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TRACE FOSSILS AND MICROBIALLY INDUCED SEDIMENTARY STRUCTURES FROM THE EARLY CAMBRIAN SUCCESSIONS OF THE CHANDRATAL AREA, SPITI BASIN, TETHYS HIMALAYA

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ABSTRACT

Trace fossils and microbially induced sedimentary structures are documented from the Early Cambrian succession of the Chandratal section in the Spiti Basin for the first time. The marine succession contains different trace fossil assemblages representing mainly horizontal and branched structures that mostly belong to arthropods, annelids and polychaets. The trace fossils include *Chondrites, Dimorphichnus, Diplichnites, Monomorphichnus,, Palaeophycus, Planolites,* and *Skolithos* along with some burrows and scratch marks. These trace fossils are preserved in shale, siltstone and sandstone, whereas microbially induced structures are preserved below the trace-fossil horizon in fine-grained sandstone. Microbially induced sedimentary structures occur in patches on the bedding planes. The described trace fossils reflect the presence of suspension and deposit feeding animals in response to changing environmental conditions. Their complexity signifies environments oscillating between subtidal and intertidal. In the basal unit of succession, the presence of microbially induced mats in the fine-grained sandstone indicates lack of grazing activity of organisms and a shallow marine environment within photic zone.

Keywords: Tethys Himalaya, Cambrian, Trace fossils, microbially induced sedimentary structures, Spiti Basin

INTRODUCTION

The Spiti Basin exposes Tethyan sedimentary succession ranging in age from Late Proterozoic to Cretaceous. The Neoproterozoic Batal Formation overlies the Crystalline basement and gradually grades upwards into the Early and Middle Cambrian of the Kunzum La Formation. The Early Cambrian succession of the Spiti Basin contains numerous trace fossils and is very useful in interpreting the palaeoecological and palaeoenvironmental conditions. The present studies were carried out in the Chandratal-Kunzum La road side section (Fig.1). Earlier, Bhargava and Srikantia (1985) reported some trace fossils from the upper part of the Debsakhad Member of the Kunzum La Formation exposed in the eastern Lahual Valley. Various workers have reported trace fossils from other sections of the Spiti Basin (Bhargava and Bassi,1988; Sudan *et al*., 2000; Sudan and Sharma, 2001; Parcha, 1996, 1998, 1999; Parcha *et al*., 2005 and Parcha and Pandey, 2011). The trace fossils identified from different lithounits of the Chandratal section in the present study are shown in Fig. 2. So far no body fossils have been reported from this section. The presence of microbially induced sedimentary structure (MISS) is reported for the first time from this section as well as from the entire Spiti Basin. In the present study the taxonomy, ethology, stratigraphic distribution and environmental significance of trace fossils as well as of microbially induced structures of the Chandratal section are discussed.

GEOLOGICAL SETTING AND STRATIGRAPHY

The Spiti Basin lies in between the Dhauladhar Himalayan range in the south and the Zanskar Range in the north. The basin represents a remarkably thick marine sedimentary succession ranging in age from the Neoproterozoic to the Cretaceous. The sedimentary succession is exposed in Chandratal- Kunzum La – Takche section and in the Pin – Parahio valley of the Spiti Basin. The basal part of this succession is represented by the Haimanta Group, which rests on the Crystalline rocks of the Vaikrita Group. The Haimanta Group ranges in age from Neoproterozoic to Cambrian. Srikantia (1981) adopted the term Haimanta Group and divided it into the Batal, Kunzum La and Thango formations. Bhargava *et al*. (1982) excluded the Thango Formation from the "Haimanta Group" due to an unconformity which is present between the Kunzum La and Thango formations. Kumar *et al*. (1984) and Srikantia and Bhargava (1998) grouped the Batal and Kunzum La formations in the Haimanta Group and the Thango Formation in the Sanugba Group (Table 1). Myrow *et al*. (2006) used the term Parahio Formation instead of Kunzum La Formation. However, Bhargava (2008a, b) kept the term Kunzum La Formation in place of the Parahio Formation, due to its mapability, which according to him, has been proved from Spiti to Kinnaur in the east and in Lahaul - Zanskar in the west. For this reason, the Kunzum La Formation has been retained in the present paper (Table.1).

SYSTEMATIC ICHNOLOGY

Seven ichnogenera along with scratch marks and burrows are described. The binominal system with alphabetical order has been followed to describe the trace fossils. Most of the specimens are *in situ*.

