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Ediacaran megaplant fossils with Vaucheriacean affinity from the Jodhpur Sandstone, Marwar Supergroup, western Rajasthan

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The present study records the discovery of megaplant fossils from the middle part of the Ediacaran Jodhpur Sandstone, exposed in the mines around Sursagar area (GPS location 26°20′03″N; 72°59′72″E), Jodhpur, Rajasthan. This is the first record of the giant size noncarbonaceous plant fossils from the Precambrian sequences. The fossils show well-developed thallus, branching pattern, development of possible oogonia and zoospores, and antheridea. Showing morphological similarity with the extant Vaucheriacean plant, the thallus is about 140 times bigger in size. Preserved on the top of the bed, these are also associated with well-developed microbial mats. The same horizon has also yielded poorly preserved circular structures with medusoidal affinity which can be compared with the *Aspidella* sp.

Keywords: Ediacaran, Jodhpur Sandstone, Marwar Supergroup, plant fossils, Vaucheriacean affinity.

DOMINATED by the abundance of well-diversified microbial life, the Proterozoic Eon shows preservation of varied stromatolite morphologies in the carbonate rocks and microbial mats in the siliciclastic rocks. However, the occurrences of megascopic body fossils of plant affinity are rare and lack diversity. Generally, they are carbonaceous with simple morphological characters. The most common forms are carbonaceous circular discs and filaments[1,2]. However, the plants preserved as non-carbonaceous structures are rare and difficult to identify in the absence of definite clues. This communication reports well-preserved non-carbonaceous megaplant fossils from the middle part of the Ediacaran Jodhpur Sandstone of the Marwar Supergroup exposed in the mines of Sursagar (GPS location 26°20′03″N and 72°59′72″E), about 5 km NNW of Jodhpur city in western Rajasthan (Figures 1 and 2). Though the plants are megascopic, they have morphological characters comparable to the Vaucheriacean plant *Vaucheria* in thallus organization, branching pattern and in having oogonia and antheridia-like structures. However, the size of the plant is about 140 times larger than the extant forms[3]. It appears that the plant life attained large size during the Ediacaran period and may

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have played a role in the proliferation of planktic animal life in the Cambrian.

The Marwar Supergroup, earlier known as the Trans-Aravalli Vindhyans, is well exposed in the west of Aravalli Range in Rajasthan. It unconformably overlies the Malani Igneous Suite which has been dated as 779–681 Ma (ref. 4). The rocks are unmetamorphosed and undeformed. The Supergroup is subdivided into three groups, viz. the Jodhpur Group, the Bilara Group and the Nagaur Group (Table 1)[5,6]. The Jodhpur Group is further subdivided into the Pokaran Boulder Bed and the Jodhpur Sandstone[6]. The Nagaur Sandstone of the Nagaur Group has yielded well-preserved trace fossils *Rusophycus*, *Cruziana* and *Dimorphichnus* and, hence, is assigned a lower Cambrian age[7]. The Precambrian–Cambrian boundary (542 Ma) has been suggested within the Bilara Group on the basis of the isotope data[8,9]. The Jodhpur Sandstone has also yielded body fossils of the Ediacaran affinity[10]. Recently *Arumberia*, *Rameshia* and *Beltanelliformis* have also been recorded in the middle part of the Jodhpur Sandstone, which also suggest an Ediacaran age (unpublished data). Thus, the available data supports an Ediacaran age to the Jodhpur Sandstone.

The Jodhpur Sandstone consists of fine- to coarse-grained sandstone showing abundant development of parallel bedding, large and small cross bedding, wave and current ripple bedding, wave and current ripples, interference ripples, adhesion ripples, starved ripples, synaeresis cracks and mud cracks[6,11]. Well-developed microbial mats are profusely developed[12]. The fossil-bearing horizon of the Jodhpur Sandstone has been considered as representing the shallowing upward cycles developed under near shore-beach environment within the confines of shoreface-backshore settings of beach environment[6]. The circular forms with medusoidal affinity are quite common which can be compared to *Aspidella* sp.

The fossil-bearing horizon is light-yellowish to brown coloured, medium grained sandstone in which fossils are characterized by brown coloured very fine sandstone. In thin section, it shows a sharp contact with the host rock. The samples are deposited in the Museum of the Centre of Advanced Study in Geology, University of Lucknow, Lucknow, UP.

