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GIANT-SIZED ALGAL FOSSILS (SEA-WEEDS) FROM THE MARWAR SUPERGROUP, WESTERN RAJASTHAN, INDIA: A STEP TOWARDS TERRESTRIALIZATION

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ABSTRACT

Well preserved giant–sized non-carbonaceous fossils have been discovered on the bedding surfaces of the Ediacaran Jodhpur Sandstone of the Marwar Supergroup in western Rajasthan. These fossils exhibit morphologies supporting their plant affinity and have striking similarity with the modern sea- weeds, assigned to green and red algae. Green algae are considered to be the ancestors of land plants which flourished well in marine environment of all ages. Red and brown macro algae are also known to survive well in similar environmental settings. Specimens in the present assemblage under study exhibit 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. All these features suggest benthic habitat and striking resemblance to the earliest land plants. Polysiphonia, Gracilaria, and Caulerpa are few extant algal forms comparable in morphology to the present assemblage. Cooksonia, Zosterophyllum, Nothia, Aglaophyton, Rhynia, Prototaxites & Sciadophytons are some of the well documented early land plants (Silurian-Devonian in age), which have several comparable features with the fossils presently described from the Ediacaran sedimentary rocks of Jodhpur Sandstone.

Since evidences of terrestrial megascopic life have already been recorded from the Cambrian sediments of China and very few reports on microscopic evidences of terrestrial life are also available from the Precambrian rocks from the Beck Spring Dolomite and Mescal Limestone and Torridonian rocks of northwestern Scotland, there is a possibility that present *assemblage is representing a transitional phase of megascopic life proceeding from water to land. It seems that megascopic plant life, was probably heading a step towards terrestrialization at the time of Jodhpur Sandstone sedimentation. Coexistence of terrestrial plants with aquatic communities (Ediacaran metazoans, microbial mats and acritarchs) also reflect an evolutionary phase of aquatic life, from coastal marine to land environment.*

Key –words: Ediacaran, Jodhpur Sandstone, Marwar Supergroup, Terrestrialization, Western Rajasthan

Introduction

TERRESTRIALIZATION of plant life is a significant biotic event in evolutionary history which played a critical role in changing the global climate and also in the evolution of multicellularity (Selden and Edwards, 1990). The fossil evidences supporting transition from algae to land plants, are almost negligible; hence any record indicating such transition is significant from a range of ecological, morphological and evolutionary perspectives. Although, it is conventionally believed that invasion of the land by plants occurred some time during Ordovician – Devonian (Gensel & Edwards 2001), but with emerging data and discoveries, its timing keeps getting pushed back in geological time scale. Fossils recorded from the Cambrian sediments (Sedlak, 1980; Yang et al., 2004), and very few reports on microscopic evidences of terrestrial life available from the Precambrian rocks of Beck Spring Dolomite and Mescal Limestone (Heckman et al., 2001, Prave, 2002) Scotland, Poland, China, eastern Siberia and India, suggest that plant life invaded the land during Proterozoic-Cambrian transitional period.

Sea weeds representing macroscopic chlorophycean and rhodophycean algae belong to a group which includes members distributed in shallow sea, fresh water as well as terrestrial habitat. Classification based on DNA sequence data place these organic remains under the group Viridiplantae (Lewis and McCourt, 2004). The molecular clock estimates suggest that the terrestrialization began at about 600 Ma (Ediacaran time). On the other hand, protein sequence analyses indicate the presence of green algae and fungi in rocks as old as ~1000 Ma, suggesting the invasion of land by plants at about 700 Ma (Heckman et al., 2001). Microbial remains comparable to the chlorophycean algae are reported from the Torridon Group, (one billion years old), Scotland (Battison and Brasier, 2009)

We report here, well preserved non-carbonaceous mega-fossils from the Jodhpur Sandstone of the Marwar Supergroup. Morphology of these fossils match some extent with extant sea- weeds (macro-algae) and has similarity with land plant fossils recorded from Silurian- Devonian rocks of UK, Canada, Australia and Scotland. Ediacaran fossils and microbial mats (Raghav et al., 2005, Kumar and Pandey, 2009, Sarkar et al. 2008, Srivastava, 2012) have already been reported from the same stratigraphic level from where the present assemblage is being reported. These macroalgae like structures are preserved as casts and molds, reflecting similar preservation mode as shown by the other Ediacaran fossils (Droser et al., 2004). Consistency in the morphology, similarity of preservation mode in the host sandstone, multiple occurrences of similar structures over a large area and presence of organic carbon (in these structures) support their biogenic nature. The morphologies displayed in medium to fine grained sandstones are endogenic and reflect least deformation. These biogenic features include terminal and lateral sporangia, dichotomously branched stems, bladder, spine and scale like leaves, leafless stems, horizontally creeping rhizomes, hold-fasts and carpospore-like structures. All these morphologies on the brown-buff sandstone surface suggest a benthic habitat and affinity towards chlorophycean and rhodophycean macro alga.

The Marwar Supergroup

The Marwar Supergroup (previously known as the Trans- Aravalli Vindhyans in western Rajasthan, attains a thickness of about 1000 meters. Unmetamorphosed, least disturbed and more or less horizontally disposed Marwar Supergroup, has three stratigraphic components, represented by the Jodhpur, Bilara and Nagaur Group in ascending order (Pareek, 1984) Fig.1, Table-1). Since last one decade, the Marwar Supergroup has emerged as one of the best repositories for Ediacaran fossils. The lithology is represented by siliciclastic sandstone, siltstone shale and carbonates. Some significant reports on various aspects like microbial mats (Sarkar et al., 2008); ichnofossil (Kumar and Pandey 2009); an Ediacaran/Cambrian boundary marker form

Treptichnus pedum and *Priapulid* worm-like fossils, which are considered to be the organisms responsible for the construction of pedum burrows (Srivastava, 2012-a,b) and mega-algal fossils (Kumar et al., 2009, Srivastava, 2011) from the supergroup have drawn attention of international scientific community.

Age of the Supergroup is considered younger than 681 Ma on the basis of dates available for Malani Rhyolite, unconformably underlying the Marwar Supergroup (Rathore et al., 1999). The upper age was a matter of debate, which is now considered to be Cambrian after the discovery of *Treptichnus pedum* demarcating Ediacaran/ Cambrian boundary in the Nagaur Group, youngest among three groups (Srivastava, 2012-a). The boundary was earlier suggested in the Bilara Group, on the basis of isotope data Pandit et al., 2001, Mazumdar and Strauss, 2006.

Previous reports of invasion by the primitive organisms in the form of medusoids (Raghav et al., 2005), microbial-mat induced structures (Sarkar, et al., 2008), *Arumberia* (Kumar and Pandey, 2009) *Vaucherian* alga (Kumar et al., 2009) are further supplemented by the discovery of *Charniodiscus*, medusoid discs and *Heimalora* (Srivastava, 2012) in various layers of the Jodhpur Sandstone, support an Ediacaran age for this lithounit. On the basis of secular variation in the carbon isotopes in the carbonate rocks of the Bilara Group (stratigraphically overlying the Jodhpur Group), the Precambrian-Cambrian boundary has been suggested within this formation (Pandit et al, 2001; Mazumdar and Strauss, 2006). In contrast, acritarchs in the bore-hole cores from this area (Prasad et al., 2010) and trilobite traces (Kumar and Pandey, 2010) in the Nagaur Sandstone near the top of the stratigraphic sequence (Fig.1 showing physical stratigraphy of the rock formation in this region), support a lower Cambrian age, nearly 200 meters above the previously postulated Precambrian-Cambrian boundary. Recent report of *Treptichnus pedum* in the Nagaur Sandstone (Srivastava, 2012) also emphatically suggests the boundary in the Nagaur Group. The Jodhpur Sandstone disposed several hundred meters below this lower Cambrian bed is therefore Ediacaran in age.

Material and methods

Exposures of Jodhpur Sandstone were examined in Sur Sagar area of the Jodhpur district, western Rajasthan (Fig.1). GPS values for the fossil bearing beds have been taken using Garmin GPS (N 26°19'53.5" E 72°59'45.3" and adjoining areas). Stratigraphic sections were measured using method of eyesight. Most of the photographs were taken in field using Nikon P-100 SLR camera. Taxonomy and biological affinity of the land plant like fossils have been suggested, following conventional palaeobotanical provisions of the International Botanical Nomenclature. Specimens collected for the present study have been deposited in the Museum of Geology Department, Lucknow University, Lucknow, India.