Ichnogenus ***Chondrites*** Von Sternberg*,* 1833
(Type *Ichnospecies*: *Fuciodes antiquus* Brongniart, 1828)

Diagnosis: Tunnel system possessing a small number of master shafts open to the surface, which ramify with depth to form a branching network. The branching angle does not interpenetrate nor cross over. Annelids, polychaetes and arthropods have been considered as a possible tracemaker of *Chondrites* (Abbassi, 2007).

Chondrites isp.
(Fig. 3 A)

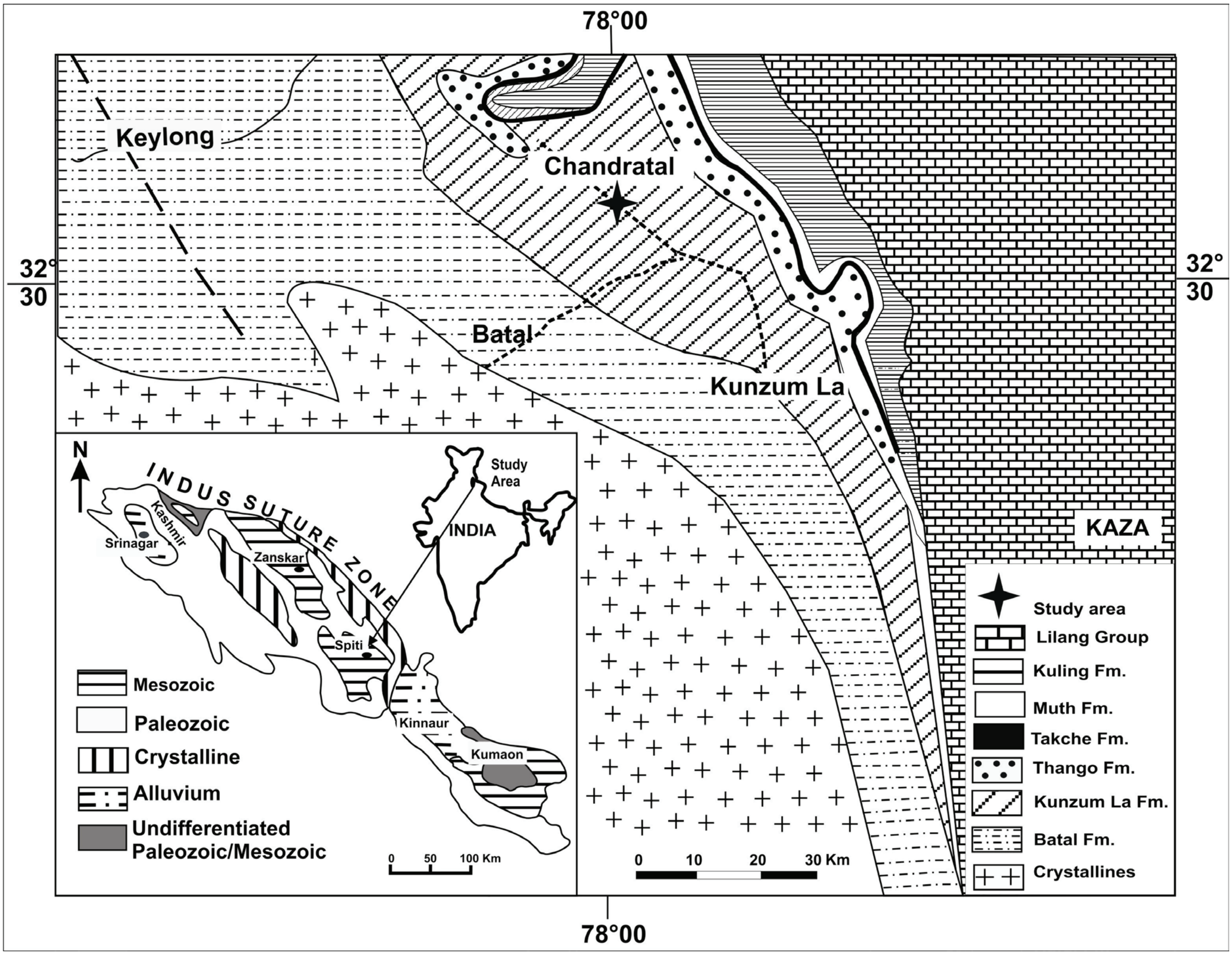

Fig.1. Geological map of the Chandratal section in the Spiti Basin. Inset showing different sedimentary basins in the Tethys Himalaya.

