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Research Paper

Treptichnus pedum: An Ichnofossil Representing Ediacaran - Cambrian Boundary in the Nagaur Group, the Marwar Supergroup, Rajasthan, India

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Complex pattern of three dimensional age-marker worm burrows of *Treptichnus pedum* are being reported from the Nagaur Group (youngest group of the Marwar Supergroup), well exposed in Dulmera area of Bikaner District, western Rajasthan. Presence of *T. pedum*; an index fossil and a direct evidence marks the Ediacaran–Cambrian boundary within lower part of the Nagaur Group. Records of acritarchs and biomineralized tubes suggestive of Ediacaran age for the Bilara Group (stratigraphically overlain by the Nagaur Group), also support the age inferences drawn here. However, study based on different proxy records like carbon, sulphur and strontium isotopes, the Proterozoic/Cambrian boundary was earlier suggested within Bilara Group. Trilobite traces have already been reported by other workers from the Nagaur Sandstone, indicating its Lower Cambrian age and domination of benthic palaeocommunity, trailing on the sea floor. The overall Nagaur ichnofossil assemblage suggests behavioural diversity from suspension to deposit feeders, which was probably governed by the availability of oxygen and nutrient influx. Morphologically, specimens of *T. pedum* from the present assemblage are well comparable with the Jensen's specimens from the Lower Cambrian Mickwitzia Sandstone of South Central Sweden. The overall Nagaur assemblage comprising *T. pedum* and associated trace fossils (especially the trilobite traces) are comparable with the Reference Stratotype Section at Fortune Head, Newfoundland and a comparable section of Nemakit-Daldynian Stage, Siberia.

Key Words : ***Treptichnus pedum*; Ediacarn-Cambrian; Marwar Supergroup; Rajasthan**

1. Introduction

Globally there is a remarkable decrease in the body fossil diversity at the Precambrian-Cambrian boundary. However, this does not hold true for trace fossils. Common presence of trace fossils in successions devoid of body fossils make significant contribution towards stratigraphy, palaeoenvironment and palaeoecology of the sedimentary unit [10, 12]. The study of trace fossils therefore provides insight into the biological events during Precambrian–Cambrian transition' which includes the globally synchronous proliferation of vertically oriented burrows in the marine sediments [13]. *Treptichnus pedum* (formerly known as *Phycodes pedum*): a complex pattern of three dimensional worm burrows created by multicellular priapulid worms is globally considered as an age-marker ichnofossil, defining the Ediacaran - Cambrian boundary [45]. The First Appearance Datum (FAD) of the *Treptichnus pedum* represents the Ediacaran/Cambrian boundary, as per the recommendations of the International Subcommission on Cambrian Stratigraphy [8, 40, 47].

Globally, the trace fossils of Ediacaran age (630-542 Ma) are simple, unbranched, small and believed to have formed near sediment water interface. Furthermore, the arthropod tracks or trails and sinusoidal nematode trails are conspicuously absent during this period [36, 37]. In contrast, the

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Cambrian ichnofossils exhibit morphologically complex and diversified traces of bilaterian animals with, wide size-range and modestly increased depth of sediment penetration [9, 10, 11]. It has also been contented that typical arthropod trace fossils especially trilobite traces are not known from the Precambrian rocks and presence of *Rusophycus* (resting traces with scratch pattern) first appeared in Cambrian [18]. The first three dimensional burrows, reflecting vertical and horizontal movement in the substrate are represented by the *T. pedum* [11, 17].

The Nagaur Group in western Rajasthan (youngest group of the Marwar Supergroup) predominantly a siliciclastic facies is well exposed in Dulmera area of Bikaner District, Rajasthan. Present paper records *T. pedum* from this lithostratigraphic unit. Globally, this Pc-C boundary marker trace fossil *T. pedum* occurs in the siliciclastic facies, whereas the carbon isotopic marker signals are obtained from the carbonate dominated sections only [10, 24]. On the basis of carbon isotopic excursions the Pc-C boundary in the Marwar Supergroup has been identified at some arbitrary level within the carbonate sequence of the Bilara Group [23, 26], which underlies the trace fossil marker *T. pedum* bearing Nagaur Group of sandstones.