Morphology of giant-sized algal fossils from the Jodhpur Sandstone

Identification of fossils in present assemblage is based on the morphological similarities with extant multicellular chlorophycean and rhodophycean macro alga. A type of body organization, unique among green algae is siphonalean organization, which is considered to be the most ecologically successful sea weed. A representative genus *Caulerpa* exhibits dichotomous branching in horizontally creeping rhizomes that grow attached to the rocky bottoms, from which numerous erect stolons (leafless stalks) and fronds arise (Fig.2-C). The assemblage under study comprises comparable morphology with genus (Fig.2-A). The specimens exhibit length (or height) between 30- 80 cm and stem width of 1- 1.5 cm. The sporangia are attached laterally on short delicate stalks of the stems (Fig.2-A). It is interesting to note that these structures resemble, Devonian land plant fossils, like *Aglaophyton, Zosterophyllum,* and *Nothia* (Figs 2-B,D are the scientific reconstructions by Gensel and Andrews, 1984). These simple land plants (considered to be the earliest), have naked, erect, dichotomized stems with lateral and terminal sporangia, as well as horizontally creeping rhizomes. These fossils have earlier been recorded from the Early Devonian Rhynie Chert, of Scotland. Although the taxonomic position of these land plants is uncertain, these are tentatively treated as Zosterophylls belonging to trachaeophytes. It is true that such advance morphology and ecological adaptation is still not reported from hitherto known Ediacaran fauna. The present observation hence justifies the interpretations given in this paper.

Well preserved terminal sporangia (Fig.3-B,C & E) has close resemblance to *Cooksonia* (Figs. 3-A,D,F), the first undisputed land plant remains from the Silurian rocks of the northern hemisphere (see Banks, 1975). Some of the researchers have placed these structures under early eutracheophyte, a transitional land plants, indicating emergence of vascular tissues in the plants (Gerrienne et al., 2006). The specimens under study are larger than the conventional size of *Cooksonia* reported earlier from other parts of the world. Larger size of the specimen under study can be accounted for by invoking the concept of 'giganticism, a feature globally seen in many ediacaran assemblages. Dichotomously branched stems, and well preserved triangular sporangia at the terminal ends of stems have lead to its identification (Figs.3-C, E) and comparison with *Cooksonia* (considered to be the earliest land plant reported from Devonian rocks) recorded from Wales (Edwards et al., 1992).

The morphology depicted by specimens (Figs. 3-G &I) is similar to *Rhynia,* but taller than *Cooksonia* (Fig.3-H), which is the earliest leafless land plant with ovoid terminal sporangia. The specimen (Fig. 3-I) also exhibits horizontal rhizome like structures. On such stems, stomata have been recorded in earlier reports, which were believed to have formed in response to increased CO_2 level in the environment (Gerrienne et al., 2006).

The morphology (Fig 7-G) is comparable to the scientific reconstruction of *Prototaxites*, which is the largest representative of Nematophyte (Schweitzer, 1983). It is reported earlier from the Silurian and Devonian rocks. Woody tissues, principally comprising lignin: a component instrumental in water transport among land plants is reported in *Prototaxites*, very close to the vascular land plants, reported from the Silurian rocks of Central Victoria (Lang and Cookson, 1935). True botanical affinity of this morphotaxa is still debatable. Earlier, it was placed with fossil conifer wood (Dawson, 1859) but after a comprehensive study these have been classified with green algae. Kräusel (1936) compared these with brown algae *Lessonia,* while Hueber (2001) compared it with red alga on the basis of structures resembling basidiomycetous clamp connections (pit plug connections, Fig.4-F). Almost similar structures have been noticed in the sample during present study (Fig. 4-E). The woody stems in present assemblage range in length from 50 cm to 2 m with 8-26 cm width.

Dichotomously branched leaf like structures range in width between 2-6 cm and show striations and tapering in distal end (Fig.9-H). Small flaps or enations (spine like structures, which are not the true leaves); a characteristic feature of Trimerophytes are also preserved in present assemblage (Fig. 7-D).

Like in Bryophytes, some of our samples without true leaves and roots are comparable to *Psilotum* (a whisk fern, Fig. 3-J). These can be differentiated from other fossil forms by the presence of synangia (fused sporangia) like structures on the tips of the lateral branches (Fig. 3-K, L). Fossils in the Jodhpur assemblage are much bigger than the conventional size assigned to the respective taxa. Specie of fork fern *Psilotum* is almost leafless epiphyte, bearing scales and spine like small leaves (Figs. 5-D, E).

Structures with radiating axes terminating in cup-like sporangial structures (Fig. 4-C) comparable to *Sciadophyton*- a member of Rhyniophytes (Fig.4-D). It was earlier considered a sporophyte, now considered a gametophyte stage of several land plants, (Kenerick and Crane, 1997; Remy et al, 1992).

Presence of carpogonium like structures similar to the *Polysiphonia;* a rhodophycean macro alga (Fig. 5-C) is also significant feature of the assemblage under study (Figure 5-A1, A2, B).

Specimens exhibiting ribbon like leaves (Fig.6-C, D) similar to extant chlorophycean alga *Ulva* (Fig. 6-A, B), suggest an affinity of these plant fossils towards chlorophycean macro alga.

A reconstruction of a Devonian land plant fossil *Pertica* (Fig.7-E), belonging to Trimerophyte (Singh, 2008), is comparable to features shown by the present assemblage (Figure 7-F).

A Lycopod fossil (*Asteroxylon* (Figure 7-B) is also comparable with the morphology displayed by the present fossil form (Figure 7-F).

Horizontally creeping rhizomes and hold fasts (features supporting benthic habitat) of variable styles in the present assemblage, have been summarised in Figure 8. Variation in morphology and position of sporangia in respective plant fossils and their scientific reconstructions have been depicted (Figure 9 and 10).

Disussion and Conclusions

Jodhpur Sandstone of Ediacaran age are inferred to have deposited in hypersaline, lagoonal to marginal marine and shallowing upward sequence, suggesting near shore- beach environment (Sarkar et al, 2008; Pandey and Tej Bahadur, 2009, Chauhan et al, 2004, Kumar et al., 2009). Giant size fossil assemblage under study with affinity for chlorophycean and rhodophycean benthic macroalgae, is unique and probably the first record from the rocks of this age. These fossils seem to represent the transition of aquatic to land plant habitat. Morphologies exhibited by the fossils in the present assemblage possibly suggest a transitional phase of terrestrial habitat acquired by the macro alga flourishing at the time of the Jodhpur Sandstone Formation. Coexistence of terrestrial plants with aquatic communities (Ediacaran metazoans, microbial mats and acritarchs), reflect an evolutionary phase of aquatic life, from coastal marine to land environment. Presence of macro alga with hold fast like structures on well preserved microbial mats and ripple marks suggests that benthic macroalga flourished on the beaches and rocky coasts affected by episodic emergence and submergence. Coastal waves seem to have ripped the algae from the substrate and virtually pasted them on the microbial mats.

The interpretation of a desiccating terrestrial habitat is supported by the preservation of mud cracks in the fine grained, muddy beds and identification of sporangia, stolons and rhizome like structures in the fossil assemblage under the present study. These physical and biological features are indicators of adaptations necessary for survival on land, which include availability of anchorage, water uptake capacity, protection from desiccation, ability to reproduce in the terrestrial domain and other related survival strategies (Taylor et al., 2009). Further studies are needed to understand the effects of invasion of land by the megascopic plants.

Studies in other parts of the world (Kenny and Knauth, 2001, Heckman et al., 2001) indicated the presence of land plants in rocks as old as 1200 Ma on the basis of isotopic composition of the carbonate rocks. Thus, our inferences of invasion of land by the terrestrial plants during the Ediacaran time, preserved in the Jodhpur Sandstone is not farfetched.

It is well known that the terrestrial plants influence nearly all biospheric changes. Oxygen-carbon-dioxide exchange rate, a well known photosynthesis phenomenon, controls the amount of carbonic acid in the environment, which in turn affects the chemical weathering followed by large scale erosion, deposition and soil formation. In view of the present discovery of a variety of land dwelling plants from the Ediacaran Jodhpur Sandstone, it would be pertinent to re-interpret the sedimentation history of this period using other geological and geochemical parameters.

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References:

Banks, H. P. 1975. Reclassification of Psilophytes, *Taxon* 24, 401- 413.

Battison, L. and Brasier, M. D. 2009. Exceptional Preservation of Early Terrestrial Communities in Lacustrine Phosphate one Billion Years Ago, *in Smith, M. R., O'Brien L. J., Caron, J-B. International Conference on the Cambrian Explosion (Walcott 2009)* Abstract Volume. Toronto, Ontario, Canada: The Burgess Shale Consortium.

Chauhan, D. C., Bhanwara, R. & Narayan, R. 2004. Jodhpur Sandstone: A gift of ancient beaches to western Rajasthan. *Journal Geological Society India* 64, 265- 276.

Dawson, J. W., 1859. On fossil plants from the Devonian rocks of Canada. Quarterly *Journal of the Geological Society of London* 15(6,8), 477- 488.