Morphology of the fossils is unusual and does not match with any of the known forms described from the Precambrian sequences. The plant fossils occur as hyporelief in the form of filaments on the top of the sandstone bed. The filaments look like the thallus of a plant. The thallus is sinuous to straight, tapering at one end with smooth surface. Large-sized forms are also striated. Branching is quite common. Beads are also seen at some of the ends of branched thallus and also attached to the thallus (Figure 3 *a–c*). Rarely, hook-like structures are also seen with the filaments which may represent young antheridia (Figure 3 *d*). Width of the thallus varies from 0.3 to 2.0 cm. Maximum recorded length is 54.0 cm. At places, the thallus also superimposes over an older thallus (Figure 3 *c*). Based on the width of the thallus at least two different forms can be recognized; one is thinner with respect to the other and is referred to as Form A (Figure 3 *a–c*, *e*, *g* and *h*) and the form with thicker thallus is

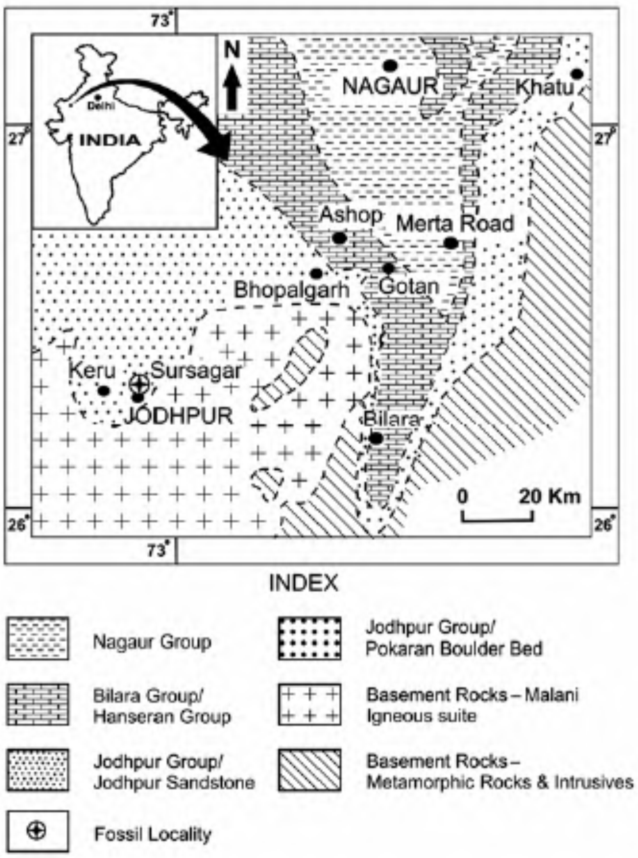

Figure 1. Geological and location map of the Jodhpur area, Rajasthan (after Pareek[5]).

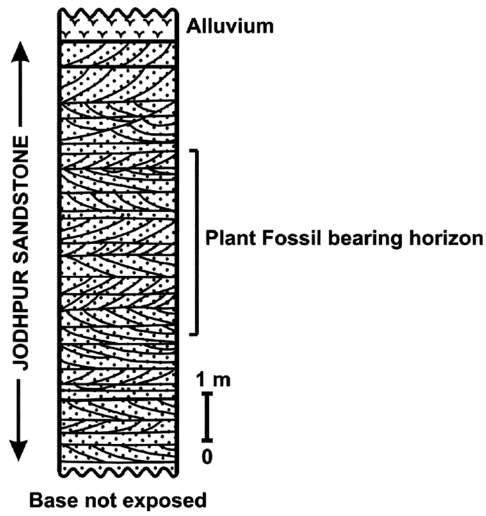

Figure 2. Litholog of the fossil bearing horizon, Sursagar mine area, Jodhpur, western Rajasthan.