Material: *In situ* specimen preserved in siltstone as negative epirelief.

Description: System of tunnels with second order of branching. The branches form sharp angles and show a branching pattern on the bedding plane. Burrows are filled with dark argillaceous material. Burrows do not cross each other nor anastomose. The maximum length of the tunnel is 2.2 cm and the diameter is 0.4 cm which is constant throughout.

Remarks: The present specimen resembles the ichnogenus *Chondrites* on the basis of ramifying tunnel structure. *Chondrites* is regarded as a feeding structure (fodinichnia). The described specimen shows some resemblance with *Chondrites* reported from the Bay Formation, South Georgia, by Macdonald (1982), in the dendritic pattern. However, our specimen differs in lacking third order branching.The present specimen differs with the ichnogenus *Chondrites* described from Rajasthan by Kumar and Pandey (2010) and from Parahio Valley by Parcha and Pandey (2011) in the dendritc pattern. Seilacher (1955, 1990), Osgood (1970), Bromley and Ekdale (1984), Savrda (1998), and Abbassi (2007) opinion that these traces were produced mainly in dysaerobic and reducing settings and can be treated as feeding structure (fodinichnia). *Chondrites* mainly belongs

Table 1. Lithostratigraphic classification given by various workers for the Cambrian successions of the Spiti Basin.

Stoliczkai (1865)	**Griesbach (1891)**	**Hayden (1904)**	**Srikantia (1981)**	**Bhargava et.al. (1982)**	**Kumar et al. (1984)**		**Myrow et al. (2006)**	**Parcha and Pandey (2011b) and Present work**	
Bhabeh Series	Haimanta System	Cambrian System	Haimanta Group	Kunzum La Formation	Kunzum La Formation	Parahio Member	Parahio Formation	Kunzum La Formation	Parahio Member
						Debsakhad Member			Debsakhad Member
				Batal Formation	Batal Formation		Batal Formation	Batal Formation	