Droser, M. L., Gehling, J. G. Mrofka, D. D. L., Kennedy, M. J. 2004. Ecology of the Ediacaran Explosion. GSA Annual Meeting. Abstract with Programme 36 (5), 521- 522.

Edwards, D., Davies, K. L. and Axe, L. 1992. A vascular conducting strand in the early land plant *Cooksonia*. *Nature* 357, 683-685.

Gensel, P. G., & Andrews, H. N. 1984. Plant life in the Devonian. Praeger Press, New York, New York, USA.

Gensel, P.G. & Edwards D., 2001. Plants invade the Land, Evolutionary and environmental perspectives. pp 289 (Columbia University Press).

Gerrienne, P. Dilcher, D., Bergamaschi, S., Milagres, I., Pereira, E., Antonieta, M. and Rodrigues,C., 2006. An exceptional specimen of the early land plant *Cooksonia paranensis*, and a hypothesis on the life cycle of the earliest eutrachyophytes. *Review Palaeobotany and Palynology* 142**,** 123-130.

Heckman, D.S., Geiser, D. M., Eidell, B. R., Stauffer, R. L. Kardos, N. L. & Hedges, S. B., 2001. Molecular evidence for the early colonization of land by fungi and plants. *Science* 293, 1129-1132.

Hueber, F. M., 2001. Rotted wood- alga fungus: The history and life of *Prototaxites* Dawson 1859. *Review of Palaeobotany and Palynology* 116(6), 123-159.

Kenny, R. and Knauth, L. P., 2001. Stable isotope variation in the Neoproterozoic. *Geological Society of America Bulletin* 113(5), 650- 658.

Kenrick, P. and Crane, P. R., 1997. The origin and diversification of land plants: A cladistic study. (Smithsonian Institute Press), Washington ,DC.

Kerp H, Hass H, Mosbrugger V. 2001. New data on Nothia aphylla Lyon 1964 ex El-Sadawy et Lacey 1979, a poorly known plant from the Lower Devonian Rhynie chert. In: Gensel PG, Edwards D, eds. Plants invade the land – evolutionary and environmental perspectives. New York, NY, USA: Columbia University Press, 52 – 82.

Knauth, L.P. and Kennedy, M. J., 2009. The late Precambrian greening of the Earth. *Nature* 460**,** 728-732.

Kräusel, R., 1936. Landbewohnende Algen - baume zur Devon-zeit)? *Berichte der Deuschen Botanischen Gesellschäft* 54, 379-385.

Kumar, S. & Pandey, S. K., 2009. Note on the occurrence of *Arumberia* and associated fossils from the Jodhpur Sandstone, Marwar Supergroup, Western Rajasthan. *Journal Palaeontological Society of India* 54(2)**,** 171- 178.

Kumar, S. & Pandey, S. K., 2010. Trace fossils from the Nagaur Sandstone, Marwar Supergroup, Dulmera area, Bikaner district, Rajasthan. *Indian Journal of Asian Earth Science. 38 (3-4*), 77-85.

Kumar, S., Misra, P. K. & Pandey, S. K., 2009. Ediacaran megaplant fossils with Vaucherian affinity from the Jodhpur Sandstone, Marwar Supergroup, western Rajasthan. *Current Science* 97(5)**,** 701- 705.

Lang, W.H. and Cookson, I.C., 1935. On a flora, including vascular land plants, associated with Monograptus, in rocks of Silurian age, from Victoria, Australia. *Philosophical Transactions of the Royal Society of London* B224, 421-449.

Lewis,L. A. and McCourt, R. M., 2004. Green algae and the origin of land plants. *American Journal of Botany* 91, 1535-1556.

Mazumdar, A., & Staruss, H., 2006. Sulfur and Strontium isotopic compositions of carbonate and evaporate rocks from the late Neoproterozoic – Early Cambrian Bilara Group (Nagaur-Ganganagar Basin, India): Constraints on intrabasinal correlation and global sulfur cycle. *Precambrian Research* 149, 217- 230.

Pandey, D. K.& Tej Bahadur, 2009. A Review of the stratigraphy of Marwar Supergroup of the stratigraphy of Marwar Supergroup of west-Central Rajasthan. *Journal Geological Society of India* 73**,** 747- 758.

Pandit, M. K., Sial, A. N., Jamrani, S. S. & Ferreira, V. P., 2001. Carbon isotope profile across the Bilara Group rocks of Trans Aravalli Marwar Supergroup in Western Rajasthan, India: Implications for Neproterozoic- Cambrian transition. *Gondwana Research* 4, 387- 394.

Prasad, B., Asher, R. & Bargohai, B., 2010. Late Neoproterozoic (Ediacaran) – Early Palaeozoic (Cambrian) acritarchs from the Marwar Supergroup, Bikaner- Nagaur Basin, Rajasthan. *Geological Society of India* 75, 415- 431.

Prave, A. R., 2002. Life on Land in Proterozoic: Evidence from the Torridonian Rocks of northwest Scotland. *Geology* 30(9), 811-814.

Raghav, K. S., De, C. & Jain, R. L., 2005. The first record of Vendian medusoids and trace fossil bearing algal mat ground from the basal part of the Marwar Supergroup of Rajasthan, India. *Indian Minerals* 59 (1-2), 23- 30.

Rathore, S. S., Venkatesan, T. R. and Srivastava, R. K., 1999. Rb/ Sr isotope dating of Neoproterozoic (Malani Group) Magmatism from southwest Rajasthan, India : Evidence of younger Pan-African Thermal Event by ^{40}Ar- ^{39}Ar studies. *Gondwana Research* 2(2), 271- 181.

Rayner,R.J.,(1983).New observations on *Sawdonia ornata* from Scotland". *Transactions of the Royal Society of Edinburgh* 74, 79–93.

Remy, W., Hass, H. & Schultka, S., 1992. *Sciadophyton* Steinmann emend. Krausel et. Weyland (1930) Der einzige Vertreter eines unterdevonischen Bauplanes? *Courier Forschungs Institut Senckenberg* 147, 87-91.

Sarkar, S., Bose, P. K., Samanta, P., Sengupta, P. & Eriksson, P., 2008. Microbial mat mediated structures in the Ediacaran Sonia Sandstone, Rajasthan, India and their implications for Proterozoic sedimentation. *Precambrian Research* 162(1-2), 248-263.

Schweitzer, H. J., 1983. Der Unterdevonflora des Rheinlandes. I-Teil. *Palaeontographica* B-189, 1-138.

Sedlak, W.,1980. Cambrian megascopic alga- like forms accompanying corallicythida in quartzite beds of Lysa Gora. *Acta Palaentologica Polonica* 25 (3-4), 669-672.

Selden, P. A. & Edwards, D., 1990. Colonization of the land. (In K. Allen and D. Briggs, eds.). Evolution and the Fossil Record (Smithsonian Institution Press, Washington, DC) 122–152.

Singh, K. J., 2008. Early Land plant developments: Global Progress and Indian priorities. *The Palaeobotanist* 57, 69-88.

Srivastava, P., 2012. '*Treptichnus pedum*: An ichnofossil representing Ediacaran - Cambrian boundary in the Nagaur Group, the Marwar Supergroup, Rajasthan, India', *Proceedings Indian National Science Academy* (in press).

Taylor, T. N., Taylor, E. N. and Krings, M., 2009. Palaeobotany: The Biology and evolution of fossil plants, (II edition, Elsevier) pp.1230.

Yang, R. D., Mao, JR., Zhang, WH Jiang, LJ & Gao, H., 2004. Bryophyte like fossil (*Parafunaria sinensis*) from Early-Middle Cambrian Kaili Formation in Guizhau Province, China. *Acta Botanica Sinica* ,46(2), 180- 185.

Explanation of Figures

Figure 1-A Geological map of the Marwar Supergroup, exposed in Jodhpur district, marking the fossil bearing locality in Sursagar aarea. (Modified after Pareek, 1984)

Figure 1-B General lithostratigraphy of the Marwar Supergroup, western Rajasthan, and marking fossil bearing beds of the Jodhpur Sandstone.

Figure 2- Noncarbonaceous plant megafossils from the siliciclastic rocks of the Jodhpur Sandstone (of Ediacaran age), exposed on bedding plane in Sursagar locality, comparable to the land plant fossils of Silurian-Devonian age in other parts of the world.

A- Marwar specimen resemble with land plant fossil *Zosterophyllum*, *Nothia* and *Lycopodium* or club moss.

B- Diagrammatic reconstruction of sporophyte *Nothia* (fertile leafy shoots belonging to *Asteroxylon* (Kerp et al., 2001), considered equivalent to *Zostrophyllum*.

C- Extant chlorophycean macro alga *Caulerpa.*

D- Diagrammatic reconstruction of *Zosterophyllum*, comparable to the fossils from China and Australia.

