



TRACE FOSSIL ASSEMBLAGE FROM THE NAGAUR GROUP, WESTERN INDIA

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ABSTRACT

The Nagaur Group represents the youngest group of the Marwar Supergroup which has yielded a good assemblage of trace fossils of Lower Cambrian age. Eighteen ichnospecies, five burrows along with two types of arthropod scratch marks have been identified. Out of this assemblage, only scratch marks and burrow structures are described from the youngest horizon of the Marwar Supergroup, i.e. the Tunkliyan Sandstone, while the other described trace fossils are from the Nagaur Sandstone exposed in the Dulmera area, Bikaner district. The present assemblage in the Nagaur Sandstone is represented by *Rusophycus carbonarius*, *Rusophycus didymus*, *Cruziana fasciculata*, *Cruziana cf. salomonis*, cf. *Isopodichnus* isp., *Diplichnites gouldi*, *Planolites beverleyensis*, *Planolites annularis*, *Bergaueria perata*, *Monocraterion* isp., *Skolithos* isp., *Monomorphichnus lineatus*, *Monomorphichnus multilineatus*, *Dimorphichnus obliquus*, *Chondrites* isp., *Treptichnus pedum*, *Palaeophycus tubularis*, cf. *Lockeia*, scratch marks and burrow forms. The assemblage suggests a Lower Cambrian age (Stage 2 and Stage 3) to the Nagaur Group, which has a close resemblance with the Tal Formation of the Lesser Himalaya of Tommotian-Lower Atdabanian age.

Keywords: Traces fossil, Nagaur Group, Lower Cambrian, Marwar Supergroup, Rajasthan

INTRODUCTION

The Marwar Supergroup (MSG) occupies a large area of about ~51,000 km² in the Jodhpur-Khatu-Nagaur-Bikaner section of western Rajasthan (Pareek, 1981, 1984; Paliwal, 2007) (Fig. 1). It unconformably overlies the Malani Igneous Suite. Earlier, the Marwar Supergroup was considered as unfossiliferous except for the occurrence of stromatolites in the carbonate facies of the Bilara Group (Khilnani, 1964; Barman, 1975, 1980 and 1987) which were not helpful in suggesting any age to the stromatolite bearing rocks. Now there are ample evidences to suggest an Ediacaran to Lower Cambrian age to the rocks of the Marwar Supergroup. For this the evidences are in the form of Ediacaran body fossils, microbial mat structures, trace fossils and body fossils of arthropod and priapulid worms (Kumar and Pandey, 2008a, 2009; Sarkar *et al.*, 2008; Srivastava, 2012b; Singh *et al.*, 2013; Kumar and Ahmad, 2014). Microfossils have also been discovered from the different stratigraphic horizons of the Marwar Supergroup suggesting the age between the Ediacaran and middle Cambrian (Prasad *et al.*, 2010). Recently the Nagaur Sandstone has been dated as ≤ 540 Ma by detrital zircon (McKenzie *et al.*, 2011). Pandey *et al.* (2014) have now given a more detailed description of the trace fossils of the Nagaur Sandstone and reported fifteen ichnospecies belonging to eight ichnogenera. They suggested that the trace fossil bearing unit belongs to the *Cruziana tenella* Ichnozone and to Stage 2 (upper part of Terreneuvian) of the Cambrian. They have not excluded the possibility of including the Middle Cambrian also. However, in the present work no body fossil has been recorded. The paper describes trace fossils from the Nagaur Group and highlights behavioral mechanism of the ichnospecies.

GEOLOGICAL SETTING

The Marwar Supergroup attains a huge thickness of 1000 m in a desert setting of the western Rajasthan represented by an argillo-arenaceous and carbonates facies in the Jodhpur-Khatu-

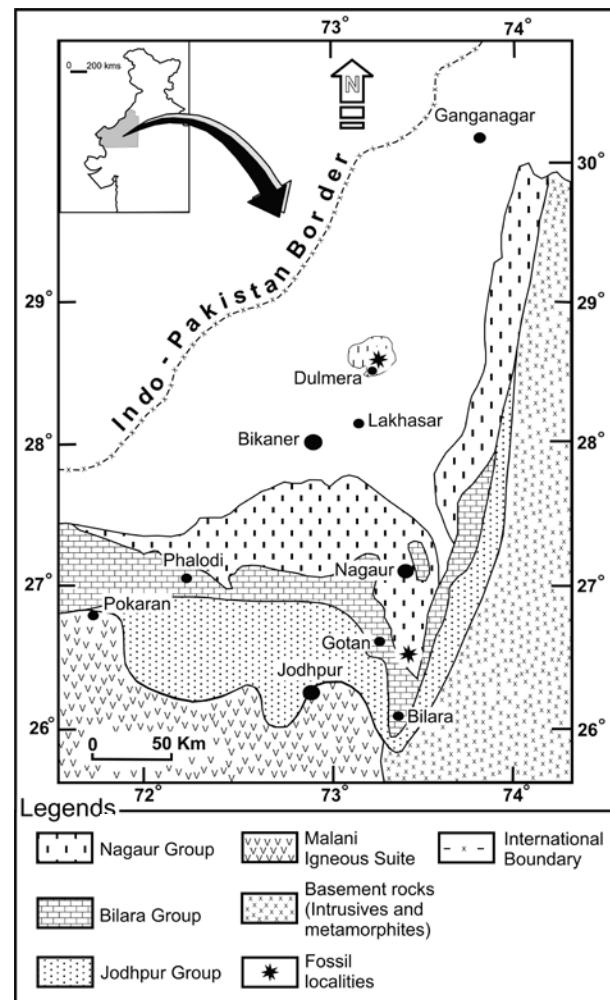


Fig. 1. Location and geological map of the Marwar Supergroup (simplified after Pareek, 1984).

Bikaner-Phalodi area. The rocks of the Marwar Supergroup unconformably overlie the Malani Igneous Suite, which has been dated as 771 ± 5 (Gregory *et al.*, 2009) and are unconformably overlain by the Permo-Carboniferous Bap Boulder Bed (Pareek, 1981, 1984). The basic lithology is represented by the sandstone, siltstone, shale, conglomerate, dolomite and limestone. The rocks are unmetamorphosed and more or less undisturbed. As such the rocks are horizontal in most of the areas or show very low dips.

The Marwar Supergroup has been subdivided into three groups. In stratigraphic order these are the Jodhpur Group, the Bilara Group and the Nagaur Group. Each group has been further subdivided into different formations (Table 1, Fig. 2). The Nagaur Group is the youngest group which has been subdivided into Nagaur Sandstone and Tunkliyan Sandstone (Pareek, 1984). The dominant lithology is represented by fine to medium grained sandstone with minor shale and siltstone. A good section is seen in Tunkliyan area (GPS Value N26°38.572' and E73°46.840') near Gotan where a number of cement factories are located which derive limestone from the Bilara Group. An excellent section of the Nagaur Sandstone is seen in the Dulmera area where the sandstone is mined. It is about 65 kms from Bikaner on Bikaner-Ganganagar motor road (GPS Value N28°24.228' and E73°39.514').

The Nagaur Sandstone is made up of brick red to red colour sandstone with green and brown shale bands. It shows parallel bedding with low angle discordances, large and small scale trough and planar cross bedding, small scale wave ripple bedding, flaser and lenticular bedding, ripple marks and mud cracks. Presence of mud gals, current crescent and primary lineations are also noted. The Tunkliyan Sandstone is fine to coarse grained, reddish brown to maroon coloured sandstone. It is intercalated with brownish red silty shale. Some horizons are pebbly and gritty. It shows large scale cross bedding. The trace fossils are poorly preserved in the uppermost part in the fine grained to silty sandstone (Fig. 2).

SYSTEMATIC PALAEONTOLOGY

In the present study 18 ichnospieces (14 ichnogenera), 5 burrow morphologies and 2 scratch marks are identified. Most of these fossils are seen on the sole of the bedding plane and also on top of the bedding surface. Lithology is represented by fine-grained sandstone, siltstone and shale (Fig 2). Twenty three different morphologies of the trace have been described from the Nagaur Sandstone while only 2 morphologies (one scratch mark and one burrow form) have been reported from the Tunkliyan Sandstone. The trace fossils represent varied morphologies and behavioral activity of ancient organisms. The preservation is excellent and their ecology could be studied in detail. All the samples have been deposited in the Museum of the Centre of Advanced Study in Geology, Lucknow University, Lucknow.

Nagaur Sandstone Trace Fossils

Ichnogenus Rusophycus Hall, 1852

Rusophycus carbonarius Dawson, 1864

(Pl. I A and B)

Repository ref. NG/SK13/1

Material: A single slab of fine grained sandstone showing 35 specimens preserved as hyporelief on the sole of the bedding.