In Indian subcontinent, ichnofossil study is still in a state of infancy, especially those which are found in the rocks of the Proterozoic-Cambrian interface. There are reports of Pc-C boundary level ichnofossils from the extra-peninsular India [3, 5, 6, 41, 43, 44, 45], but the available data from the peninsular region [19, 21] are still nascent. *T. pedum* has been reported from the Lesser Himalayan successions of Tal Group and Garbyang Formation, Kunzum-La Formation and Lolab Formation of the Tethyan Himalayas [7, 7a, 27, 28, 32, 38, 44], but not precisely at the designated Pc-C boundary. Present report of *T. pedum* from the Marwar Supergroup is the first record of this index ichnofossil from the Peninsular India, demarcating the Ediacaran-Cambrian or Proterozoic-Cambrian boundary. In the past, some of the trace fossils from this area were identified differently by other workers [19, 21], although *T. pedum* was not recorded by these workers.

2. Geological Setting

The Marwar Supergroup, previously known as Trans –Arvalli Vindhyans is represented by unmetamorphosed and virtually undeformed sediments deposited west of the Aravalli Range. The succession is represented by different types of sandstones, carbonates, evaporates and shales [16, 30]. Detailed geological studies along with carbon and sulphur isotopic studies indicated a close affiliation of the Marwar Supergroup sediments with Tethys sediments of the Salt Range in Pakistan [1].

The Marwar Supergroup constitutes about 2 km thick sequence of almost horizontal beds, unconformably overlying the acid volcanics of the Malani Group, dated 779-681 Ma [33, 39]. The overall lithology of the supergroup is represented by sandstone, shale, carbonates and evaporates occupying an area of about 51, 000 sq. kms [25]. It is unconformably overlain by the Permo - Carboniferous Bap Conglomerates [29]. The Marwar Supergroup comprises of three Groups: Jodhpur, Bilara and Nagaur (Table 1, Fig. 1) in ascending stratigraphic order [20, 21]. The Jodhpur and Nagaur groups constitute predominantly siliciclastic rocks; whereas the Bilara Group is dominated by carbonates and evaporites (Table 1). The Nagaur Group is divided into a lower Nagaur Sandstone and an upper Tunklian Sandstone. The Nagaur Sandstone hosting the *T. pedum* is made up of medium to fine-grained massive sandstone intercalated with thin bands of silt and shale bands exhibiting a maximum thickness of about 20 meters (lower-middle part of the Nagaur Sandstone). The trace fossil bearing horizon is overlain by a compact sandstone, inter layered with claystone and siltstones (Fig. 2) from which trilobite traces have been reported by other workers [19, 21].

Treptichnus pedum has been recorded from the Nagaur Sandstone exposed in the Dulmera area, 65 Kilometers from the Bikaner, Rajasthan (Fig. 1). The fossil locality is a sandstone quarry (GPS Co-ordinates N28°24'13.9", E73°39'29.8") about 5 km

Table 1: Lithostratigraphic succession of the Marwar Supergroup, Rajasthan (After Pareek [23], [29])

Supergroup	Group	Formation	Lithology
		Bap Boulder Beds	
— — — — — — — —	— — — —	Unconformity	— — — — — — — —
	Nagaur Group	Tunklian Sandstone	Brick red sandstone, siltstone & red clay stone
		Nagaur Sandstone	Brick red sandstone, siltstone & red and green clay beds
Marwar Supergroup	Bilara Group	Pondlo Dolomite	Cherty dolomitic limestone
		Gotan Limestone	Interbeded dolomite & limestone
		Dhanapa Dolomite	Dolomitic limestone with cherty lenses sandstone with cherty lenses
	Jodhpur Group	Jodhpur Sandstone	Reddish gritty sandstone with maroon clay beds
		Pokaran Boulder Bed	Conglomerate
— — — — — — — —	— — — —	Unconformity	— — — — — — — —
		Malani Igneous Complex (780–681 Ma)	

east of the main road from Bikaner to Ganganagar. The burrows are well preserved in pink-orange and chocolate-brown shale, intercalated with sandstone, siltstone and green mudstone (Fig. 2). *Treptichnus pedum* bearing bed lies adjacent to and just below the trilobite traces bearing beds in the same horizon (Fig. 2).