Figure 3- Noncarbonaceous plant megafossils from the siliciclastic rocks of the Jodhpur Sandstone (of Ediacaran age), exposed on bedding plane in Sursagar locality, comparable to the land plant fossils of Silurian-Devonian age in other parts of the world.

A- Earliest vascular land plant fossil *Cooksonia*, reported from Early Devonian rocks of Parana Basin, Brazil (Gerienne et al., 2006).

B-C- Marwar specimen comparable in morphology with *Cooksonia*.

D- *Cooksonia* reported from 420 Ma old rocks of North Wales (Edwards, 1992).

E- Marwar specimen comparable with *Cooksonia.*

F- Diagrammatic reconstruction of *Cooksonia* from Late Silurian rocks published by R. E. Taggart, from the Michigan State University.

G- Marwar specimen comparable with *Rhynia.*

H- Diagrammatic reconstruction of *Rhynia* (with ovoid terminal sporangia) from Middle Devonian published by R. E. Taggart from the Michigan State University.

I- Marwar specimens (with rhizomes and terminal sporangia) comparable with *Rhynia* and *Aglaophyton* (first sculpted by University of Aberdeen)

J- Extant whisk fern: *Psilotum*, comprising three fused sporangia termed a synangium located on the sides of stem.

K- Marwar specimens with synangia like structures located on the sides of stem.

L- Marwar specimen with lateral sporangia.

Figure 4- Noncarbonaceous plant megafossils from the siliciclastic rocks of the Jodhpur Sandstone (of Ediacaran age), exposed on bedding plane in Sursagar locality, comparable to the land plant fossils of Silurian-Devonian age in other parts of the world.

A- Marwar specimens comparable with extant land plant *Psilotum* exhibiting synangia like structures located on the sides of stem.

B- Marwar specimens comparable with *Sawdonia*, categorized among vascular land plants fossils of *Zostreophyllum* affiniy and inclined towards modern *Lycophytes*.

C- Marwar specimens comparable with *Sciadophyton*, representing gametophyte stage of several land plants.

D- Diagrammatic reconstruction of *Sciadophyton* (published by Taylor and Taylr, 1993).

E- Marwar specimens comparable with rhodophycean pit plugs.

F- Pit plugs in extant rhodophycean algae, formed during cytokinesis, protein plugs formed in the centre of cell wall separating adjacent cells.

Figure 5- Noncarbonaceous plant megafossils from the siliciclastic rocks of the Jodhpur Sandstone (of Ediacaran age), exposed on bedding plane in Sursagar locality, comparable to the land plant fossils of Silurian-Devonian age in other parts of the world.

A-B Marwar specimens comparable with modern rhodophycean macroalga *Polysiphonia*, with carpogonium like structure

C- Marwar specimens comparable with *Sawdonia*, categorized among vascular land plants fossils of *Zostreophyllum* affiniy and inclined towards modern *Lycophytes.*

D- Modern rhodophycean macroalga *Polysiphonia* with carpogonium.

E-F Marwar specimens comparable with *Rhacophyton* (a fern-like plant), with well preserved spine like structures.

G- Fossil plant *Rhacophyton* from Upper Devonian Belgian rocks exhibiting spine like leaves.

A_2- Closure view of figure A_1

Figure 6- Noncarbonaceous plant megafossils from the siliciclastic rocks of the Jodhpur Sandstone (of Ediacaran age), exposed on bedding plane in Sursagar locality, comparable to the land plant fossils of Silurian-Devonian age in other parts of the world.

A- Modern Chlorophycean alga *Ulva compressa.*

B- Modern rhodophycean alga *Gracilaria truncata*.

C-D Marwar specimens comparable to A and B.

E- Marwar specimens comparable with modern *Psilotum.*

F- Modern whisk fern *Psilotum:* a Pteridophyte (fern)

Figure 7- Noncarbonaceous plant megafossils from the siliciclastic rocks of the Jodhpur Sandstone (of Ediacaran age), exposed on bedding plane in Sursagar locality, comparable to the land plant fossils of Silurian-Devonian age in other parts of the world.

A,C- Marwar specimens comparable with *Zosterophyllum* (or *Asteroxylon*).

B- Devonian land plant fossil *Zosterophyllum* (also classified with Asteroxylon).

D- Marwar megaplant fossil exhibiting dichotomous branching and small leaf like enations.

E- Diagrammatic reconstruction of Trimerophyte, *Pertica* (Singh, 2008).

F- Marwar specimens comparable with *Pertica.*

G- Marwar megaplant fossil exhibiting lignin (woody plant) like structure.

Figure 8- Noncarbonaceous plant megafossils comparable to the land plant fossils from the siliciclastic rocks of the Jodhpur Sandstone (of Ediacaran age), exposed on bedding plane in Sursagar locality. Here fossils exhibit horizontally creeping rhizomes in Figure A, G and J. In rest of the photographs, fossils exhibit hold-fast like structures (marked by arrows).

Figure 9- Noncarbonaceous plant megafossils from the siliciclastic rocks of the Jodhpur Sandstone (of Ediacaran age), in Sursagar locality, exhibiting different shapes and positions of sporangia.

A-E,G Terminal sporangia varying in shapes from spherical, elongate and more or less triangular.

F, H, I lateral sporangia irregular in shape.

Figure 10- Diagrammatic reconstruction of horizontal rhizome, hold fast and sporangia bearing plants observed in Jodhpur Sandstone, Marwar Supergroup.

A- Horizontally creeping rhizomes and lateral sporangia as in *Nothia*, *Zosterophyllum* and *Lycophytes* comparable with chlorophycean form *Caulerpa.*

B- Hold fast as in *Sciadophyton.*

C- Hold fast like structure.

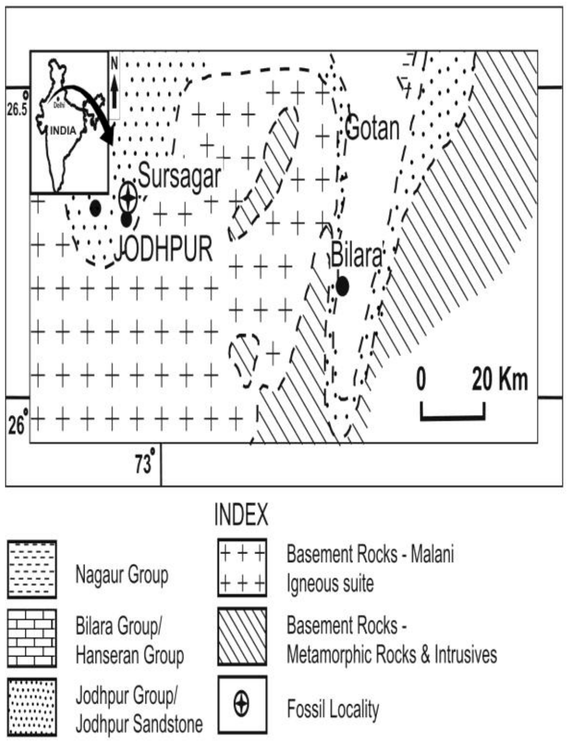
D- Hold fast as in *Charniodiscus*.

E- Hold fast as in chlorophycean alga *Ulva*.

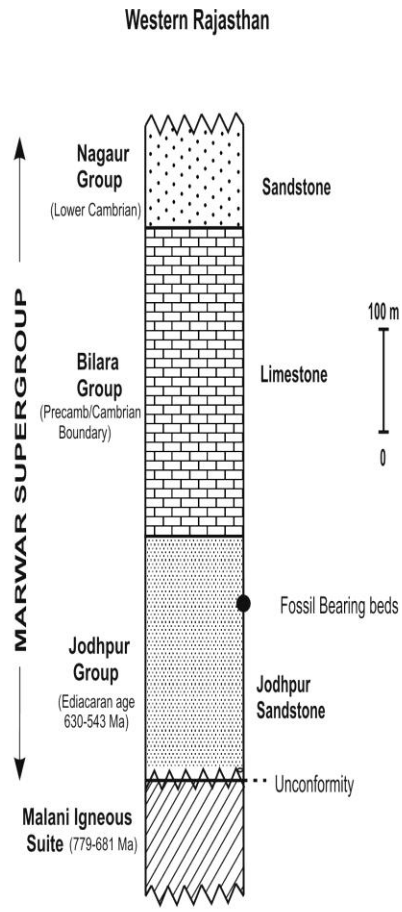
F- Small leaf like enations.