Description: Convex, coffee-bean-shaped hypichnia, 0.5 to 1.5 cm long with mean value as 1.03 cm (N=35) and 0.4 to 0.9 cm wide with mean value as 0.6 cm (N=35). The individual lobe is 0.2 to 0.7 cm wide. The two symmetrical lobes are separated by a distinct furrow. The furrow is 0.1 to 0.2 cm wide. Lobes are parallel, rarely oblique and 0.3 to 0.5 cm in height from the bedding surface. The median furrow runs through full length of hypichnion.

Remarks: The specimens do not display the stripes on the lobes, which is a typical characteristic of *Rusophycus carbonarius* (Schlirf *et al.*, 2001) but Keighley and Pickerill (1996) interpreted such specimen as taxonomic variant of *R. carbonarius*. The Early Cambrian *R. carbonarius* was possibly produced by small or juvenile trilobite (Stachacz, 2012). *R.*

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

Supergroup	Group	Formation
MARWAR SUPERGROUP	Nagaur Group (75-500 m)	Tunkliyan Sandstone Nagaur Sandstone
	Bilara Group (100-300 m)	Pondlo Dolomite Gotan Limestone Dhanapa Dolomite
	Jodhpur Group (125-240 m)	Jodhpur Sandstone Pokaran Boulder Bed
	Basement	Unconformity
		Malani Igneous Suite / Metamorphites

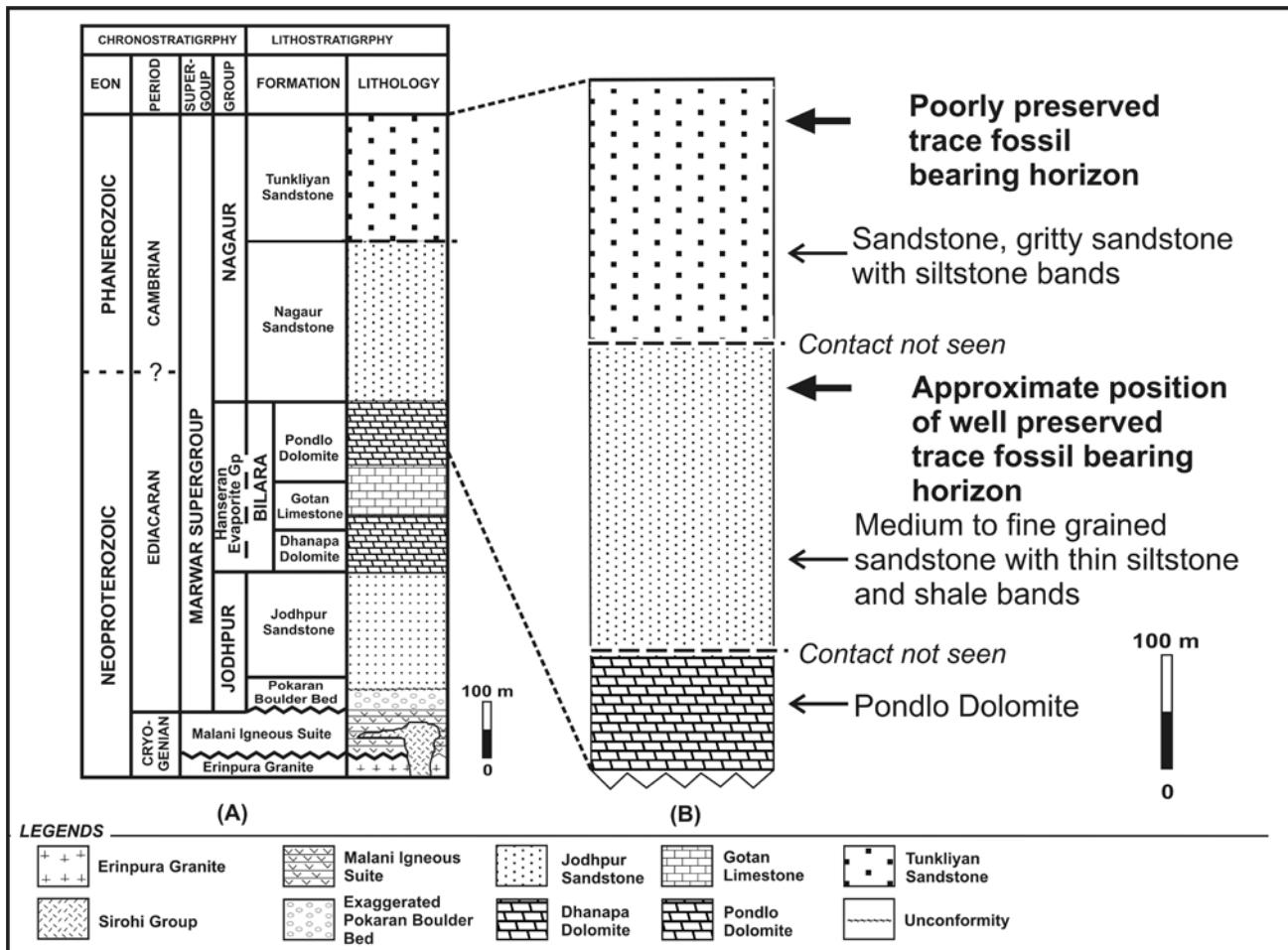


Fig. 2. A. Litholog of the Marwar Supergroup (after Cozzi *et al.* 2013) B. Trace fossil bearing horizon in the Nagaur Group.

carbonarius is believed to be a resting trace of tiny arthropod (Hofmann *et al.*, 2012). Present form is slightly larger in size and closely resembles ichnospecies *R. carbonarius* reported from the Holycross Mountain, Poland (Stachacz, 2012). Recently, Pandey *et al.* (2014) described *Rusophycus* cf. *carbonarius* from the Nagaur Sandstone in which both the lobes are joined at one end and open at other end, but in the present samples lobes are parallel to each other. The *Rusophycus* cf. *carbonarius* described by Pandey *et al.* (2014) seems more close to *R. didymus*.

Rusophycus didymus Salter, 1856
(Pl. I C)

Repository ref. D-108/08

Material: One slab of fine grained sandstone showing two well preserved specimens on top and nine on the sole of the bedding.

Remarks: The same form has been described by Kumar and Pandey (2010). Both lobes are smooth devoid of any stripes. This ichnogenus has worldwide occurrence from the lower Cambrian such as Europe, North America, North Africa, Asia including Pakistan (Moore, 1962). Seilacher (1953) has interpreted *Rusophycus* as a trilobite resting excavation.

Ichogenus Cruziana d' Orbigny, 1852
Cruziana fasiculata Seilacher, 1970
(Pl. I D, E and F)

Repository ref. DL-45, 47, 51, 52, 56, 60, 102, 124, NS-12 and NS-24

Material: Ten slabs of fine-grained sandstone containing more than fifty two specimens oriented broadly in a particular direction or randomly arranged on the sole of the bedding plane, while four specimens are preserved on the bedding surface.

Description: Elongate furrow, herringbone-shaped ridges with sub-equal scratches. A median furrow runs parallel and divides the structure into two lobes and continues uninterrupted. The specimens taper at posterior end and broader at anterior end. Width varies from 1 to 3 cm with a mean value as 1.6 cm (N=56), length ranges from 1.4 to 30 cm with a mean value as 5.8 cm (N=56). The traces are 0.5 to 1 mm in height. The scratch marks are prominently seen on the lobes and the gap between the two consecutive scratch marks is 1 to 2 mm. Maximum 10 scratch lines are counted in 1 cm. The furrow width ranges up to 0.2 cm. Length of median furrow is as per the size of the specimen. The podial marks on the lobes meet centrally at a furrow making V-shaped structure with varying angle which ranges from 50-60°. Scratch marks present on both the lobes are not identical. Each lobe showing scratch marks in bundles which is comparatively unequal in 1 cm length. The podial marks are counted as 8 to 10 lines/cm.

Remarks: Present specimen is very close to ichnogenus *Cruziana fasiculata* Seilacher in terms of podial marks. *Cruziana* is considered a burrow produced by trilobites (Seilacher, 1970). *Cruziana fasiculata* is also described by Kumar and Pandey (2010) from the same horizon simply as *Cruziana* isp. The specimen also shows some similarity with

Rusophycus bikanerius (Pandey *et al.*, 2014) in terms of podial marking. *Rusophycus bikanerius* appears as a transitional form between the ichnogenera *Rusophycus* and *Cruziana*. It appears that a combination of crawling and resting behaviour produced *R. bikanerius*. Thus, the creation of a new species is not justified.

Cruziana cf. salomonis Seilacher, 1990

(Pl. II A)

Repository ref. NG/SK-13/4 & 5

Material: Two slabs of fine grained sandstone comprising 5 specimens collected from the Dulmera mine preserved as hyporelief on the sole of the bedding surface.