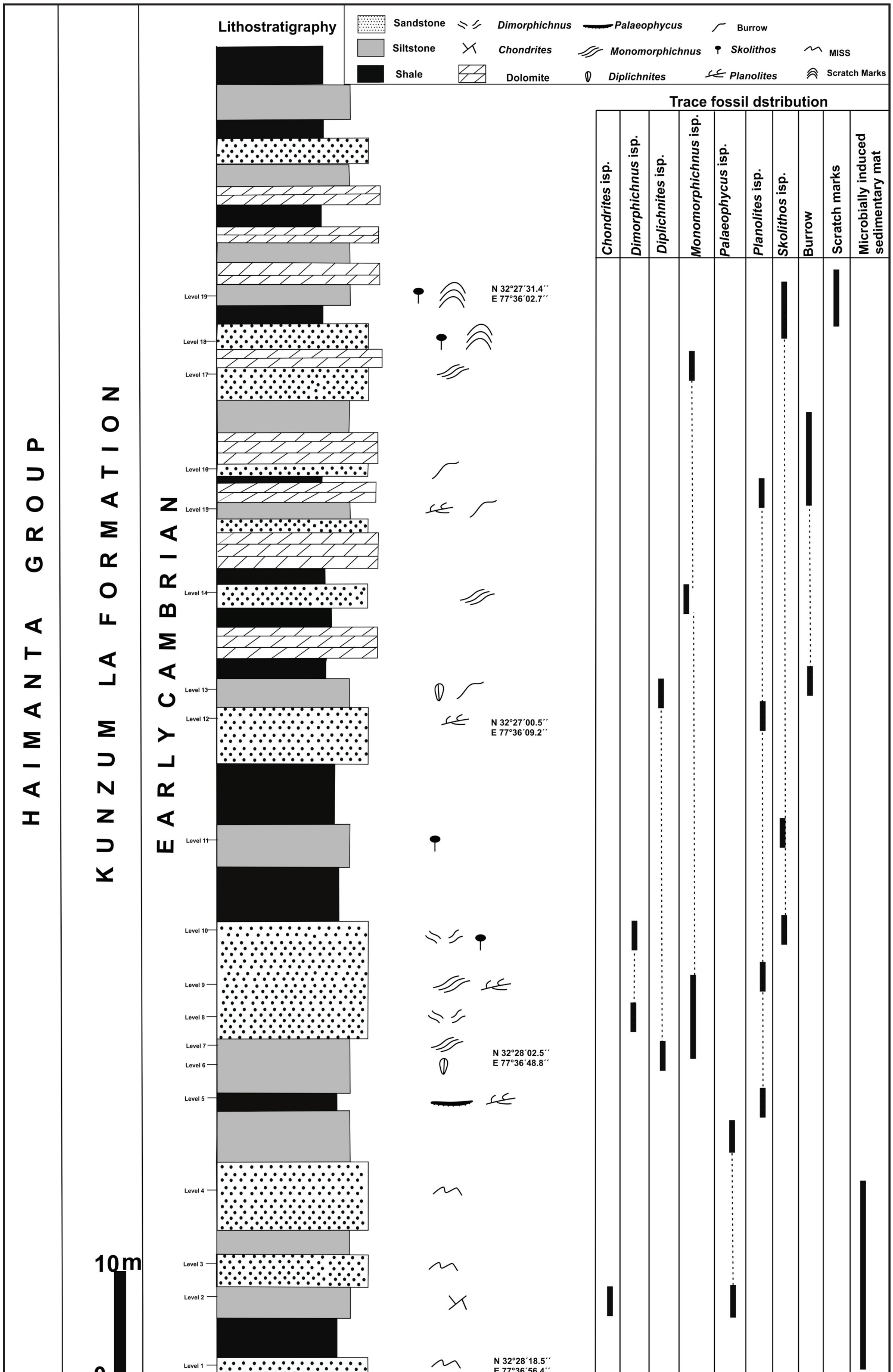

Fig. 2. Distribution of trace fossils in the early Cambrian succession of the Chandratal section.

to the composite trace fossil. Discrete feeding or dwelling trace like *Diplocraterion* and *Gyrolithes* are reworked by *Chondrites* (Bromley and Frey, 1974; Ekdale and Bromley, 1991). In all its morphological characters the present specimen shows close similarity with Ichnogenus *Chondrites*. Hence it has been grouped under this Ichnogenus.

Ichnogenus ***Dimorphichnus*** Seilacher, 1955
(*Type Ichnospecies*: *Dimorphichnus obliquus* Seilacher, 1955)

Diagnosis: A series of long track imprints made by the appendages of arthropods on the lee side of body; the legs of other side provide body support; thus these imprints resembles a series of small pits (Osgood and Drennen, 1975).

Dimorphichnus isp.
(Fig. 3 B a)

Material: Specimen preserved as positive hyporelief in sandstone.

Description: Comma shaped asymmetrical imprints composed of two set. Both types of claw are arranged in alternating series with variable size. One side claw is longer than the other one. The number of claw impressions are four. The width of individual claw marking varies from 0.2 to 0.3 cm and their length from 0.4 to 1.2 cm. Distance between the two individual imprints in one row varies from 1 to 1.3 cm, and distance between two parallel claws is nearly 1cm.

Remarks: The described specimen is grouped under the ichnogenus *Dimorphichnus* due to its close similarity in the nature and pattern of asymmetrical trackways. *Dimorphichnus* is a grazing trace formed by the activity of arthropods, scratching the sea bottom with their appendages (Seilacher, 1955, 1990; Crimes, 1970; Fillion and Pickerill, 1990). In some cases *Dimorphichnus* has been misinterpreted as *Monomorphichnus* due to the presence of one set of curved and sub- parallel ridges. However, Crimes (1970) and several other workers have discussed the distinction between these two ichnogenera.

Ichnogenus **Diplichnites** *Dawson, 1873*
(*Type Ichnospecies Diplichnite aenigma* Dawson, 1873)

Diagnosis: A series of isolated ridges with wide spacing mainly produced by arthropods.

Diplichnites isp.
(Fig. 3 C)

Material: Specimen preserved as positive hyporelief in siltstone.

Description: Well-preserved minute imprints in a single row; elongate to subcircular in shape and parallel to each other. The length of the individual marking varies from 0.5 – 0.7 cm and their width from 0.2 - 0. 3 cm. The distance between two parallel markings is 0.3- 0.6 cm.

