.)

Locality: Sursagar mines, Jodhpur area

Lithology: Fine to medium grained sandstone

Stratigraphic horizon: Middle part of the Jodhpur Sandstone (Sonia Sandstone of Pareek, 1984)

Derivation of name: Genus is named after Jodhpur city, Rajasthan from where it is being reported for the first time.

Generic diagnosis: Body fossil, preserved as cast, rarely as mould, on the bedding surface and within the bed, represented by filamentous tube with a shrub-like arrangement of filaments resulted from profuse branching (Pl. III. figs. A, B). Filament nonseptate, cylindrical and tubular body, straight to sinuous (Pl. III, fig. E), freely branched with a tapering end and with interwoven nature (Pl. III, fig. A). Tip of some filaments swollen, having circular or elliptical shape with diameter of 0.4 to 1.4 cm. Filaments show abundance of bead-like bodies attached at the margins giving serrated appearance (Pl. III, fig. D). Presence of small curved bodies on the filaments seen.

Remarks: *Jodhpurophycus* differs from *Vendophycus* in its smaller dimensions, more profuse branching pattern and abundance of bead like bodies on the tubular/cylinderical thallus. The thallus never breaks or splits in the middle as is commonly seen in *Vendophycus.* Size is smaller in comparison to *Vendophycus* and the branching is more common giving a shrub-like appearance to *Jodhpurophycus*.

Jodhpurophycus marwarensis n. sp.
(Pl. III, Figs. A-G; Fig. 3 C)

Holotype: Sample no.SS/SK-1

Paratypes: Sample no. SS/SK-2, 3, 4, 6

Locality: Sursagar mines, Jodhpur, Rajasthan.

Lithology: Fine to medium grained sandstone.

Stratigraphic horizon: Jodhpur Sandstone (Sonia Sandstone).

Derivation of name: The species is named after the Marwar region of the western Rajasthan.

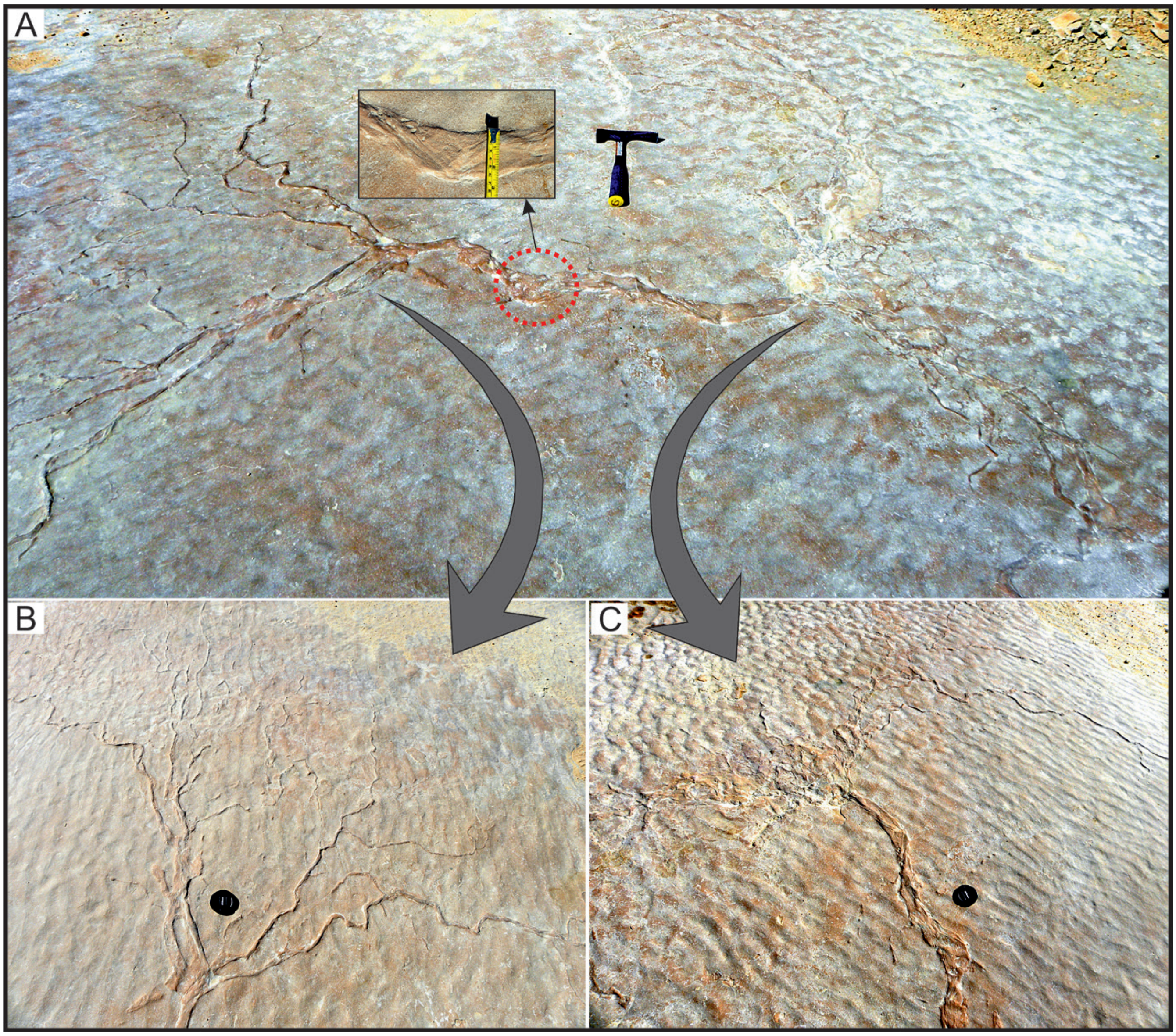
Species diagnosis: Body fossil, preserved as cast, rarely as mould on the bedding surface within the bed, represented by filamentous tube with a shrub like arrangement of filaments resulted from profuse branching (Pl. III, figs. A, B). Filament nonseptate, cylindrical and tubular body, straight to sinuous, with smooth to uneven or serrated margins (Pl. III, figs. E) freely branched with a tapering end and with interwoven nature (Pl. III, fig. A). Maximum length of filament is 72 cm and width varies from 0.5 to 3 cm. In a few filaments a depression is seen. Tip of some filaments swollen having circular or elliptical shape with diameter of 0.4 to 1.4 cm. Filaments show abundance of bead like bodies attached at the margins (Pl. III, fig. D). Presence of small curved bodies seen on filaments whose length is up to 1.0 cm and 0.5 cm in width.