Description: The form is having the typical morphology of *Cruziana* isp. The endopodal scratches are prominent in the frontal part of the furrow. The median furrow has constituent width all along the trace. The traces are 1.4 to 2.8 cm long with a mean value as 1.7 cm (N=5) and is 2.4 cm wide. The width of lobes ranges from 0.9 to 1.3 cm. Both lobes are more or less symmetrical in shape. The continuous length of furrow is up to 1.8 cm with a mean value as 1.5 cm (N=5) and 0.1 to 0.3 cm wide with the mean value as 0.2 cm (N=5). The striation joins at the furrow at about 150° to 170° making an obtuse angle. 10 podial marks are counted in 1 cm length.

Remark: The present form has close resemblance with the form reported from the eastern desert of Egypt (Seilacher, 1970) in furrow morphology and obtuse angle relationship between two sets of podial markings. *C. salomonis* has been endorsed to the activities of small to medium trilobite mostly digging activity within the sand (Hofmann *et al.*, 2012). The specimen is close to *C. salomonis* only in terms of the angular relationship of podial marks with respect to median furrow, but differs in lacking 3 to 4 podial marks in groups.

Ichnogenus cf. Isopodichnus Bornemann, 1889

Isopodichnus isp.

(Pl. II B)

Repository ref. DL-108/106/115 and 202

Material: Four slabs of muddy to fine grained sandstone with three specimens preserved on the top and three on the sole.

Description: Paired ribbon like trail, smooth walls, straight to curved, separated by fine prominent furrow. There is no marking observed on the wall of the track. Trails are 3.4 to 9 cm long and 0.9 to 1.5 cm wide. The furrow runs parallel to the structure and ranges from 0.1 to 0.4 cm in width.

Remarks: Specimen is comparable to *Cruziana* as far as the morphology and the outline of the trail is concerned, but it lacks any type of scratch marks (*sensu* Fürsich, 1974). The specimen closely resembles *Isopodichnus* described by Kumar and Pandey (2010) from the Nagaur Sandstone. *Isopodichnus* is typical of non-marine strata and can be distinguished from *Cruziana* on the basis of the shape of the trace ending (Trewin, 1976).

Ichnogenus Diplichnites Dawson, 1873

Diplichnites gouldi (Bradshaw, 1981)

(Pl. II C and D)

Repository ref. NG/SK-13/18

Material: Two specimens preserved as hyporelief in the fine grained sandstone.

Description: Trackway consisting two parallel series of fine ridges, oriented perpendicular to the track axis. The width of the

trackway 1.7 cm and length measured up to 5.2 cm. Individual ridge elongated, 0.4 to 0.6 cm in length. Both rows of are 0.6 cm apart. The gap between the two contiguous ridges is 0.3 cm. Both series are well preserved.

Remarks: Specimen shows close resemblance with ichnogenus *Diplichnites* isp. Dawson (1873), which is interpreted as a walking trace of trilobite (Seilacher, 1955; Radwanski and Roniewicz, 1963; Crimes 1970). Specimen quite differs from *Dimorphichnus* in respect of lacking prominent ridges. During the movement, the width of the trace will depend on the size of the animal and how far its limbs extend outside (Crimes and Harper, 1970). The specimen shows fine imprints oriented perpendicular to the midline of the trackway which is similar in *Diplichnites gouldi* Bradshaw, 1981 (see Minter and Lucas, 2009). *Diplichnites* is abundantly reported from the Cambrian rocks (Seilacher, 1955). Kumar and Pandey (2010) reported it as *Diplichnites* isp. from the same horizon. It is also reported from the Tethyan region (Table 2).

Ichnogenus Planolites Nicholson, 1873

Planolites beverleyensis, Nicholson and Hinde, 1875

(Pl. II E)

Repository ref. NG/SK-13/23

Material: Four specimens preserved as positive hyporelief in fine-grained sandstone.

Description: Full relief, unbranched, horizontal to the bedding surface, straight to slightly curved burrow, partly infilled with host sediments. Individual burrow is 2.0 to 8.5 cm long and 1 to 3 mm wide.

Remarks: The specimens closely resemble *Planolites beverleyensis*, Crimes and Anderson (1985), in unbranched nature of burrows. It is often difficult to distinguish between *Planolites* and *Palaeophycus* Hall, 1847 except in non branching nature of the burrow. *Planolites beverleyensis* is known from the Precambrian to Recent.

Ichnogenus Planolites Nicholson, 1873

Planolites annularis Walcott, 1890

(Pl. II F)

Repository ref. NG/SK-13/39

Material: One slab of fine-grained sandstone having ten specimens preserved as positive hyporelief on the sole of the bedding.

Description: Transversely annulated, horizontal burrow, generally straight, slightly curved, arranged in a back to back pattern. The single burrow form varies from 1.0 to 3.9 cm long and width 2 to 4 mm. The gap between the annulations is normally 1mm. There are 6 to 8 transverse annulations counted per cm.

Remarks: The specimen shows resemblance with *Planolites annularis* Walcott, 1890. The annulations are very closely spaced; width of burrow is also less than the form described by Crimes and Anderson (1985). They have also mentioned that it is reported from the Lower Cambrian, New York; White Inyo Mountain, California and Lintiss vale beds, N.S.W. Australia.

Ichnogenus Bergaueria Prantl, 1945

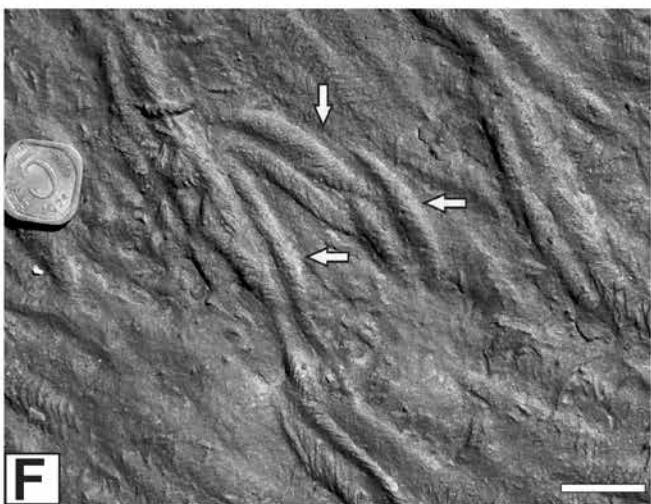
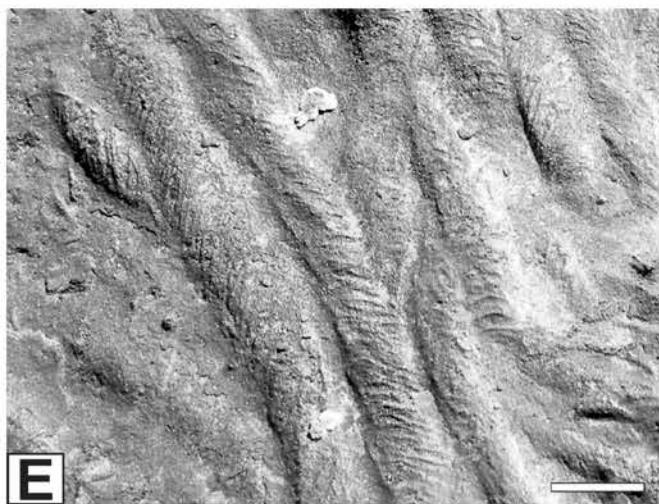
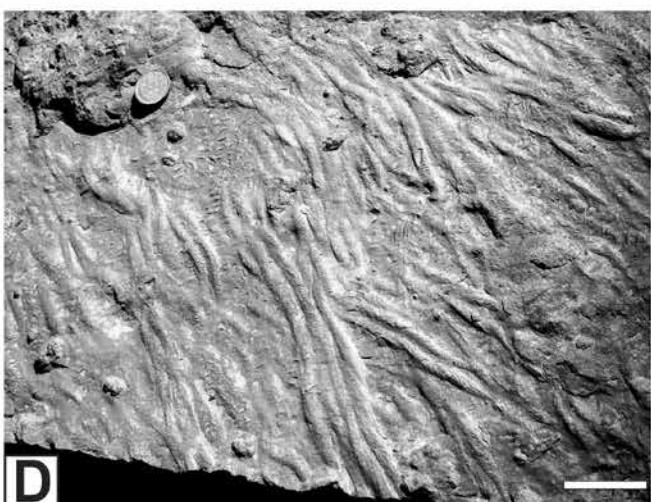
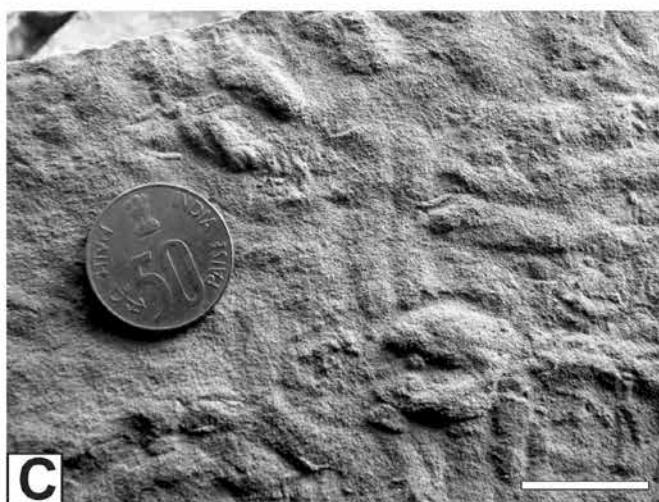
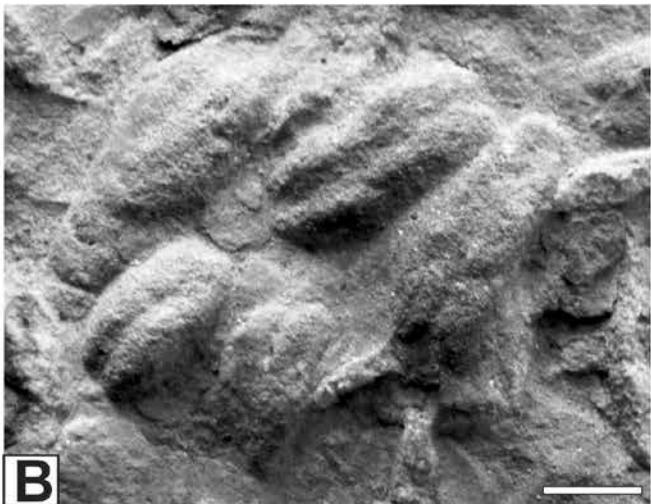
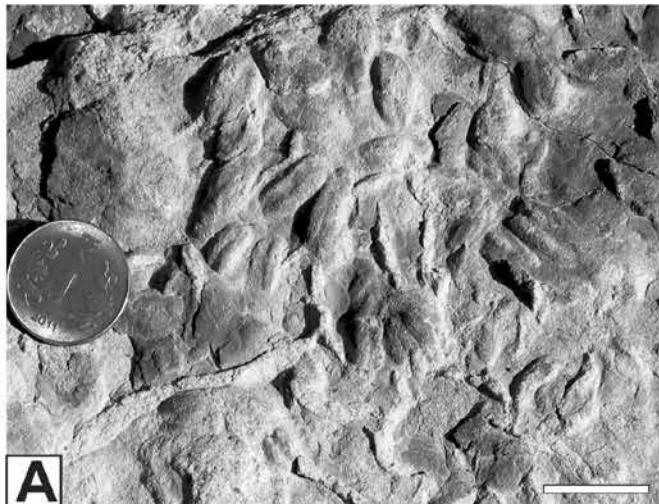
Bergaueria aff. perata Prantl, 1945