G- Hold fast in *Gracilaria* like rhodophycean macroalgal form

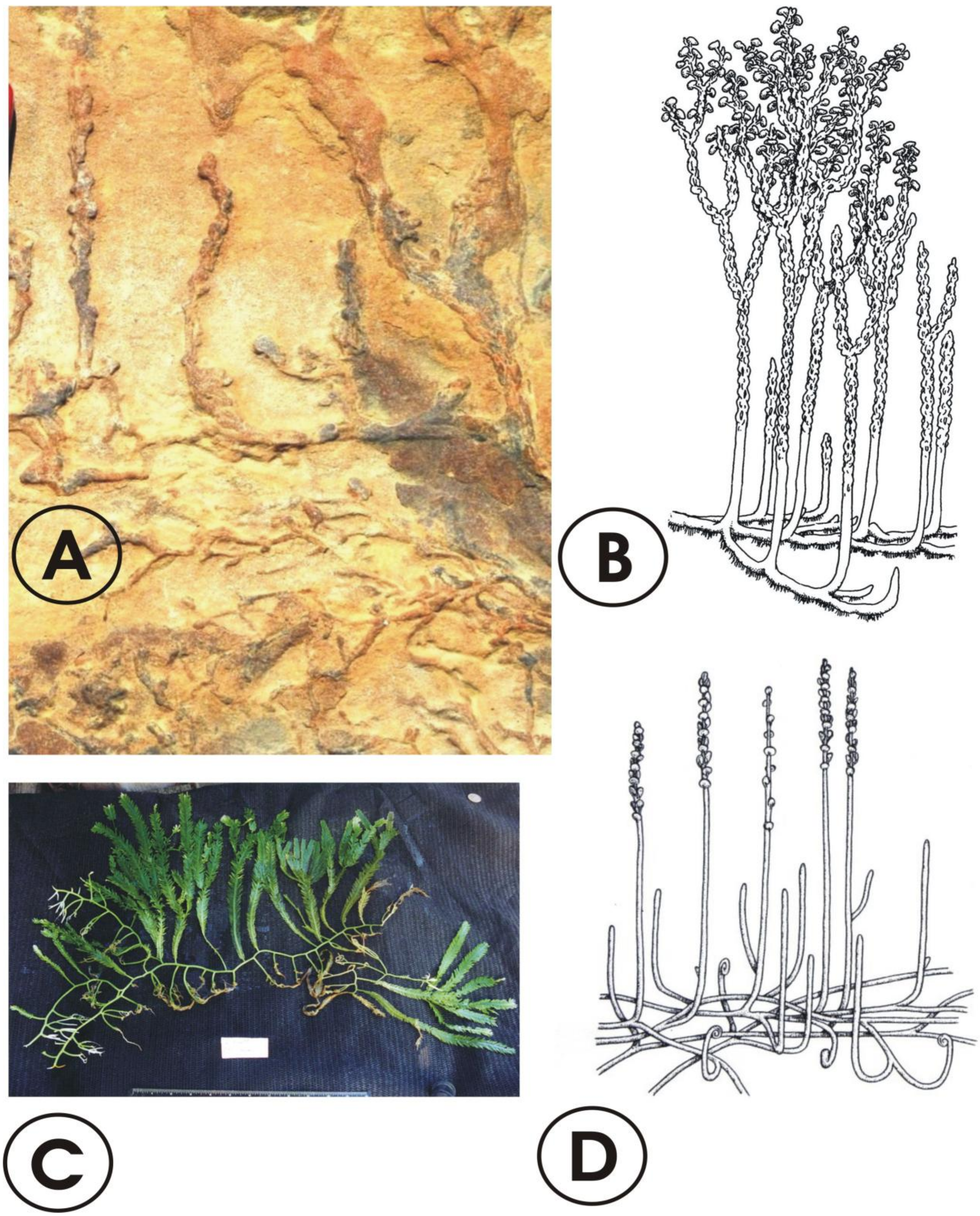
H- Terminal sporangia as in *Cooksonia.*


26.5°
INDIA
N
Sursagar
JODHPUR
Gotan
Bilara
0 20 Km
26°
73°
INDEX
Nagaur Group
Bilara Group/
Hanseran Group
Jodhpur Group/
Jodhpur Sandstone
Basement Rocks - Malani
Igneous suite
Basement Rocks -
Metamorphic Rocks & Intrusives
Fossil Locality

A


Western Rajasthan
Nagaur
Group
(Lower Cambrian)
Sandstone
MARWAR SUPERGROUP
Bilara
Group
(Precamb/Cambrian
Boundary)
Limestone
100 m
0
Fossil Bearing beds
Jodhpur
Group
(Ediacaran age
630-543 Ma)
Jodhpur
Sandstone
Unconformity
Malani Igneous
Suite (779-681 Ma)