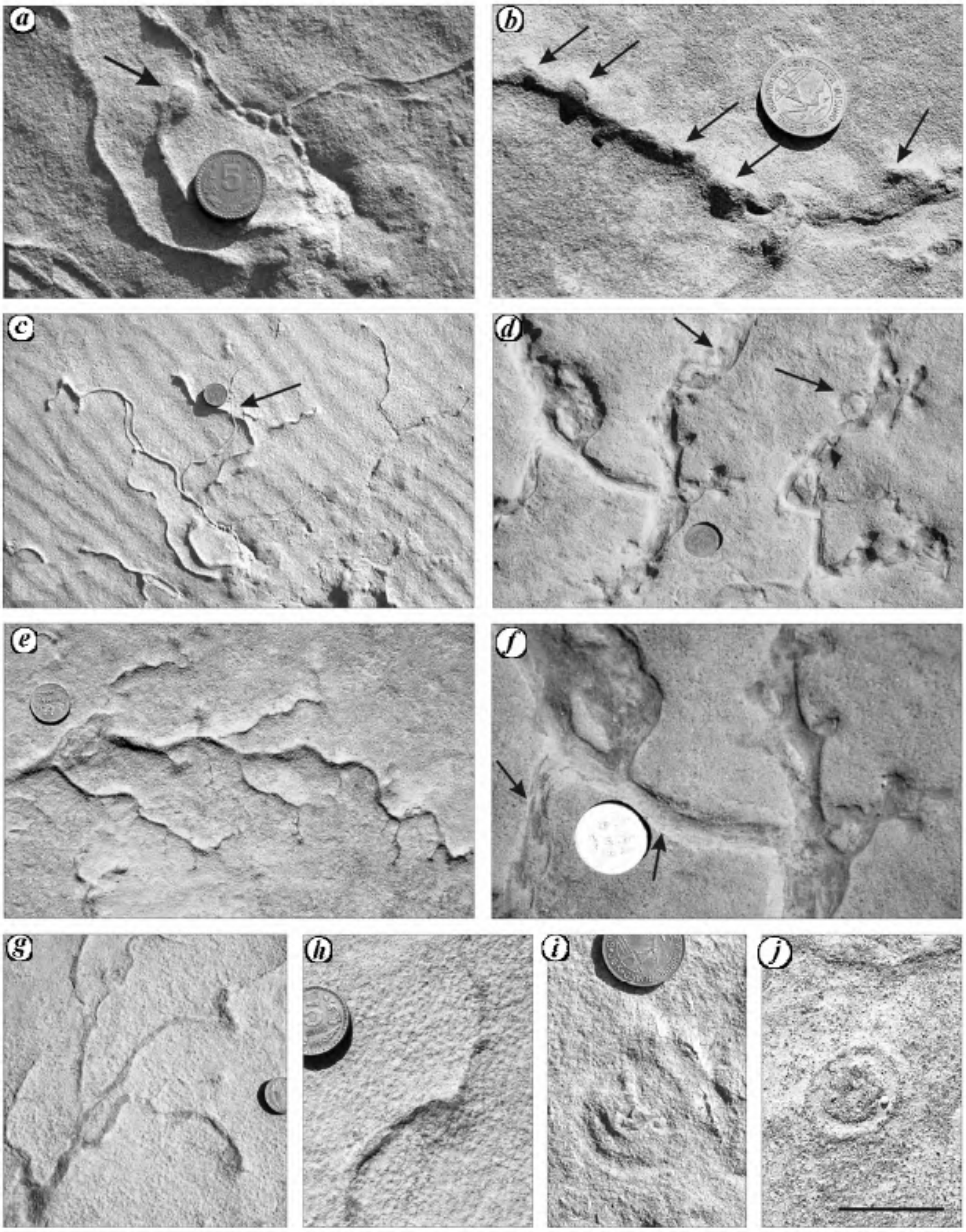

Figure 3. Fossils recorded in the Jodhpur Sandstone, Sursagar area, Jodhpur, western Rajasthan. ***a***, Close-up view of (***c***) showing development of beads at the end of the branched thallus; arrow marks the bead (diameter of coin = 2.3 cm); ***b***, Plant fossil (Form A). Arrow marks the beads attached on the thallus (diameter of coin = 2.0 cm); ***c***, Plant fossil (Form A) showing thinner and smooth thallus preserved on the top of the rippled surface of medium grained sandstone. Arrow marks the overlapping of the thallus (diameter of coin = 2.3 cm); ***d***, Plant fossils referred to as Form B showing thicker thallus. Arrow marks the hook like structure (young antheridea) attached to the thallus (diameter of coin = 2.0 cm); ***e***, Branching pattern of plant fossils (Form A) seen on the bedding surface (diameter of coin = 2.0 cm); ***f***, Close-up view of plant fossils referred to as Form B (thallus with larger width). Arrow marks the parallel markings on the thallus (diameter of coin = 2.0 cm); ***g***, Development of microbial mat over the thallus of plant fossil (Form A) on the bedding surface (diameter of coin = 2.3 cm); ***h***, Close-up view of south-eastern part of (***g***) showing development of microbial mat over the thallus of plant fossil (Form A; diameter of coin = 2.3 cm); ***i***, *Aspidella* sp. of medusoidal affinity (diameter of coin = 2.0 cm); ***j***, *Aspidella* sp. of medusoidal affinity (scale = 2.3 cm).

Table 1. Stratigraphic succession of the Marwar Supergroup (after Pareek[5], and Chauhan *et al.*[6])

	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

referred to as Form B (Figure 3 *d* and *f*). The width of the thinner thallus (Form A) varies from 2.0 to 5.0 mm and the diameter of the beads varies from 2.0 to 9.0 mm (Figure 3 *a* and *c*). Width of the thicker thallus varies from 10 to 20 mm and diameter of the beads between 4.0 and 8.0 mm (Figure 3 *d* and *f*). They also differ in surface markings; thinner form (Form A) showing smooth surface whereas the thicker form (Form B) with markings parallel to the outer margins of the thallus (Figure 3 *f*).