(Pl. III A and B)

Repository ref. NG/SK-13/24

EXPLANATION OF PLATE I

Trace fossils reported from the Nagaur Sandstone, Dulmera area, Rajasthan. A) *Rusophycus carbonarius* (Scale bar = 2 cm); B) Close up view of *Rusophycus carbonarius* (Scale bar = 0.5 cm); C) *Rusophycus didymus* (Scale bar = 2 cm); D, E and F) *Cruziana fasiculata* (Scale bar for D = 5 cm and for E, F=1 cm).



Material: Four specimens preserved in fine-grained sandstone as positive hyporelief.

Description: Cup-shaped protrusion with smooth walls, wider than deeper, perpendicular to bedding. Circular to sub-circular in outline 2 to 4 cm in diameter and 0.4 to 1.0 cm deep. Lower end rounded, with shallow depression. Outer wall smooth, devoid of any striations. The surface is slightly irregular which may be due to load effect.

Remarks: *Bergaueria* is interpreted as a domichion or cubichion produced by actinarian and ceriantharian coelenterates (Fillion and Pickerill, 1990; Bromley, 1996). *Bergaueria* is regarded as a dwelling structure, and present specimen shows close resemblance with *Bergaueria perata* Prantl (1945). The specimen has global occurrences from Cambrian to Ordovician strata (Häntzschel, 1975) but most common in Lower Cambrian (McKee, 1945; Seilacher, 1956; Crimes and Anderson, 1985; Gamez Vintaned *et al.*, 2006). It is also reported from the Tethys Himalaya (Table 2).

***Ichnogenus Monocraterion* Torell, 1870**

***Monocraterion* isp.**

(Pl. III C and D)

Repository ref. NG/SK-13/44

Material: Two specimens with full relief within fine-grained sandstone.

Description: Knob-like circular structure projecting downward, perpendicular to the bedding plane, never branched. The center of burrow is deep and unornamented; two circular rings are present; one central and other marking the outline of the burrow. The diameter of the outer ring is 3 to 4.5 cm and up to 1.5 cm deep, while the inner circle is 1.8 to 2.3 cm in diameter and up to 0.5 cm deep.

Remarks: The specimen shows close resemblance with the ichnogenus *Monocraterion* in terms of its cylindrical burrow and concordant funnel at the top. But present specimen is not so much deep and it also lacks the well-developed, funnel-like structure, which is a diagnostic feature of *Monocraterion* (Häntzschel, 1975). The specimen is also comparable with the ichnogenus *Bergaueria* but differs in the presence of circular rings. It is also reported from the Tethys Himalaya (Table 2).

***Ichnogenus Skolithos* Haldeman, 1840**

***Skolithos* isp.**

(Pl. III E)

Repository ref. NG/SK-13/36

Material: One slab of fine grained sandstone containing six burrows on the sole of bed.

Description: Vertical tubes perpendicular to the bedding plane, unbranched, circular, sub cylindrical burrows. The diameter of burrow is 0.3 to 0.5 cm with a mean value as 0.4 cm (N=5).

Remarks: The present form shows resemblance with the ichnogenus *Skolithos*. Hallam and Swett (1966) proposed that *Skolithos* tubes were made during the period of negligible sedimentation by the same animal that produces *Monocraterion* tubes by the upward movement due to influx of sand. It is widely reported from the Lesser Himalaya and Tethys Himalaya (Table 2).

***Ichnogenus Monomorphichnus* Dawson, 1873**

***Monomorphichnus lineatus*, Crimes *et al.*, 1977**

(Pl. III F)

Repository ref. NG/SK-13/28

Material: Two specimens preserved as hyporelief in fine-grained sandstone.

Description: Five sets of curved ridges arranged in a row. The gaps between the two consecutive ridges are 1 cm. The ridge is 5.4 cm long and is 3 mm in width. The specimen comprises of 4 to 5 curved ridges.

Remarks: The specimen is morphologically close to the *Monomorphichnus* Crimes, 1970. *M. lineatus* was originally described from the Lower Cambrian from N. Spain (Crimes *et al.*, 1977) which had 6-7 ridges but in the present forms the ridges are only upto 5. The form closely resembles with forms described from Boya Formation, Cassiar Mountain, Canada (Fritz and Crimes, 1983). It is also reported from Paseky Shale of Czech Republic by Mikulas (1995). It is suggested that the structure was formed by the sideways propagation of the animal (Häntzschel, 1975; Seilacher, 2007).

***Ichnogenus Monomorphichnus* Crimes, 1970**

***Monomorphichnus multilineatus* Alpert, 1976**

(Pl. IV A and B)

Repository ref. NG/SK-13/309

Material: Ten slabs of fine-grained sandstone having fifteen specimens preserved as positive hyporelief.

Description: Series of straight to curved prominent ridges in bundles, which are 4.0 cm long. The gap between the two consecutive ridges is 0.2 mm. The maximum number of ridge is 5-15 in a single bunch.

Remarks: The present specimens resemble with the *Monomorphichnus multilineatus* Alpert 1976. The specimen has also resemblance with *Monomorphichnus gregarius* (Pandey *et al.*, 2014) but in overall shape it is slightly bigger. The *Monomorphichnus* is identified by the presence of narrow ridges produced by the sideways propagation of the animal. The *Monomorphichnus* is regarded as swimming grazing traces (Crimes *et al.*, 1970). Jensen (1997) stated that both ichnogenera *Monomorphichnus* and *Dimorphichnus* may represent different behaviour with the same producer.