Remarks: *Diplichnites* is a crawling trace, which is mainly produced by trilobites. The present specimen differs from *Diplichnites* isp. described from the Lesser Himalayas (Tiwari and Parcha, 2006), from Spiti (Parcha and Pandey, 2011) and from Zanskar Himalaya (Parcha, 1998; Parcha and Singh, 2010) in the absence of two parallel, equally spaced rows.

Ichnogenus ***Monomorphichnus*** Crimes, 1970
(*Type Ichnospecies*: *Monomorphichnus bilineatus* Crimes, 1970)

Diagnosis: *Monomorphichnus* consists of a series of ridges that may be repeated laterally, and which have been explained as leg imprints of swimming or grazing arthropods. It appears close to the base of the Cambrian (Narbonne *et al.*, 1987) and represents the earliest arthropod-type trace fossil.

Monomorphichnus isp. A
(Fig. 3 D, E, F and K)

Material: Specimen preserved in sandstone and siltstone as positive hyporelief.

Description: Three to four individual sets composed of three to five densely packed parallel ridges; straight to slightly bent ridges preserved as convex hyporelief. The ridges are arranged in distinct bundles. The minimum length of an individual ridge is 0.77 cm, whereas the maximum length is 1.6 cm, the minimum width of individual ridge is 0.2 cm and the maximum width is 0.4 cm. The distance between two parallel bundles of ridges varies from 1.2 to 1.8 cm and the distance between two individual ridges is greater than the width of an individual ridge. Ridges are slightly pointed towards one end.

Remarks: *Monomorphichnus* comprises a series of ridges that may be repeated laterally, and have been explained as leg imprints of swimming or grazing arthropods. It appears close to the base of the Cambrian and represents the earliest arthropod-type trace fossil (Narbonne *et al.*, 1987). The specimen shows close similarity with *Monomorphichnus* isp. A is described by Parcha and Pandey (2011) from the Parahio Valley in the densely packed parallel ridges. Both the forms are identical.

Monomorphichnus isp. B
(Fig. 3 B b, G – I)

Material: Specimen preserved in the sandstone bed as hyporelief.

Description: Deep straight to slightly comma-shaped parallel ridges, with length varying from 0.6 to 1.2 cm and width from 0.2 to 0.5 cm. Distance between two parallel ridges varying from 0.8 to 1.3 cm. Ridges are slightly pointed towards one end and the infilled material is the same as that of the host rock.

Remarks: The present specimen resembles *Monomorphichus* in having parallel ridges with a comma shape. The deep straight to slightly comma-like ridges show close similarity to *Monomorphichnus* isp. as described by Aceñolaza (2004) from the Cambrian succession of the Puncoviscana Formation of Argentina, but differs due to the presence of densely packed ridges. The illustrated specimen differs from the known species of *Monomorphichnus,* as well as from the above described *Monomorphichnus* isp. A in the pattern of ridges.

Ichnogenus ***Palaeophycus*** Hall, 1847
(*Type Ichnospecies*: *Palaeophycus tubularis* Hall 1847)

Diagnosis: Branched or unbranched, smooth or ornamented, lined essentially cylindrical, predominantly horizontal burrows of variable diameter, mostly structureless and filled with the same material as that of host rock (Pemberton and Frey, 1982).

Palaeophycus isp.
(Fig. 3 J and 4. A a)