3. Age of the Marwar Supergroup

Age of the Marwar Supergroup is considered younger than ~681 Ma, on the basis of dates available for the underlying Malani Rhyolites [33]. Recently reported megafossil assemblages from the Jodhpur Sandstone Formation represented by Ediacaran medusoids, microbial mats and megaplant fossils, support Ediacaran age for the Jodhpur Group [31, 34, 18, 21]. Recent data on carbon, sulphur and strontium isotopes from the Bilara Group, indicates Late Neoproterozoic - Early Cambrian age [4, 42, 26]. Inferences based on sedimentological and stable carbon isotope study of Bilara carbonates revealed that among several characteristic carbon isotopic excursions, only one has been tentatively correlated with globally recorded excursion close to the Neoproterozoic/Cambrian boundary. In contrast, the other peaks were attributed to fluctuations in bioproductivity, correlatable with variation in nutrient supply on a basinal scale [23]. Cryptic bioentities represented by acritarchs and bio-mineralized tubes reported from the Gotan Formation of Bilara Group suggested Ediacaran age for the Bilara Group [2]. The Nagaur Group has been correlated with the Purple Sandstone of the Salt Range, Pakistan, whose lower Cambrian age is well established [22, 35]. Recently reported trace fossils assemblage from the Nagaur Sandstone (horizon just above the *T. pedum* bearing beds of the present assemblage) includes *Cruziana*, *Rusophycus*, *Dimorphichnus*, *Chondrites*, *Isopodichnus*, *Monomorphichnus*, *Diplichnites*, *Skolithos*, *Palaeophycus*, *Planolites* and *Aulichnites* which confirms a lower Cambrian age of these lithounits [19, 21].

Treptichnus pedum

Treptichnus pedum samples from the Nagaur Sandstone have complex but very distinct three dimensional burrows preserved in convex relief. The burrow patterns are sometimes sinuous and looping