B


A
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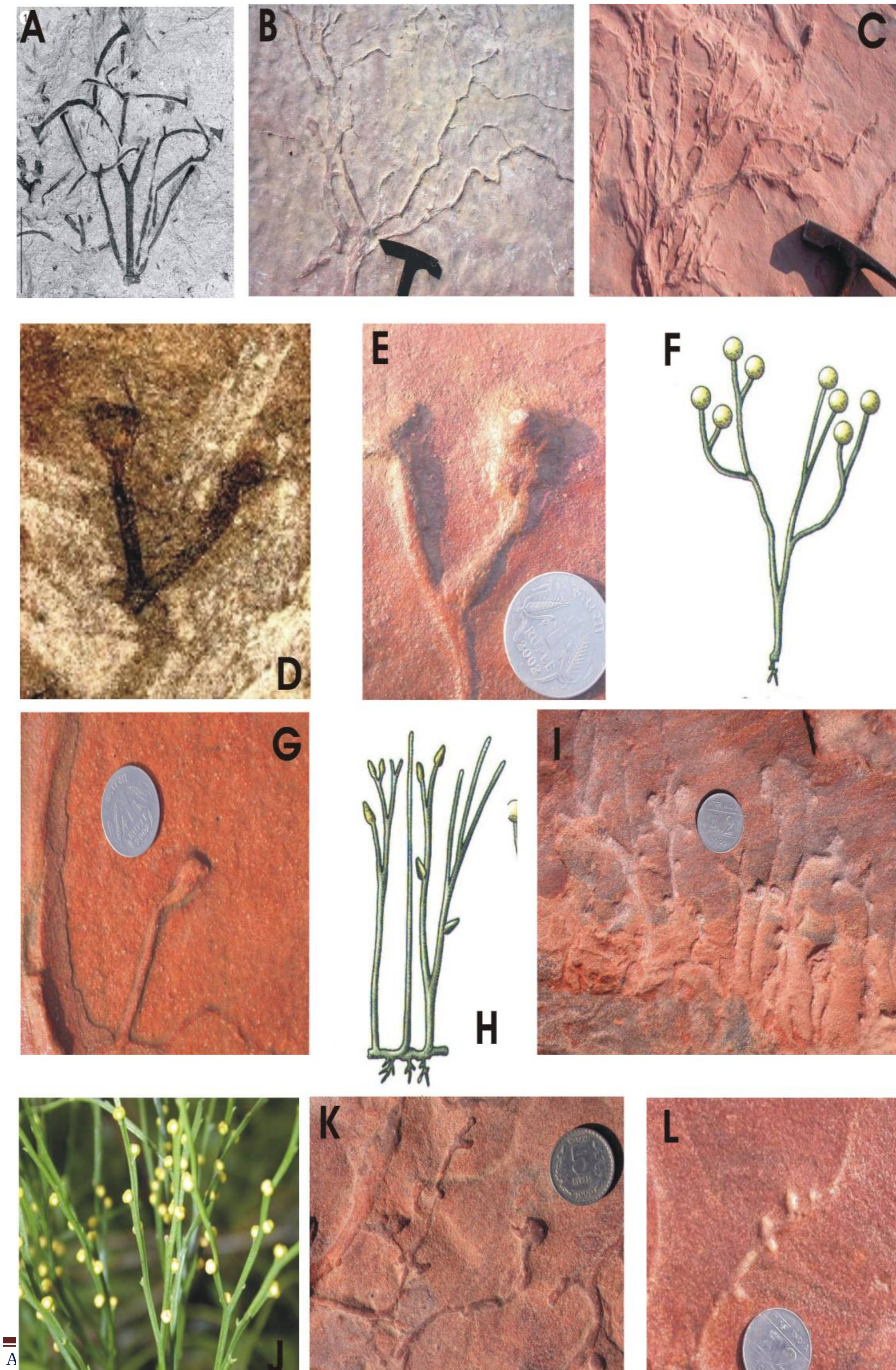
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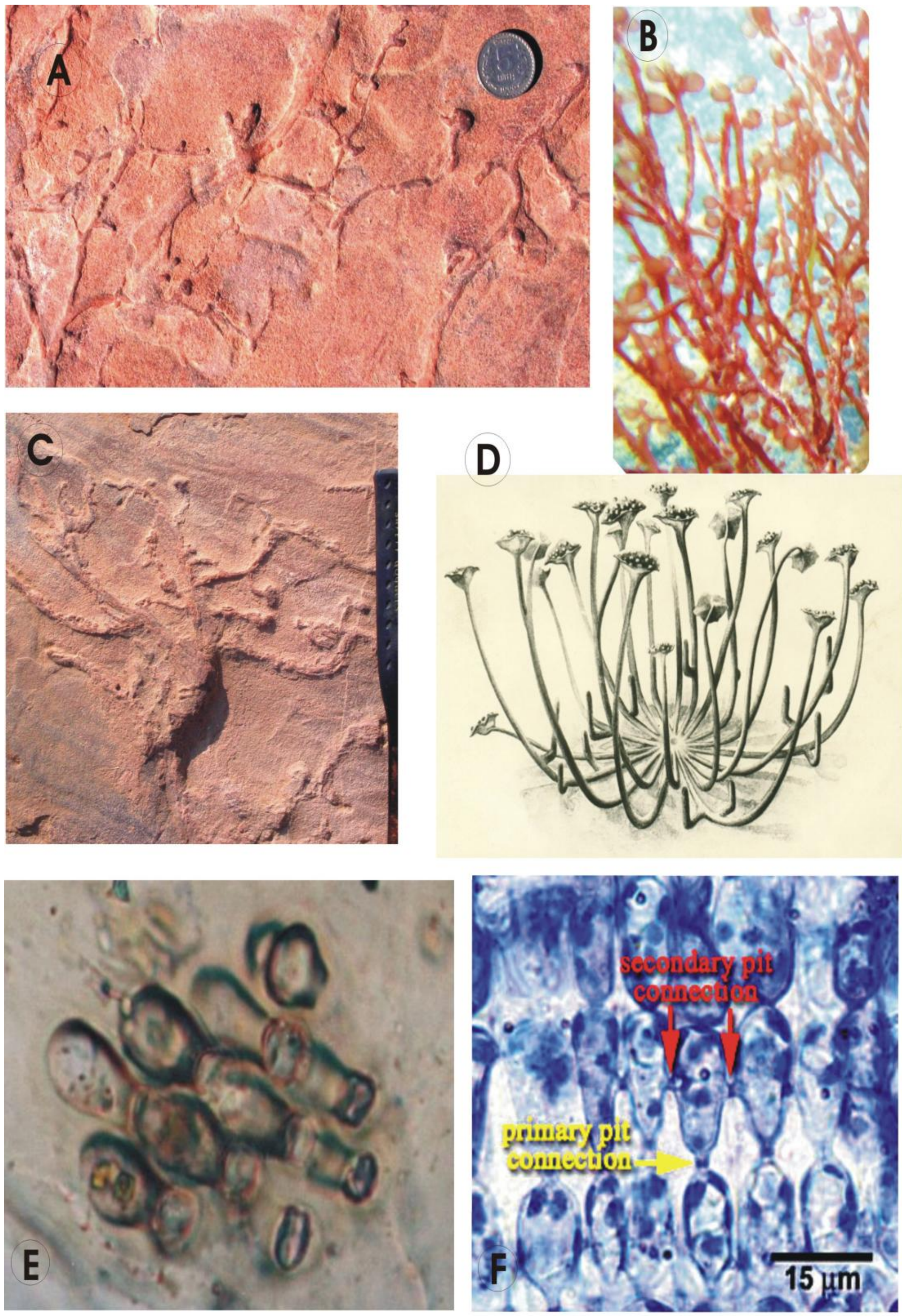
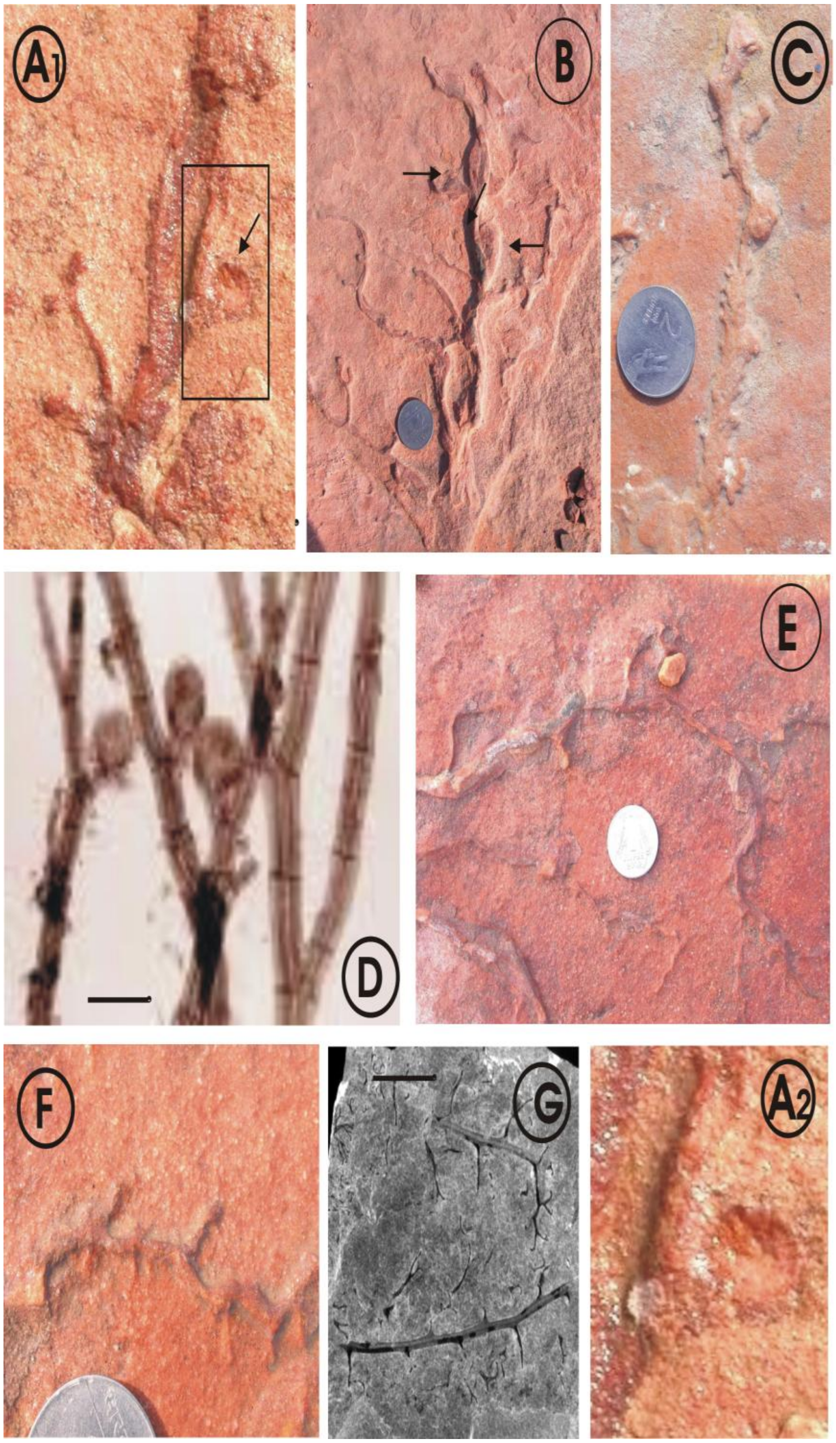