***Ichnogenus Dimorphichnus* Seilacher, 1955**

***Dimorphichnus cf. obliquus* Seilacher, 1955**

(Pl. IV C)

Repository ref. NG/SK-13/29

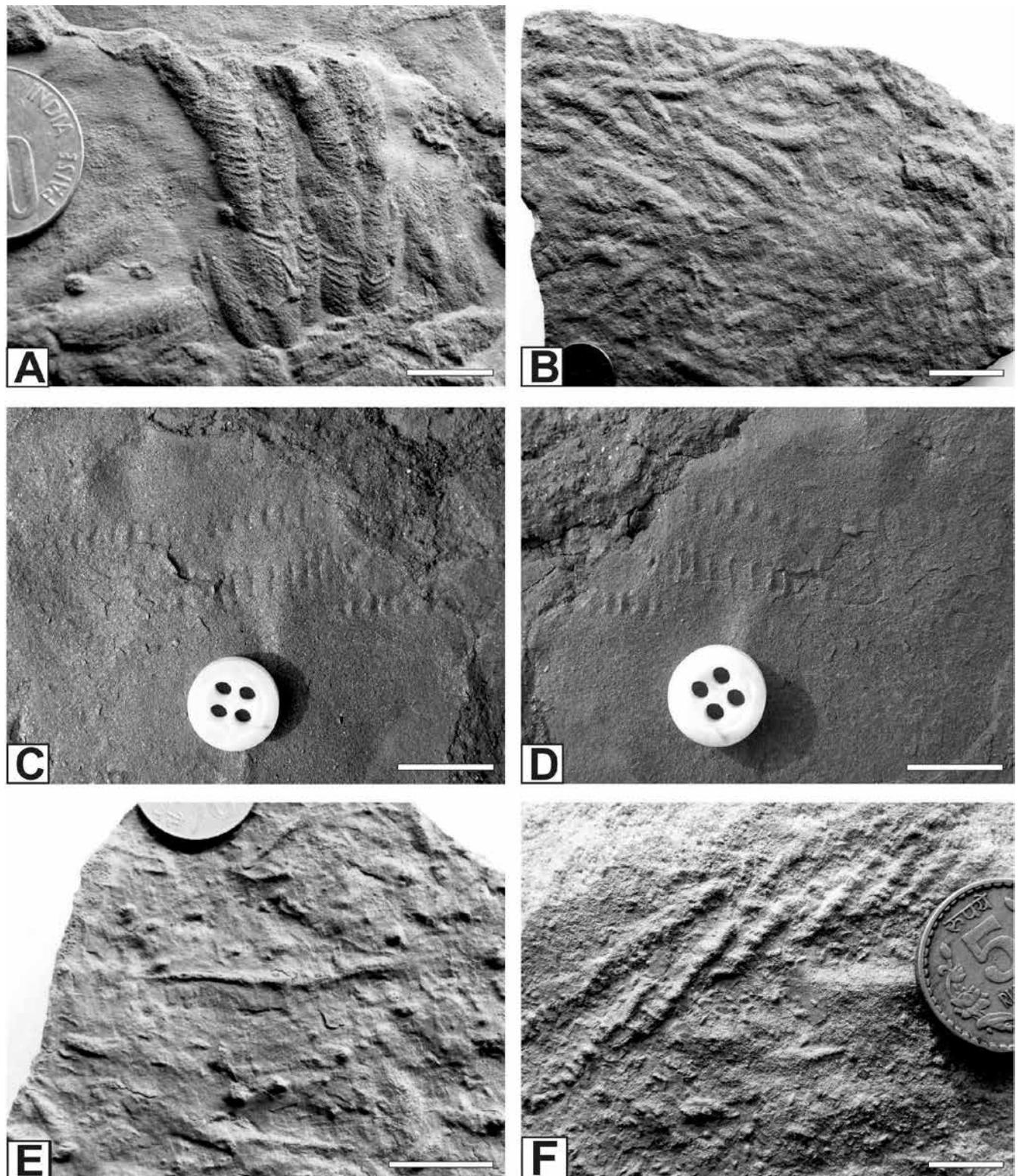
Material: One slab of fine grained sandstone with two specimens preserved as positive hyporelief.

Description: A pair of symmetrical trails horizontal to the bedding plane. The length of the structure is up to 1 cm and width 1mm, and is less than 1 mm apart from each other.

Remarks: The specimen described herein resembles *Dimorphichnus cf. obliquus* Seilacher (1955). According to Seilacher (1955), *Dimorphichnus* is a grazing trace formed by trilobites while scratching the sea bottom with appendages in search for food. This ichnogenus is also known from the Lower Cambrian succession of Wales (Crimes, 1970b), Lesser Himalaya (Tewari and Parcha, 2006), Zanskar Basin of Tethys

EXPLANATION OF PLATE II

Trace fossils reported from the Nagaur Sandstone, Dulmera area, Rajasthan. **A**) *Cruziana cf. salomonis* (Scale bar = 1 cm); **B**) *cf. Isopodichnus* isp. (Scale bar = 1 cm); **C**) *Diplichnites* preserved as negative relief (Scale bar = 1 cm); **D**) Counter part of C showing positive relief (Scale bar = 1 cm); **E**) *Planolites beverleyensis* (Scale bar = 2 cm) and **F**) *Planolites annularis* (Scale bar = 1 cm).



Himalaya (Parcha and Singh, 2010), Krol-Tal succession of Lesser Himalaya (Singh and Rai, 1983). The specimen is showing close resemblance with the form reported by Hofmann *et al.* (2012) from Jordon.

Ichnogenus Chondrites von Sternberg, 1833

Chondrites isp.

(Pl. IV D)

Repository ref. CH/SK-13/34

Material: Single slab of fine grained sandstone with specimen preserved on the top of the bed.

Remarks: Kumar and Pandey (2010) have described the form which resembles in all respect *Chondrites* von Sternberg. It undoubtly belongs to the fodinichnia and is to be regarded as a feeding structure of animals (Seilacher, 1955; Osgood, 1970) and not a dwelling burrow of filter-feeding annelids (Osgood, 1970).

Ichnogenus Treptichnus Miller, 1889

Treptichnus pedum Seilacher, 1955

(Pl. IV E and F)

Repository ref. NG/SK-12/05

Material: The specimen preserved as a positive hyporelief in fine-grained sandstone. Two slabs having four specimens were collected.

Remarks: Srivastava (2012a) was first to describe this form from the Dulmera area. Subsequently, Pandey *et al.* (2014) redescribed it from the same locality. The form occurs in association with *Bergaueria* and *Rusophycus*. On the basis of its diagnostic characteristic of feather-stitch like arrangement of segments, the present specimen appears close to ichnogenus *Treptichnus* Miller, 1889. The burrow probably produced by the sediment-feeding animal (Häntzschel, 1975). The present burrow system *Treptichnus* is interpreted as fodichnion made by vermiciform animals (Buatois *et al.*, 1998). The specimen shows some comparison with the *Phycodes palmatum* by Seilacher (1955) (Salt Range, Pakistan). Parcha and Pandey (2011) considered *Treptichnus* in Phylum Annelida. Now, *Phycodes pedum* is considered as *Treptichnus pedum* (Seilacher, 2007).

Ichnogenus Palaeophycus Hall, 1847

Palaeophycus tubularis Hall, 1847

(Pl. V A and B)

Repository ref. NG/SK-13/40

Material: One specimen preserved as full relief on the bedding surface in fine grained sandstone.

Description: Horizontal to the bedding plane, cylindrical in outline, solid, infilled with host rock. Straight to slightly curved, unbranched and smooth body wall. The dimensions of the structure are 1.6 cm (longer axes) in diameter, 12.5 cm in length. Width varies from one end to the other end, maximum width recorded at the middle part (2.6 cm) and tapering at the posterior end.

Remarks: Morphologically, it resembles the *Palaeophycus* Hall, 1847. The structure is interpreted as the result of dwelling activity of the animal. The present form is quite large and bulbous in outline. It is also comparable with the form reported from the Tethys Himalaya by Parcha and Pandey (2011) but the present form does not show any striae on the body wall.

Ichnogenus cf. Lockeia James 1879

Ichnospecies: cf. *Lockeia* isp.

(Pl. V C)

Repository ref. NG/SK-13/45

Material: Four specimens preserved as epirelief in fine grained sandstone and siltstone.

Remarks: Pandey *et al.* (2014) have described this form from the Dulmera area. The morphology of the specimen resembles ichnogenera *Lockeia*. Most of the workers have interpreted these structures as resting traces of bivalves (Seilacher, 1953, Osgood, 1970, Hakes, 1977). Small crustaceans are also potential producers of *Lockeia* (Bromley and Asgaard, 1979; Pollard, 1981).

Form "A" (Needle-like burrow)

(Pl. V D)

Repository ref. NG/SK-13/35

Material: Twenty six specimens preserved as hyporelief in fine grained sandstone.

Description: Small, needle-like, uniform, epichinal cast ranging from 0.3 cm to 1.0 cm in length; 0.1 cm in width. These structures are randomly arranged.

Remarks: These structures show resemblance with forms reported as exichnial and hypichnial cast of horizontal burrows by Crimes (1970a). Small needle-like burrows may indicate the size of the animal.