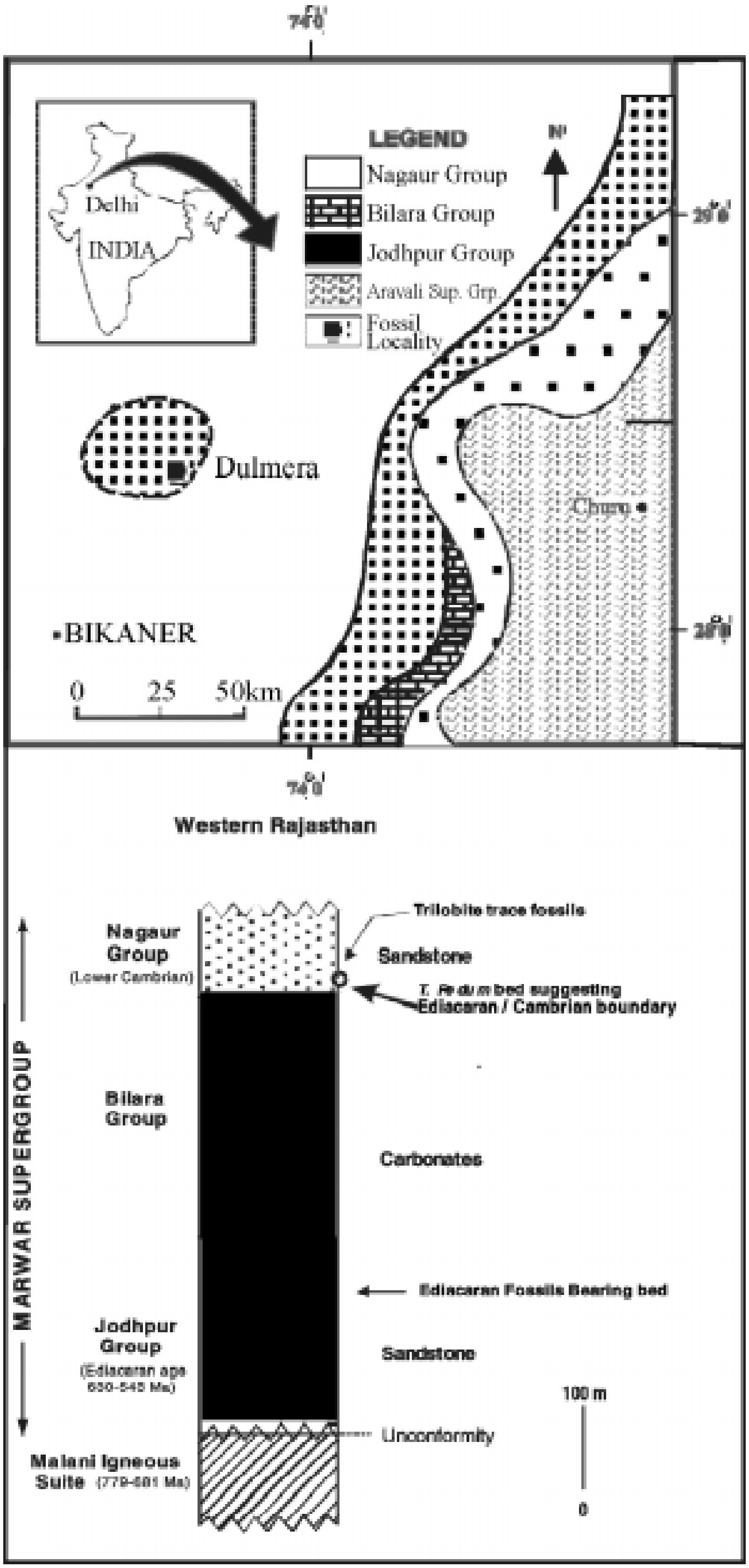

Fig. 1: Geological map and lithostratigraphy of the fossil bearing horizon in Dulmera area, Bikaner District, Rajasthan (modified after [29], [19]).

made by successive upward probes through the sediments (Figs. 3-C, F, H). At places they exhibit branching twig like structures (Figs. 3- E, I), very close to the forms already published (17, 45). Burrows follow straight, sinuous, arcuate, quasipalmate or coiled path (Fig. 3-C, E, F, H), suggesting the movement of the animal in search of the nutrients [35, 36]. In such cases it resulted in a trace pattern reminiscent of a twisted rope like structures and overlapping of burrows (see Fig. 3-F, H). The overlapping of elongated burrows are well comparable with *T. pedum* (Figs. 3-A,B,) reported by Jensen from the lower Cambrian Mickwitzia Sandstone of the south Central Sweden [17]. Morphology exhibited by specimens (in Fig. 3-E, I) closely matches with *Treptichnus* reported from Poland [45]. Sometimes, these burrows exhibit partial loops characterized by probes oriented on the convex side of the burrow turn (Fig. 3-F, H), where they are moderately scoured by deposition of the overlying bed or probes. The probe shapes include lobate, tear drop and curved morphologies. They also occur as cluster or pairs of elongated burrows (Fig. 3-C, E, I). Burrows show a wide size range with width varying between 4mm and 12 mm, and length between 4mm and 3cm (based on 58 measurements).

4. Discussion and Conclusion

Treptichnus pedum is considered to be the earliest globally wide-spread complex trace fossil. Its earliest appearance, contemporaneous with the last of the Ediacaran biota, is used to define the dividing line between the Ediacaran and Cambrian periods