A
B
C
D
secondary pit connection
primary pit connection
E
F
15 µm

A


A1
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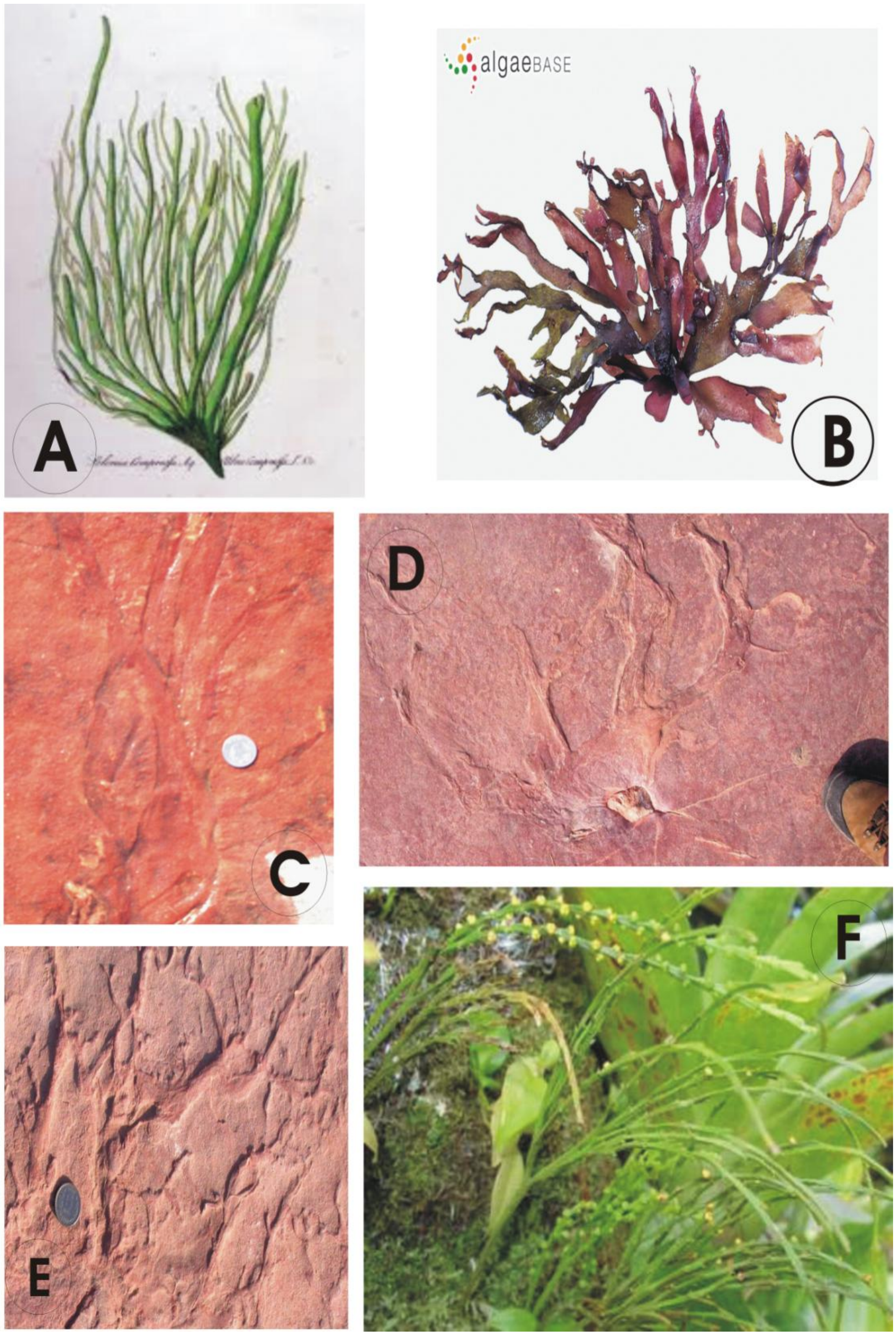
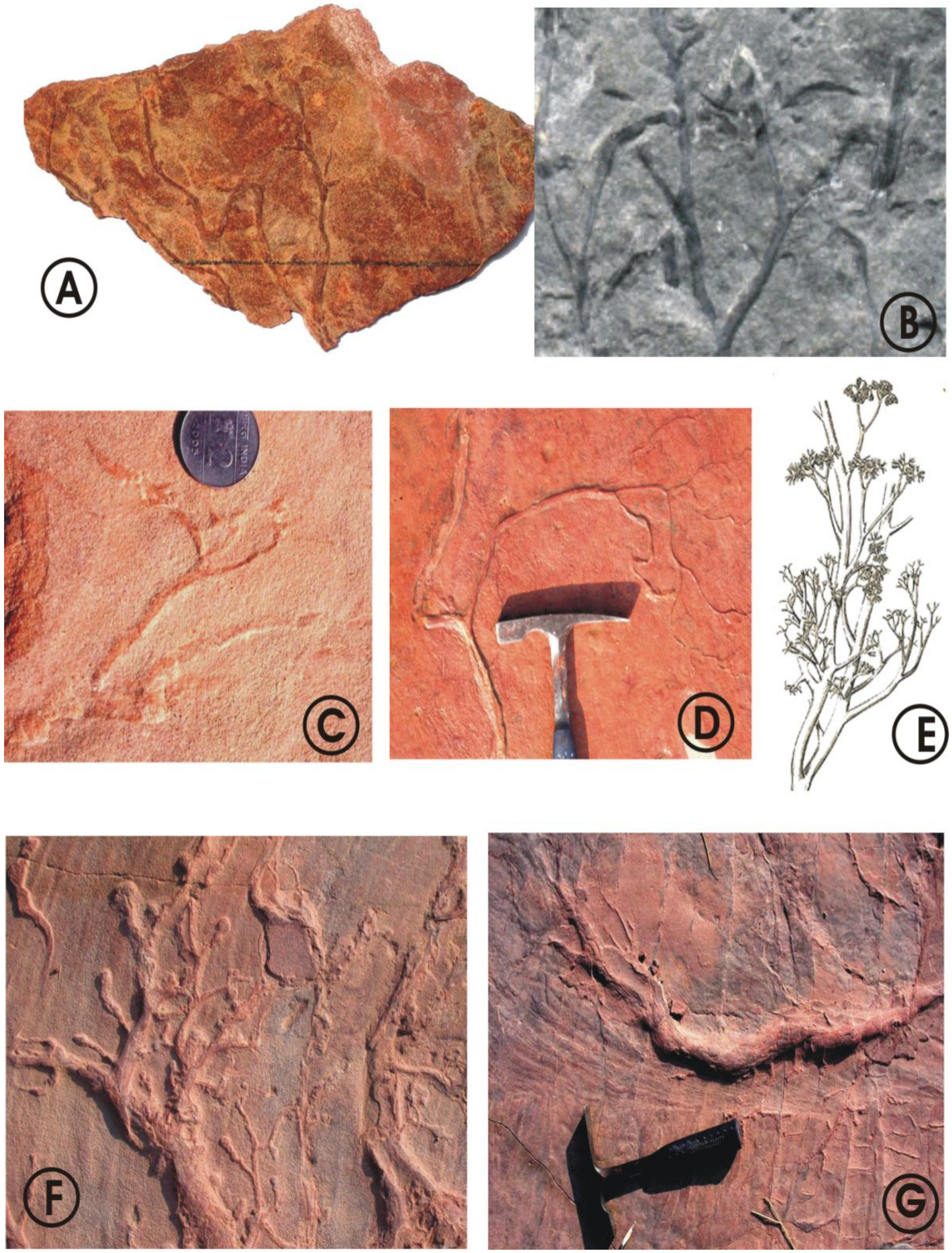
A2