*Remarks***:** Because of profuse branching, the present species looks like a shrub. The body of the filament has abundant bead like projections which also give irregular margins or even serrated margins. The curved bodies on the filament can be compared with antheridia (male sex organ; see Pl. III, fig. G marked by arrow "a").

Proposed model for the development of problematic fossils

The microbial community which flourished at the time of deposition of the Jodhpur Sandstone formed a variety of microbial mat-related morphologies in the sandstones (Sarkar *et al*., 2008; Kumar and Ahmad, 2014). Their abundance is noteworthy. The problematic fossils have been recorded from the section where the microbial mat or biomat-related structures have been abundantly developed in the fine to medium grained sandstone in the middle part of the Jodhpur Sandstone. The microbial community played the most significant role in stabilizing the sand at the sediment-water interface up to a depth of few millimeters to several centimeters. This inference can be drawn on the basis of available sedimentary structures; for example, even incomplete ripples are recorded overlying a plain sandstone layer (Kumar and Ahmad, 2014). This is possible only when the underlying layer of sand has been made strongly cohesive by the growth of microbial mat for the overlying sand to produce incomplete ripples. The incomplete ripples are formed when insufficient sand is available for the current or wave to cover the entire surface on a firm bottom (Reineck and Singh, 1980). The firm sandy bottom layer is possible only when the sand is made firm by the formation of microbial mat developed

Plate III



KUMAR AND AHMAD

EXPLANATION PLATE IV

A) Field photograph of the ***Vendophycus sursagarensis*** showing complete preservation of the thallus on the rippled surface of the sandstone (Scale: length of hammer=30.48 cm). B) and C) showing the branching pattern of the thallus in the left and right sides of the photograph.

at the water/sand interface which offered resistance to erosion. In addition, the absence of benthic animal population which could have produced burrows for living and were sediment feeders, the microbial mats were not bioturbated and remained stable. Thus, a stabilized and firm ground was available in sandy substrate for the nonvascular plants (which possibly have an algal affinity) to flourish near the sediment water interface.