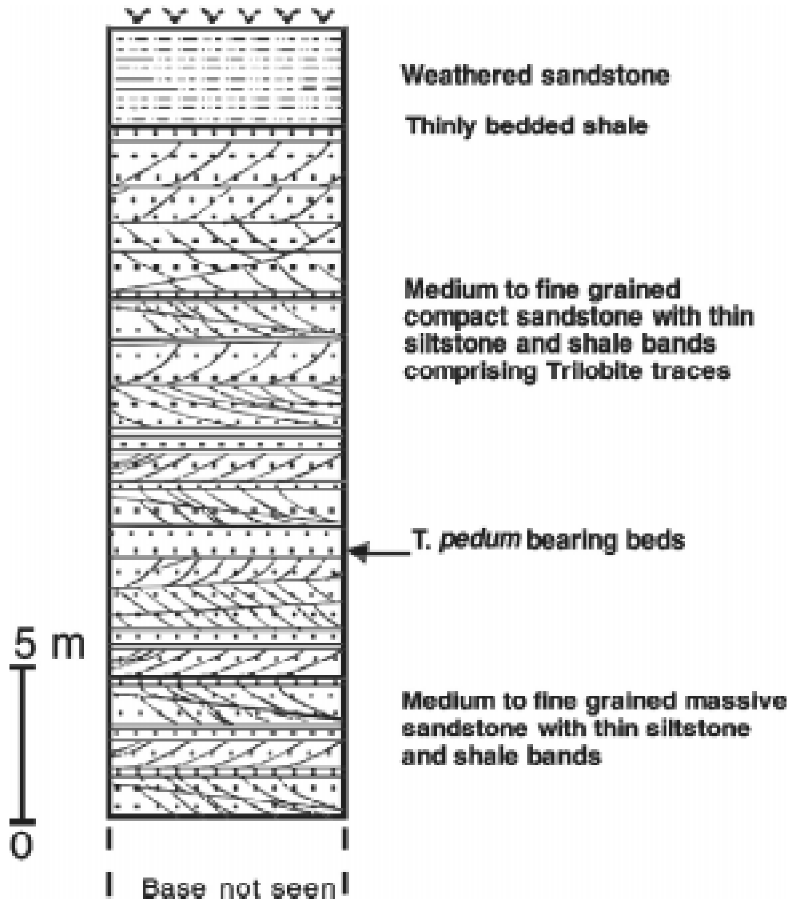

Fig. 2: Generalized lithostratigraphy of the Marwar Supergroup, Rajasthan, exhibiting fossils bearing Horizons and corresponding ages of different lithounits [21].

[15]. The burrow is considered to be the result of rhythmical probing and backfilling action of a priapulid worm- like undermat - miner, because the burrow as a whole follows the bedding plane without ever probing into the underlying mud layer [37]. It is inferred that the animal had left and right side and had a sense for up and down [14]. Organisms that left such traces are considered more complex than earlier Ediacaran fauna, and these trace fossils, which occur world-wide are usually found in strata above Ediacaran fossil bearing horizon [24]. Since only burrows of *T. pedum* have been found, it is presumed that the treptichnid animals lacked any hard anatomical features such as shells or bones. Till very recent time, the morphology and relationship of Treptichnids with the modern animals was unknown and had remained an enigma, despite their importance in biostratigraphy. It has now been agreed upon that Treptichnids are subhorizontal burrow systems produced in subsurface and had a world-wide distribution throughout the Cambrian [13]. Experimentally it has been displayed that Treptichnid burrow system was most probably produced by priapulid worms that used the same locomotory mechanisms as shown by the recent priapulids [46].

In Nagaur Sandstone the other ichnofossils, occurring in association with *T. pedum* are *Cruziana*, *Rusophycus*, *Diplichnites* and plug-shaped burrows comparable to *Bergaueria*. It is therefore inferred that, the present assemblage provides a unique opportunity to trace the evolution of earliest benthos from the Ediacaran to lower Cambrian transition within twenty meter thick sedimentary horizon of the Nagaur Sandstone in Dulmera area.