Form "B" (Horizontal Burrow)

(Pl. V E)

Repository ref. NG/SK-13/34

Material: Three slabs with randomly oriented specimens preserved as positive relief in fine-grained sandstone.

Description: Randomly arranged, horizontal to the bedding plane, varying in size. Length 3 to 4 cm, width up to 0.4 to 0.8 cm. These structures are tapering at both ends.

Remarks: The present specimen closely resembles the burrow morphology shown by Crimes and Harper (1970). The morphology of these burrows is straight and tapering at both ends while in other forms like *Palaeophycus* and *Planolites* it is curved.

Form "C" (Animal escape structure)

(Pl. V F)

Repository ref. NG/SK-13/33

Material: Two specimens preserved in fine grained sandstone.

Description: Vertically perpendicular to the bedding plane depicting "U"-shaped morphology. The burrow structures are 3.8 cm in depth and 1.7 cm in width. There are 7 to 8 concentric "U"-shaped lines in 1 cm. Both limbs of the burrow are parallel. The distance between the limbs at the surface is less than 1 cm.

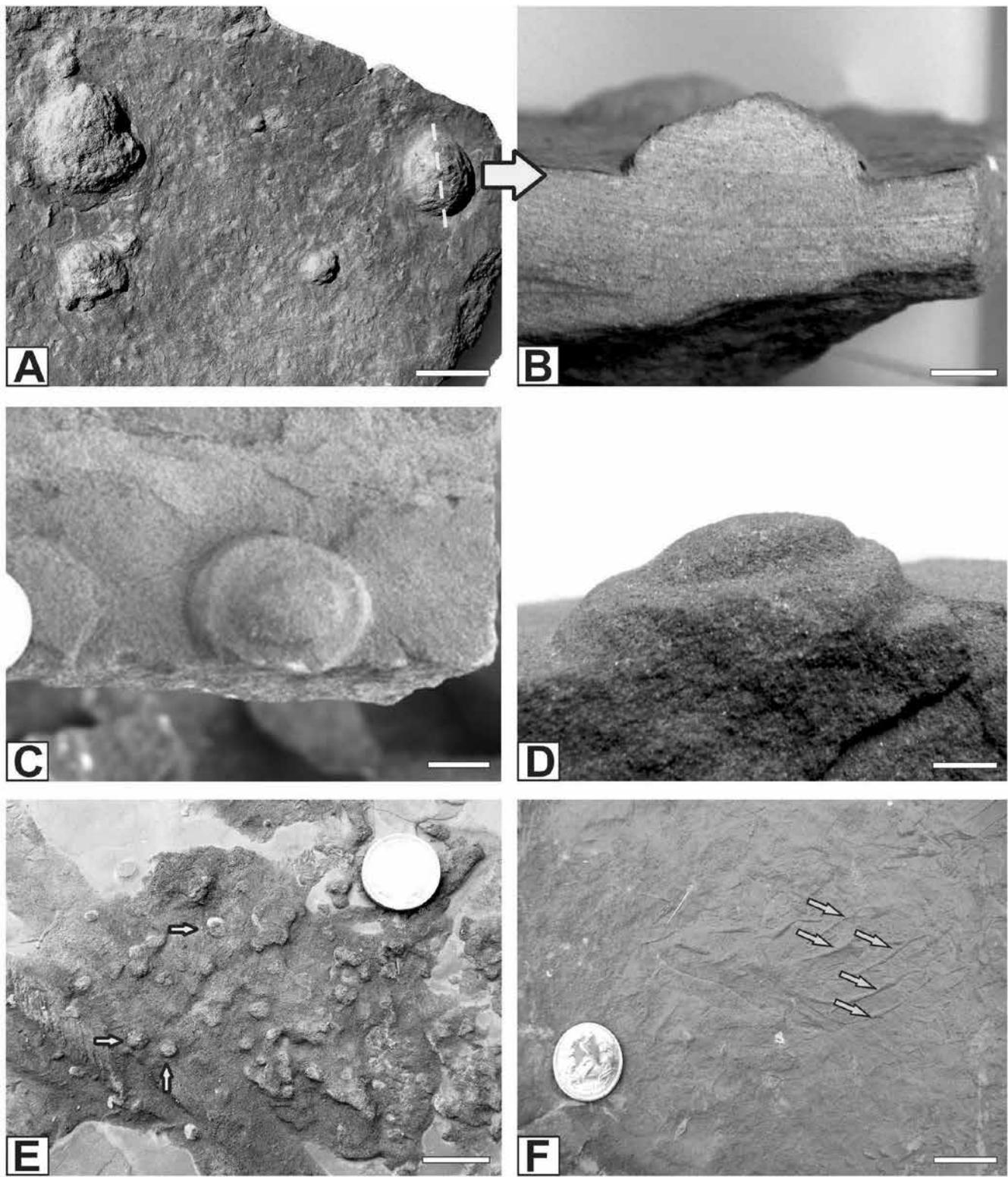
Remarks: The present structure is formed by hideaway activity of the animal during its life span. The specimen resembles *Diplocraterion* Torell (1870) but lacks a typical "U" shaped burrow without any opening structure at the bedding plane. It closely resembles the structure known as animal escape structure reported by Hofmann *et al.* (2012).

Form "D" (Tubular burrow)

(Pl. VI A and B)

EXPLANATION OF PLATE III

Trace fossils reported from the Nagaur Sandstone, Dulmera area, Rajasthan. A) *Bergaueria* aff. *perata* (Scale bar = 2 cm); B) *Bergaueria* aff. *perata* in cross section view (Scale bar = 1 cm); C) *Monocraterion* isp. in a plan view (Scale bar = 1 cm); D) *Monocraterion* isp. showing concordant funnel like structure (Scale bar = 1 cm); E) *Skolithos* isp (Scale bar = 2 cm) and F) *Monomorphaichnus lineatus* (Scale bar = 2 cm).



Repository ref. NG/SK-13/36

Material: A single slab containing 60 forms, preserved as positive relief in fine grained sandstone on the sole of the bedding plane.

Description: Randomly distributed, medium to small worm-like burrows, length ranges between 0.2 to 1.9 cm, while width varies from 0.1 to 0.3 cm; the specimens are 0.2 cm in height. Both ends of the structure are curved and rounded. Out of sixty, 25 specimens relatively of bigger size while rest are smaller in size.

Remarks: Possibly, this structure could be a burrow formed by worm-like animals.

Scratch marks

(Pl. VI C)

Repository ref. NG/SK-13/42, 42, 44 and 45

Material: Ten specimens of fine grained sandstone collected as positive relief from the sole of bedding plane.

Description: Even spaced deep imprints, comb shaped, generally straight, sometime curved with very prominent ridges from 2.0 to 3.5 cm long and 1 mm in width. The distance between the two consecutive imprints is 0.2 cm. The fingerprint like imprints possessing 4 to 5 divisions/cm.

Remarks: The structures show close resemblance with the scratch marks possibly produced by arthropods. These structures are formed by digging activity of the animal. These have also been described as trilobite finger prints by Seilacher (2007). Possibly, the scratch marks/fingerprints are left by the tips of the endopodites displaying groupings of claws or setae. These specimens also show similarity with the dig mark of one lobe produced by trilobite (Crimes and Harper, 1976).

Tunkliyan Sandstone Trace Fossils

Only a few burrows and scratch marks have been identified in the Tunkliyan Sandstone.

Burrows

(Pl. VI D)

Repository ref. TNK/SK-12/36

Material: Six slabs of sandstone comprising twelve specimens preserved as hyporelief on the sole of the bedding.

Description: Small tubular burrow, horizontal to the bedding plane, spindle shaped, smooth wall. Specimens randomly preserved. Burrow width maximum at the middle part varying from less than 0.1 to 0.2 cm; 0.4 to 1 cm in length.

Remarks: The present structure depicts the burrow morphology which is similar to forms reported from the Nagaur Sandstone (Kumar and Pandey, 2010); however, the difference is that these forms are small and straight, whereas the burrow forms reported earlier from the Nagaur Sandstone are slightly larger and curved in nature.

Scratch marks

(Pl. VI E)

Repository ref. TNK/SK-12/16

Material: Four specimens collected from the Tunkliyan Sandstone preserved as positive hyporelief.

Description: Specimen shows a large number of scratch marks which are randomly preserved. The width of the scratch mark is 0.4 to 0.7 cm, while individually it is up to 0.2 cm wide and a length of scratch marks 2.5 cm. The consecutive gap between the podial marks is 0.1 cm.