A possibility of such structures being of nonbiotic origin has been reviewed before giving them a status of the fossils. If the morphologies are produced by inorganic processes then the only possibility is: (a) either they represent synaeresis cracks formed in the microbial mats which made the sand cohesive or (b) these are diagenetic structures. The morphology of the structures is not comparable with any known structures reported in the *Atlas of microbial mat features preserved within the siliciclastic rock record*[13]. Here the mode of preservation is such that the plant body is marked by fine sand and/or silt within the relatively coarser host rock. The microbial mats which are so commonly developed in the Jodhpur sandstones cover at places as part of the thallus (Figure 3 *h*), which suggests that the plant was deposited with the sand and subsequently a part of the thallus was engulfed by the microbial mats (Figure 3 *g*). This suggests that the thallus was present before the development of the microbial mats and thus cannot be related to microbial decay process. Thus, the mode of preservation excludes the possibility of these structures being synaeresis cracks as the fossils occur as full relief.

Concretions, nodules and tubes produced by the diagenetic processes in siliciclastic sediments are in no way related to the present forms. They are formed *in situ* and are composed of the same material with which the host rock is made up of. Generally, the cement minerals play the most significant role in producing such structures[14]. However in the present case, the plant morphology is marked by terrigenous material of very fine sand compared to the medium sand of the host rock. Thus, it appears that these structures must have been formed after the decay of the plant material which was replaced by very fine sand. The fine sand may have been available in a high energy beach like environmental setting. Moreover, these structures also cannot represent trails of animals as they occur as tubes within the host rock. Further, their morphology is also not like a burrow. The present forms differ from *Aristophycus*[15] in not forming regular anastomosing raised pattern by branching structure. In addition, the present structures also show presence of beads at the end of the branches as well as on the thallus and hook-like structures. Both these features are absent in *Aristophycus*. Because the overall morphology of the structures resemble that of Xanthophyceaen plant *Vaucheria* (De Candolle 1833)[16] morphology, which possesses small or large branched filamentous thallus with zoospore or oogonia and antheridia, these structures are considered as true biogenic structures.

The occurrence of giant-sized plant fossils in Ediacaran Jodhpur Sandstone has opened a new window for understanding the evolution of life during the Ediacaran, especially the giganticism in plants. It also has implication for the sudden explosion of animal life in the Cambrian with availability of more advanced food chain as the Vaucheriacean plants are known to have reserve food oil material[17,18]. With the presence of megaplant fossils in the Jodhpur Group, the possibility of the presence of hydrocarbons in the Marwar Basin may be quite high as the much needed organic source was available in the basin. The detailed work is under progress.

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Periodicities and non-stationary modes in tree rings temperature variability record of the western Himalayas by multitaper and wavelet spectral analyses

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We examined a newly constructed tree ringtemperature variability record from the western Himalayan regions to investigate trend and periodic signatures, if any, and their possible link with external and/or internal forcing. Two powerful spectral techniques, e.g. multi-taper method (MTM) and wavelet transform analysis were used to identify coherent periodic and non-stationary modes in the data. MTM spectral analyses of the tree-ring record spanning from AD 1200 to about AD 2000 revealed evidence for statistically significant, at more than 95% confidence level, periodicities in the range of inter-annual 3.5–8.9 years and a multi-decadal 35–40 years frequency band. A detailed analysis by dividing the record into two parts, AD 1200–1600 and AD 1600–2000 years, further suggests that a quasiperiodicity of 65–90 years was also dominant in the later part of the record. Solar forcing fluctuation on this time scale (Gleissberg cycle) could be the pacemaker of the temperature variability and global warming. Higher frequency signals in ENSO and North Atlantic Oscillation (NAO) continue to be recorded by tree rings and match well with the above frequency bands signifying their possible linkages. Wavelet spectral analysis of the same data also revealed almost similar periodicities with intermittent cyclic pattern. Cross and coherency spectra between NAO and temperature records further emphasize the link. A striking feature of the wavelet power spectra, however, is the sudden 'breakdown' in spectral power along the multidecadal cycle of 30–40 years, which might suggest a phase change in forcing mechanism leading to fundamental reorganization in land–ocean–atmospheric processes.

Keywords: Atlantic Multidecadal Oscillation, Himalayas tree-ring record, multi-taper method, North Atlantic Oscillation, wavelet analysis.

THERE is widespread evidence for a possible link between global temperature oscillations, Indian and Asian monsoon system, North Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO) on interannual and interdecadal time scales. Instrumental record of North Atlantic sea surface temperature (SST) has shown significant multidecadal variability over the previous 150 years with

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