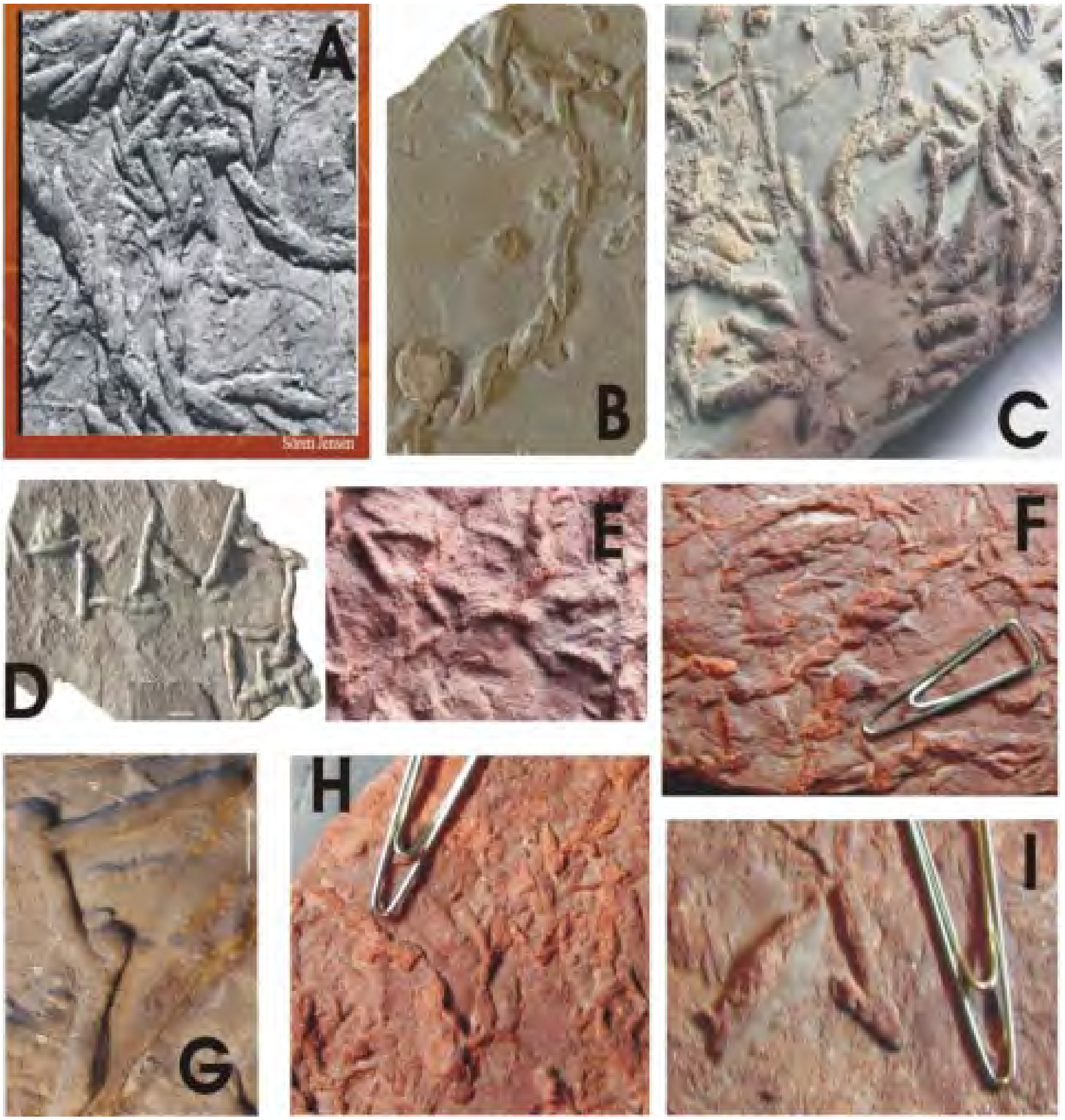

Fig. 3: Comparative illustration of *Treptichnus pedum* from the Nagaur Sandstone and similar burrows described from Sweden and Poland. A-B: *Treptichnus pedum* in cluster and rope like manner from the Lower Cambrian Mickwitzia Sandstone, Sweden, (SGU 8558 Jensen 1997) displaying (See Vannier *et al.* 2010 Fig. 2A) Scale bar 1cm.; C: *Treptichnus pedum* showing random movement paths, A part of U clip on upper right corner=3cm. Nagaur Sandstone; D: *Trepichnus rectangularis* from the Furongian to the Holy Cross Mountains, Poland (See Orlowski and Zylinska, 1996) (See Vannier *et al.* 2010. Fig.2B) Scale bar 1cm.; E: Elongated burrows of *Treptichnus pedum* from the Nagaur Sandstone, Scale same as in D; F: *Treptichnus pedum* burrows from the Nagaur Sandstone, acquiring sinuous path in a twisted rope like structure, Uclip on upper right corner = 3 cm.; G: Details of striated segments *Treptichnus rectangularis* from Poland Scale bar 5 mm. (See Vannier *et al.* 2010 Fig 2 E); H: Overlapping, branching and linearly arranged *Treptichnus pedum* from the Nagaur Sandstone; I: Branched twig like burrows of *Treptichnus pedum* from the Nagaur Sandstone.

T. pedum in the present area as well as in the GSSP at the Fortune Head, Burin Island occurs in the siliciclastic facies. In carbonate dominant sections the boundary is marked by characteristic carbon isotope excursions [24, 10]. In the Marwar Supergroup, the Pc-C boundary was located on the basis of very poorly constrained single carbon isotopic excursion [23] in the carbonates of the Bilara Group which is stratigraphically older than the sandstones from where *T. pedum* was recovered [26]. The presence of *T. pedum,* in the shallow marine siliciclastic facies of rocks is a more robust indicator of the Ediacaran/Cambrian boundary which lies in the lower parts of the Nagaur Sandstone Formation.

The sandstone horizon within Nagaur Sandstone Formation therefore correlates with the Stratotype Reference Section of the Fortune Head, Newfoundland and Nemakit-Daldynian Stage of Siberia. The morphology exhibited by specimens of present assemblage is very close to the already established and published *T. pedum* from the Sweden [17]. The identification of *T. pedum* in the shaly rocks along with previously reported trace fossil assemblages have contributed significantly towards establishment of age and a proper stratigraphic status for the Nagaur Sandstone Formation.

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