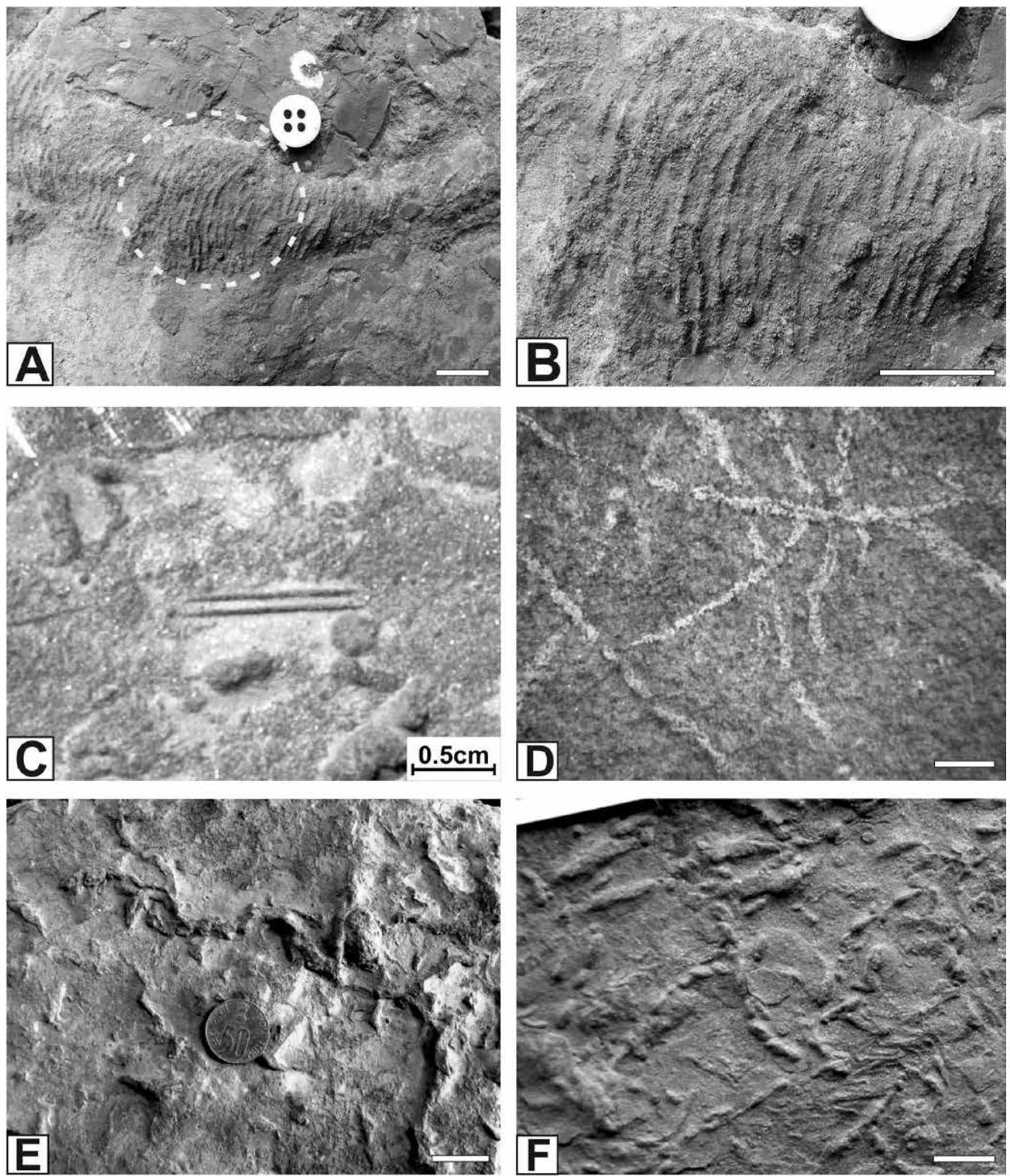
Remarks: Morphologically, the specimens are close to scratch marks produced by trilobite. The podial markings are in ascending order. The present specimen is similar to the scratch marks reported from the Nagaur Sandstone by Kumar and Pandey (2010).