It is suggested that there are two possibilities for the growth of algal plant; a). the plant was growing vertically with a hold-fast for the stability of plant, but under the impact of storm the plant was uprooted and redeposited on the bedding surface, or b). the plant had developed a creeping mode of growth on the surface of the bed but slightly embedded within the microbial mat. It is envisaged that during the Ediacaran period, these nonvascular plants were not growing vertically which required a holdfast of large dimension as the height of plant was more than 2.70 m. No well defined holdfast has been identified which could have given stability to the plant and thus this possibility is ruled out. Moreover, uprooting of large-sized vertically erect thallus should have been deposited as irregular broken pieces in an irregular manner and not restricted to bedding surface of sandstone. It is suggested that the nonvascular plants developed a creeping mode of growth near the sediment/water interface slightly embedded within the microbial mat. This inference is based on two observations; 1. since, the length of the thallus is very large and it needed a very strong holdfast apparatus. No such holdfast is noted. 2. at one place, a very large and thick thallus shows growth in opposite directions without any evidence of holdfast in the middle (Plate IV). This is possible only when the algal plant has a creeping mode of growth and the growth was possible in the opposite directions. The preservation of the nonvascular plant also suggests that it is preserved at the place of its origin and not transported.

The make-up of the microbial community is unknown as it did not leave any record in the sediments. The community must have been destroyed due to decay. On the basis of the available information on the modern microbial mats it must have been made up of cyanobacterial, bacterial and algal forms (see Noffke, 2010). Most mats in marine or hypersaline environment are principally cyanobacterial mats built predominantly by eukaryotic micro-organisms and are cosmopolitan in shallow marine lacustrine and flowing waters (Ward *et al*., 1992). The decay of the microbial community produced abundant nutrients. With abundant supply of nutrients and availability of space a few forms increased their size and became megascopic and their nutrients supply was through surface membrane. Slightly embedded nature gave stability to nonvascular plants. The plant did not survive in the Cambrian because of the appearance of animal life which must have fed on them or destroyed due to some unknown reasons. Fig. 3 (A-C) gives the line sketch of the three plant species to highlight their morphological differences and Fig. 3, D shows a schematic diagram showing the development of the Jodhpur nonvascular plants partly embedded in the microbial mats.

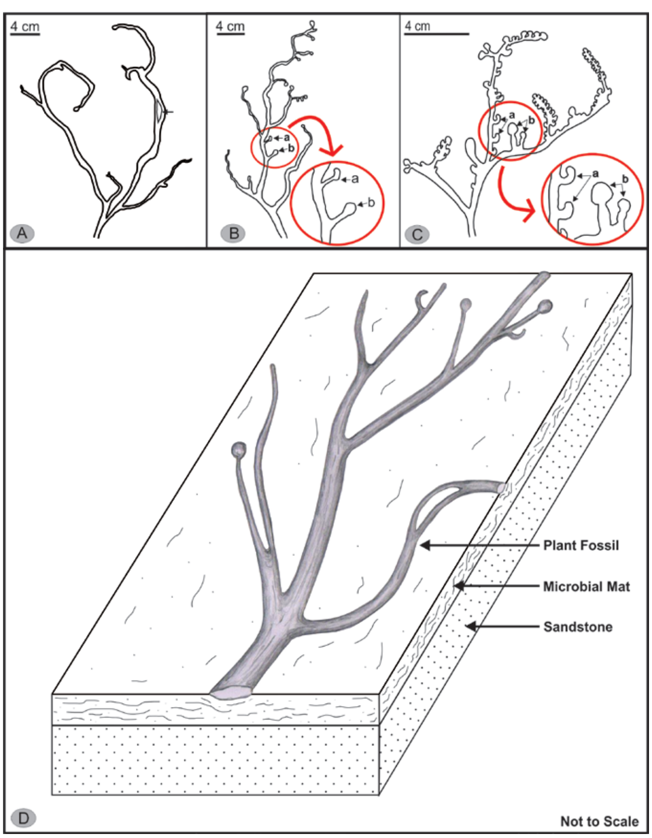


Fig. 3. Schematic diagrams of Jodhpur plants. a- sickle shaped structure comparable to antheridium, b- bead like structure comparable to oogonia; **A**) *Vendophycus sursagarensis,* **B**) *Vendophycus rajasthanensis* **C**) *Jodhpurophycus marwarensis.* **D**) Schematic diagram depicts the mode of occurrence of the Jodhpur plant. The plant is embedded within the microbial mat in the Jodhpur Sandstone.

CONCLUSIONS

1. These enigmatic forms represented by filamentous morphologies are considered as nonvascular plant fossils.
2. Two genera and three species of nonvascular megaplant fossils viz., *Vendophycus rajasthanensis, Vendophycus sursagarensis* and *Jodhpurophycus marwarensis* have been described. The three forms show many morphological characters comparable to modern algal forms but their true affinity is not suggested.
3. The association of microbial mats and megaplant fossil is noteworthy and significant.
4. The nonvascular plants fossils were growing as a creeper slightly embedded within the microbial mat. They are preserved as casts and moulds on the top of the sandstone beds.
5. These plants lost their existence in the Cambrian due to the appearance of animal life which browsed upon them or due to some unknown reasons.

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