A
algaeBASE
B
C
D
E
F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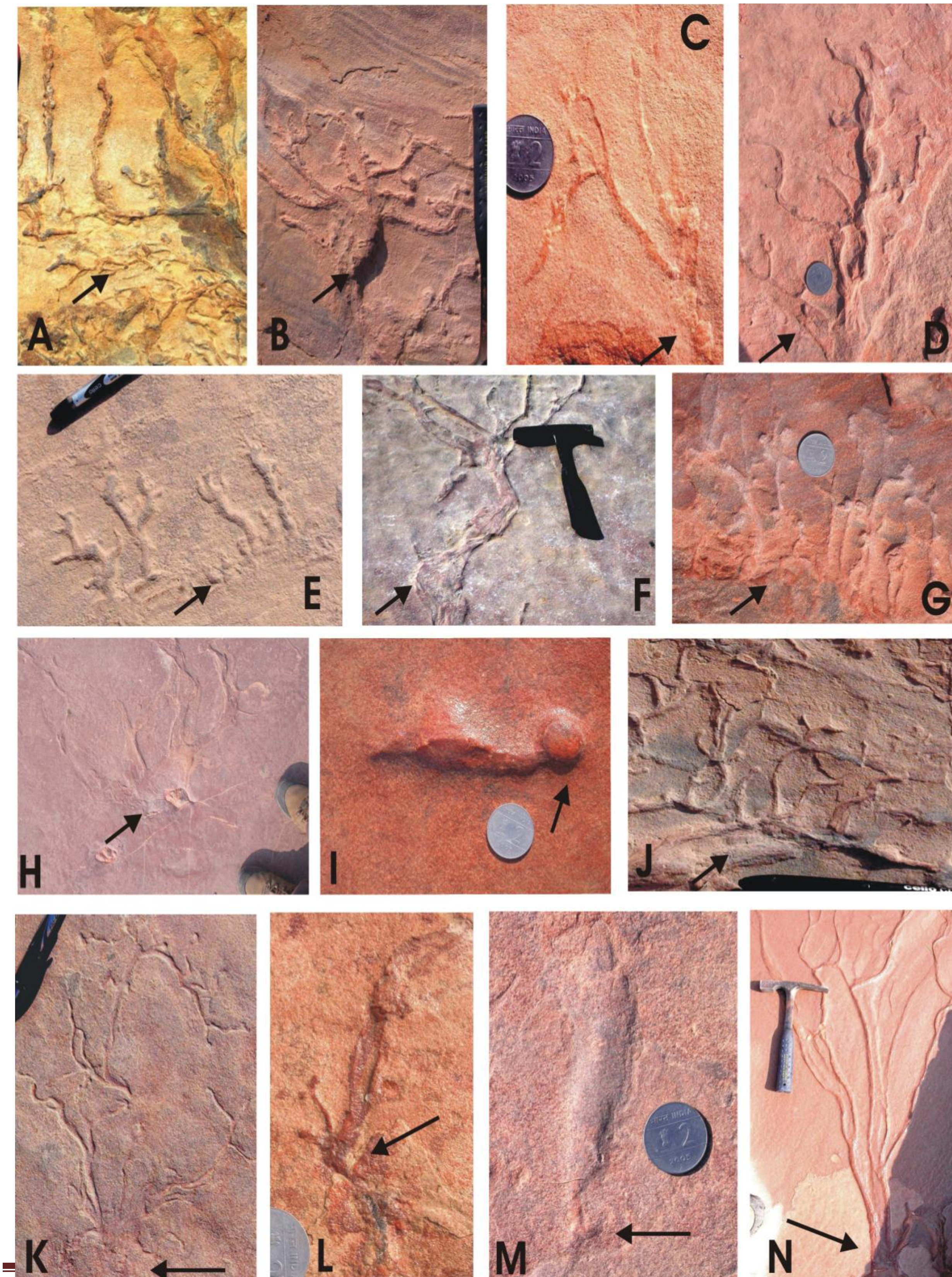
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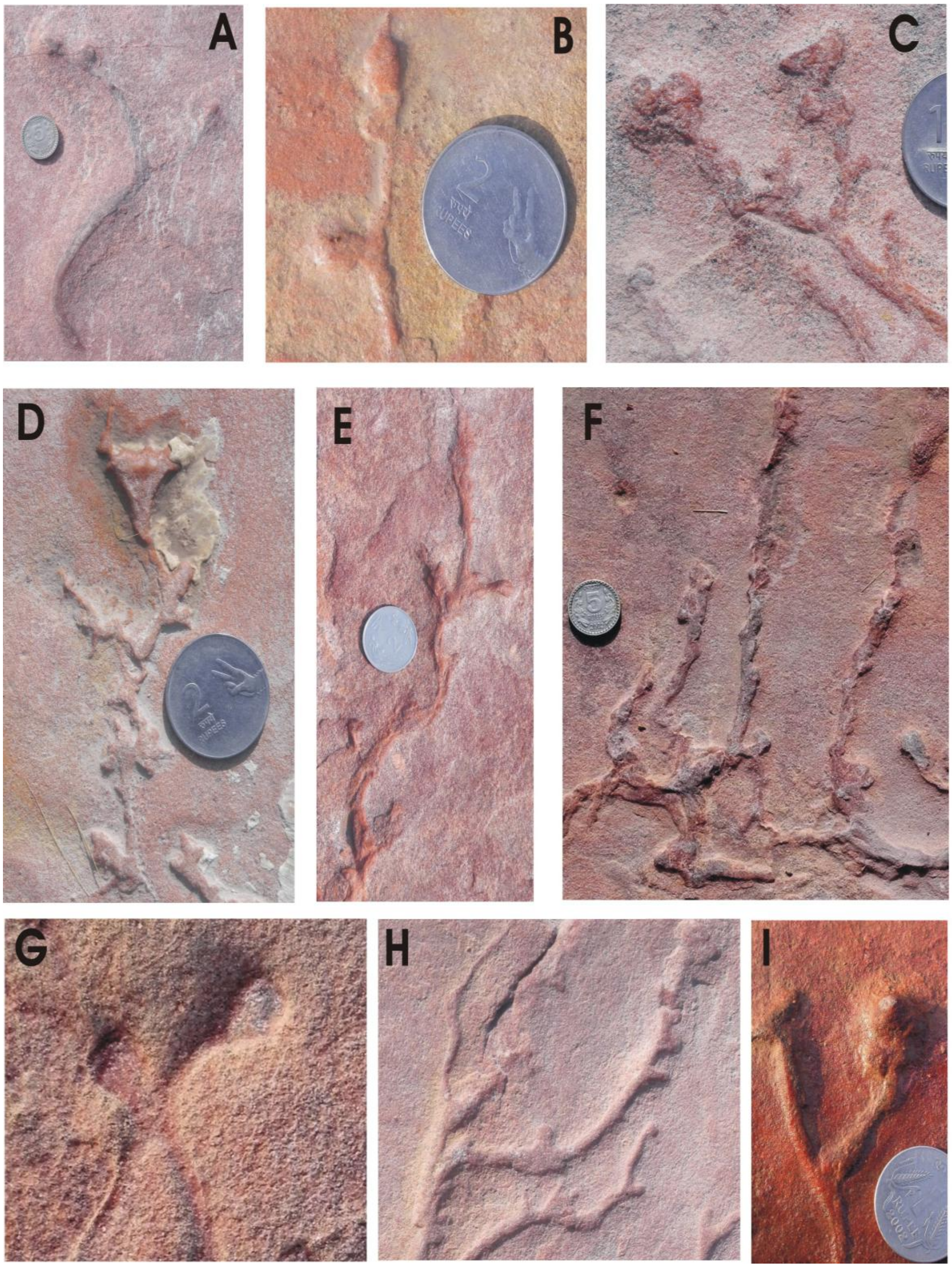
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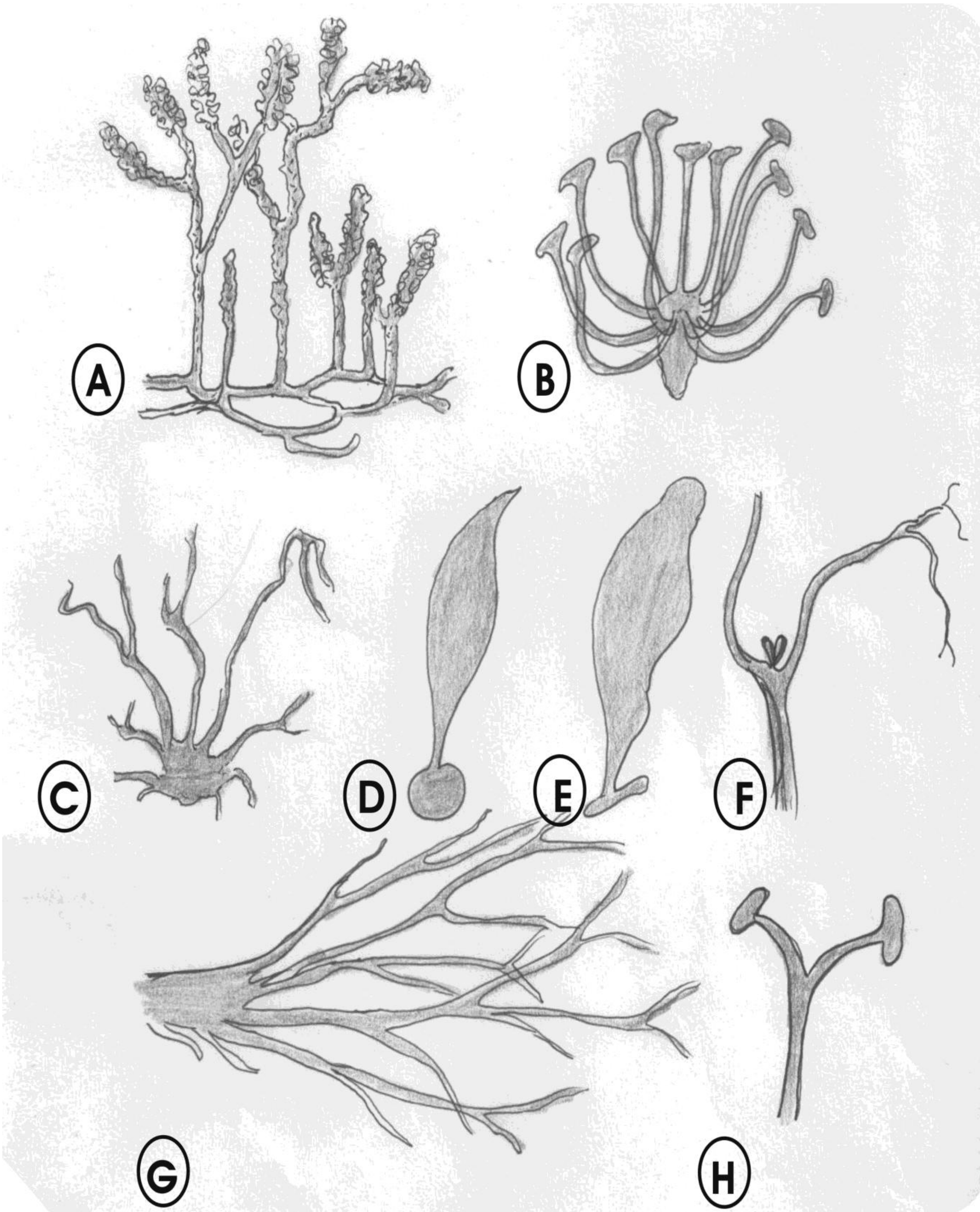
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