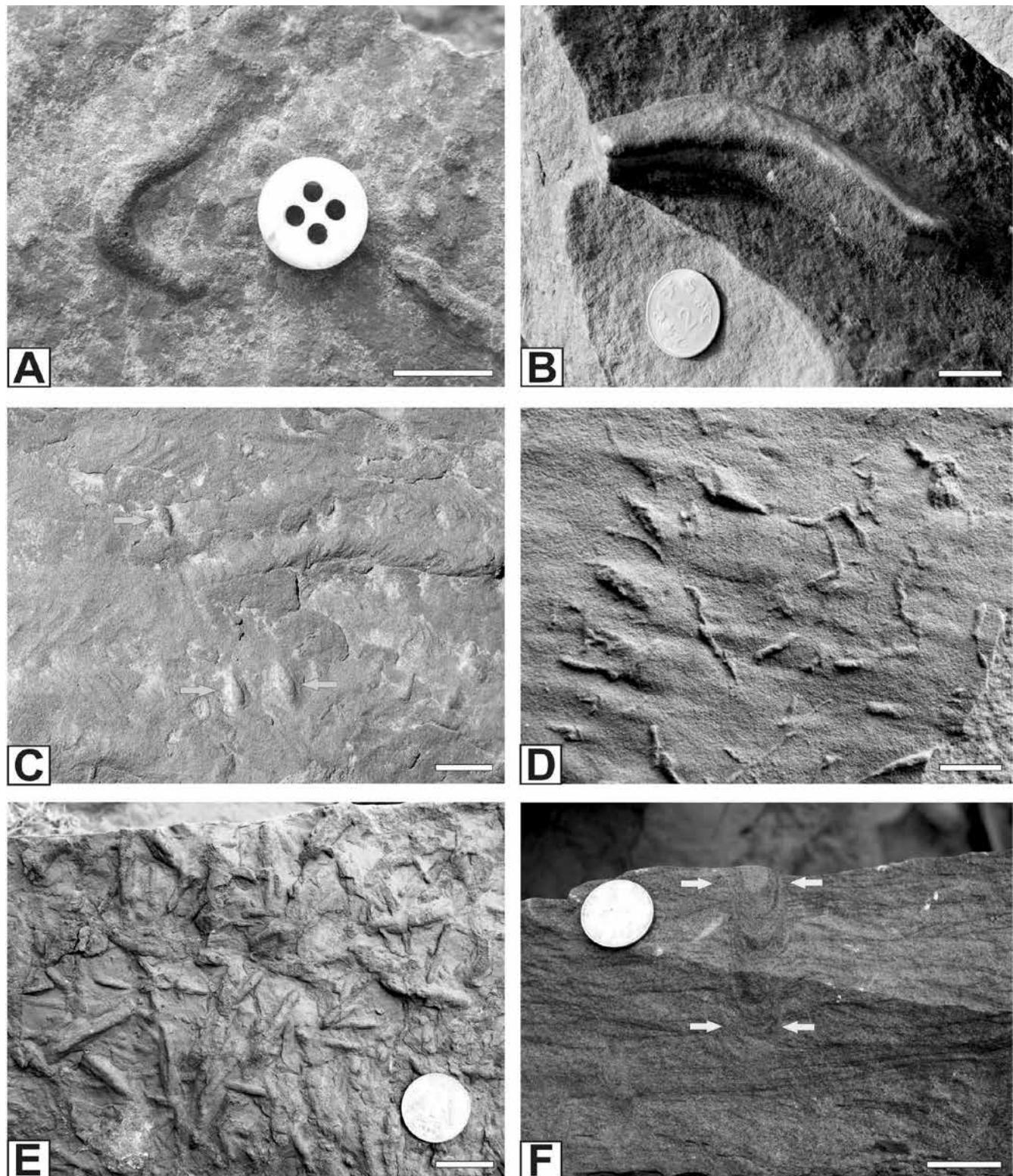
DISCUSSIONS AND CONCLUSIONS

1. The paper describes 18 ichnospecies belonging to the 14 ichnogenera, 5 types of burrow structures and 2 types of scratch marks. They have been classified on the basis of behavioral pattern. The fossil assemblage reflects mostly *Fodinichnia* (Feeding structure) followed by *Cubichnia* (Resting trace of trilobites), *Repichnia* (Crawling trace), *Pascichnia* (Grazing trace), *Domichnia* (Dwelling Structure) and walking traces etc (Fig. 3). The ichnofossils assemblage of Nagaur Sandstone signifies the ichnocenosis is dominated by high behavioral diversity from suspension feeder to deposit feeders.
2. The *Cruziana* and *Rusophycus* ichnofossils are oriented in a particular direction and their impressions are very prominent on bedding planes. It appears that these creatures used the energy of water current for locomotion in search of food.
3. Presence of *T. pedum* in the Nagaur Sandstone suggests its age as Lower Cambrian but could not mark the Pc-C boundary as the first appearance of *T. pedum* is still not known in the Dulmura Mine section. Moreover, the recent study reveals that the understanding of environmental distribution and ecological tolerance of *T. pedum* is significant in critically assessing its value and potential as a fossil guide for the Ediacaran-Cambrian boundary (Buatois *et al.*, 2013). It appears that there is a possibility that the Pc-C boundary may lie within the Nagaur Sandstone (see fig. 2 A).
4. Morphology of the specimens suggests that most of the structures are formed by the activity of arthropod (mostly trilobite), while the trail marks are formed by various vermiform and priapulid worms. Such an enormous variety of life signatures draw the attention towards the palaeoecological condition, including the availability of oxygen and nutrient influx.
5. The present fossil assemblage supports very close correlation with the Tal Formation of Lesser Himalaya and Tethys Himalaya region (Table 2). The Tethys Himalayan formations are represented by the Garbyang Formation, Kunzum-La Formation, (Spiti Valley), Zanskar Region and Lolab Formation (N-W part of Kashmir Himalaya). It can also be correlated with the Magnesian Sandstone, Salt Range (Pakistan).
6. Pandey *et al.* (2014) suggested that the age of Nagaur Sandstone as Stage 2 (upper part of Terreneuvian), while the age of Tal Formation (Lesser Himalaya) ranges from upper Tommotian-Lower Atdabanian age (Rai and Singh, 1983). The present fossil assemblage has close resemblance with the fossil assemblage of Tal Formation, which implies that the age of the present finding may also range from Tommotian-Lower Atdabanian. Thus the age can be bracketed between Stage 2 and Stage 3 of Cambrian.

EXPLANATION OF PLATE IV

Trace fossils reported from the Nagaur Sandstone, Dulmura area, Rajasthan. **A**) *Monomorphichnus multilineatus* encircled by dotted lines (Scale bar = 1 cm); **B**) Magnified view of A (*Monomorphichnus multilineatus*) (Scale bar = 1 cm); **C**) *Dimorphichnus cf. obliquus* (Scale bar = 0.5 cm); **D**) *Chondrites* isp. (Scale bar = 2 cm); **E** and **F**) *Treptichnus pedum* (Scale bar for E = 2 cm and for F = 1 cm).

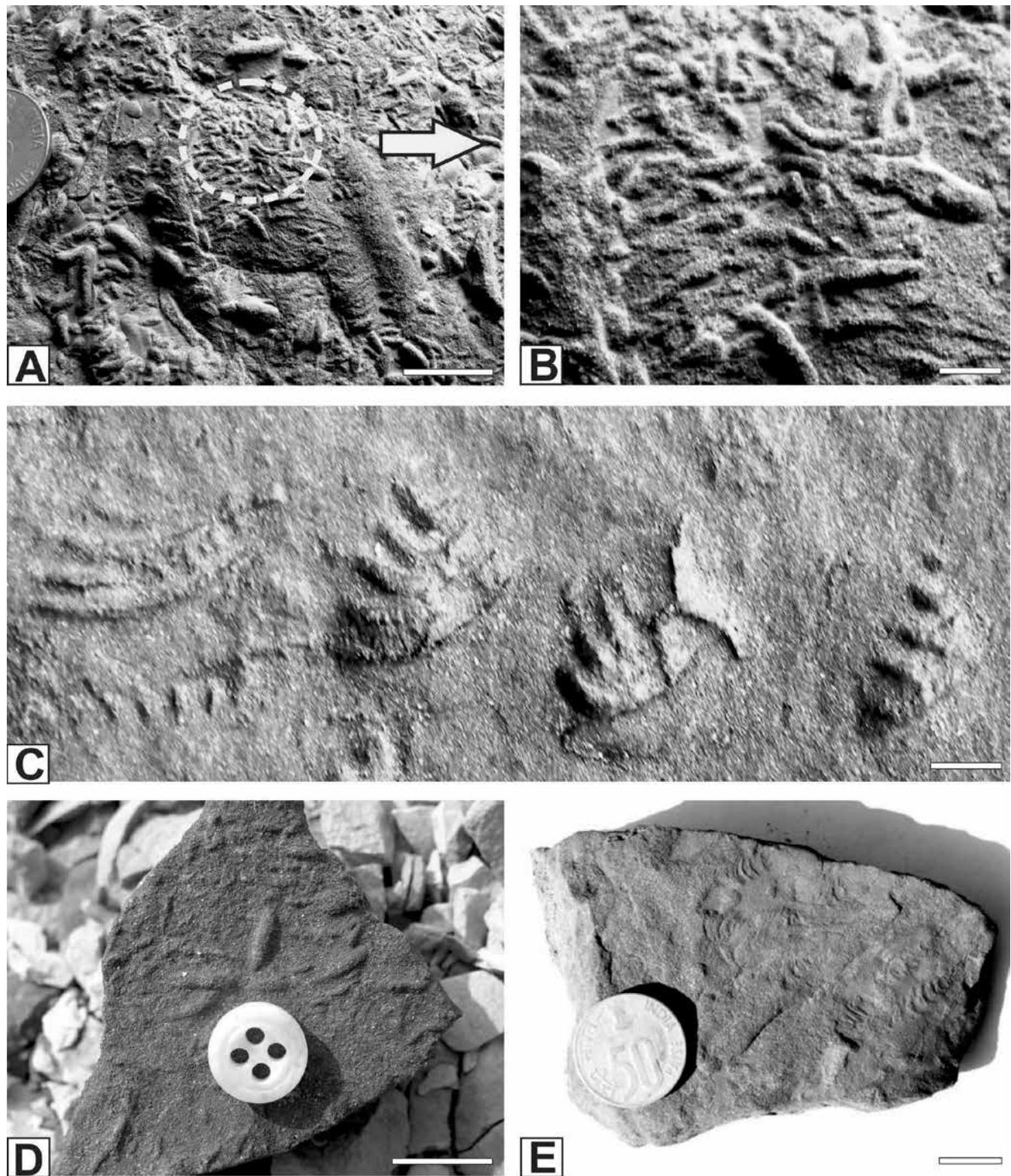




AHMAD AND KUMAR

EXPLANATION OF PLATE V

Trace fossils reported from the Nagaur Sandstone, Dulmura area, Rajasthan. **A** and **B**) *Palaeophycus tubularis* (Scale bar for A= 1 and for B = 2 cm); **C**) cf. *Lockeia* (Scale bar = 1 cm); **D**) Form "A" Needle like burrow (Scale bar = 1 cm); **E**) Form "B" Horizontal burrow (Scale bar = 2 cm) and **F**) Form "C" Animal escape structure (Scale bar = 2 cm).



AHMAD AND KUMAR

EXPLANATION OF PLATE VI

Trace fossils reported from the Nagaur Sandstone, Dulmera area, Rajasthan. **A** Form "D" Tubular burrow (the dotted circle marks the smaller forms), (Scale bar = 2 cm); **B** Magnified view of tubular burrow (smaller form) (Scale bar = 0.5 cm); **C** Scratch marks from Nagaur Sandstone (Scale bar = 0.5 cm); **D** Small burrows reported from Tunkliyan Sandstone (Scale bar = 1 cm) and **E** Scratch marks reported from the Tunkliyan Sandstone (Scale bar = 2 cm).

Table 2: List of Cambrian trace fossils in different stratigraphic horizons from Indian Subcontinent.

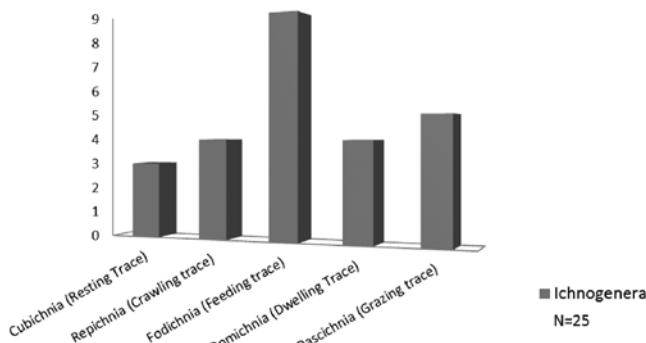


Fig. 3. Histogram of behavioural trends of trace fossils.

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2ND PROF. R.C. MISRA MEMORIAL LECTURE AND 3RD PROF. R.C. MISRA LIFETIME ACHIEVEMENT AWARD

2nd Prof. R. C. Misra Lecture was delivered on 28th November, 2014 by Padma Shri Prof. K. S. Valdiya, FNA, Honorary Professor of Geodynamics at Jawahar Lal Nehru Centre for Advance Scientific Research, Bangalore on “Effective Endeavours for unity of People of India in Puraan times: Role of Geology” in the Centre of Advanced Study of Geology, University of Lucknow, Lucknow. He was also conferred upon the 3rd Prof. R. C. Misra LifeTime Achievement Award by Dr. S. B. Nimse, Vice Chancellor, University of Lucknow.