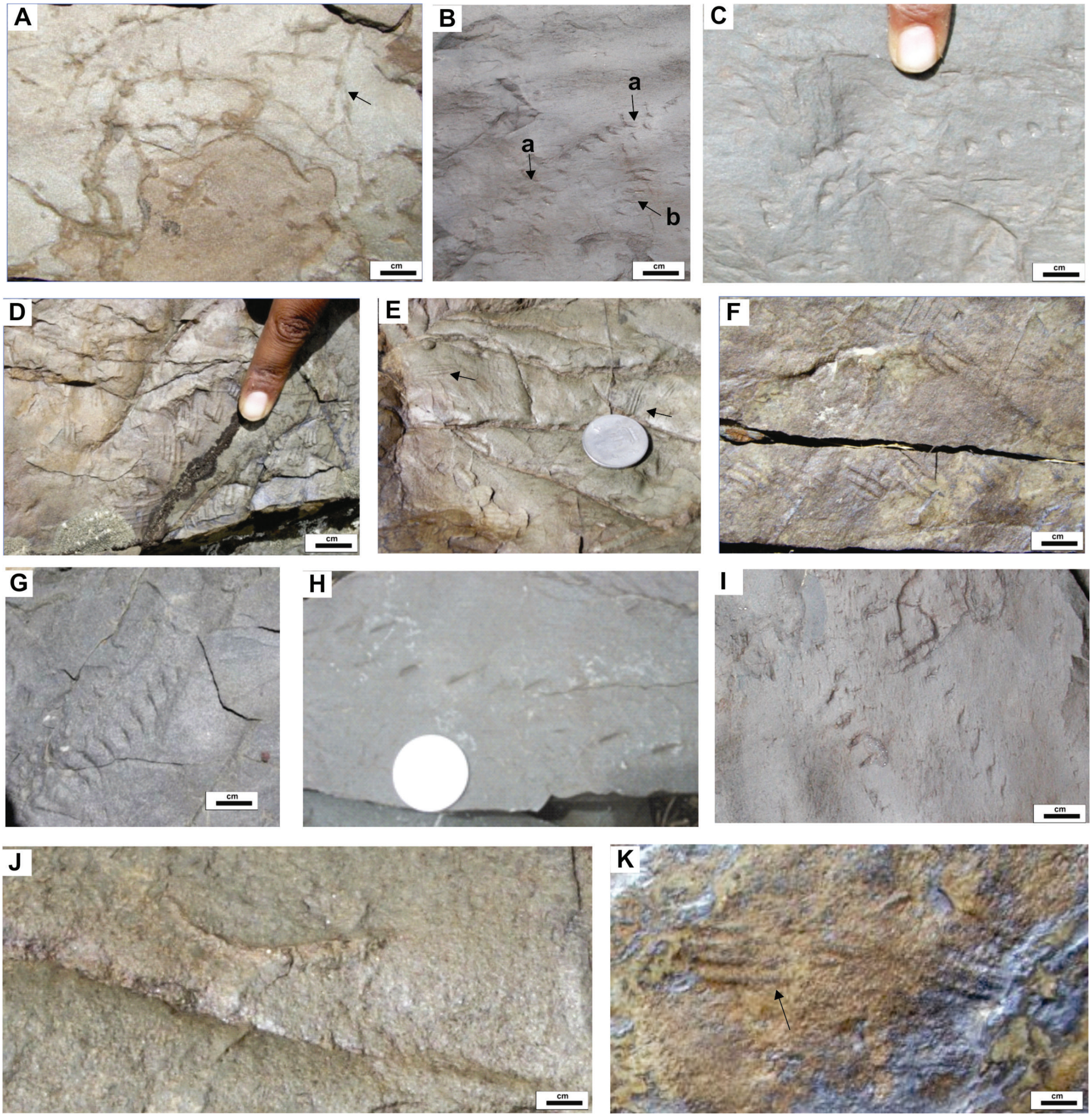

Fig. 3. Tracefossils from the early Cambrian succession of the Chandratal section. A, *Chondrites* isp. B a, *Dimorphichnus* isp. C. *Diplichnites* isp. D-F and K, *Monomorphichnus* isp. A., G- I, *Monomorphichnus* isp. B., J, *Palaeophycus* isp.

Material: Specimens preserved as full relief in shale and siltstone.

Description: Unbranched, cylindrical to subcylindrical burrow; surface of walls smooth, oriented more or less obliquely to bedding. The fill is massive and identical to host sediment. The specimen length varies from 2.3 to 2.8 cm and the width from 0.3 to 0.6 cm. The ichnogenera shows common type of burrow fill in open gallery system. In the entire section we could not get any specimen were we can have cross section preserved.

Remarks: *Paleophycus* is a lined burrow with lining thin or thick. Due to poor preservational quality the line structure are not clear in the present specimens, but it shows other morphological characters, which shows the closest similarity with the ichnogenus *Palaeophycus*. The distinction between *Palaeophycus* and *Planolites* has been described by Pemberton and Frey (1982), Fillion (1989), Fillion and Pickerill (1990). Pemberton and Frey (1982) and Keighley and Pickerill (1995) reviewed the controversies between *Planolites* and *Palaeophycus* and suggested that lined burrows can be grouped with *Palaeophycus*. *Palaeophycus* is a eurybenthic, facies-crossing trace produced probably by polychaetes or annelids (Pemberton and Frey 1982). The specimen shows

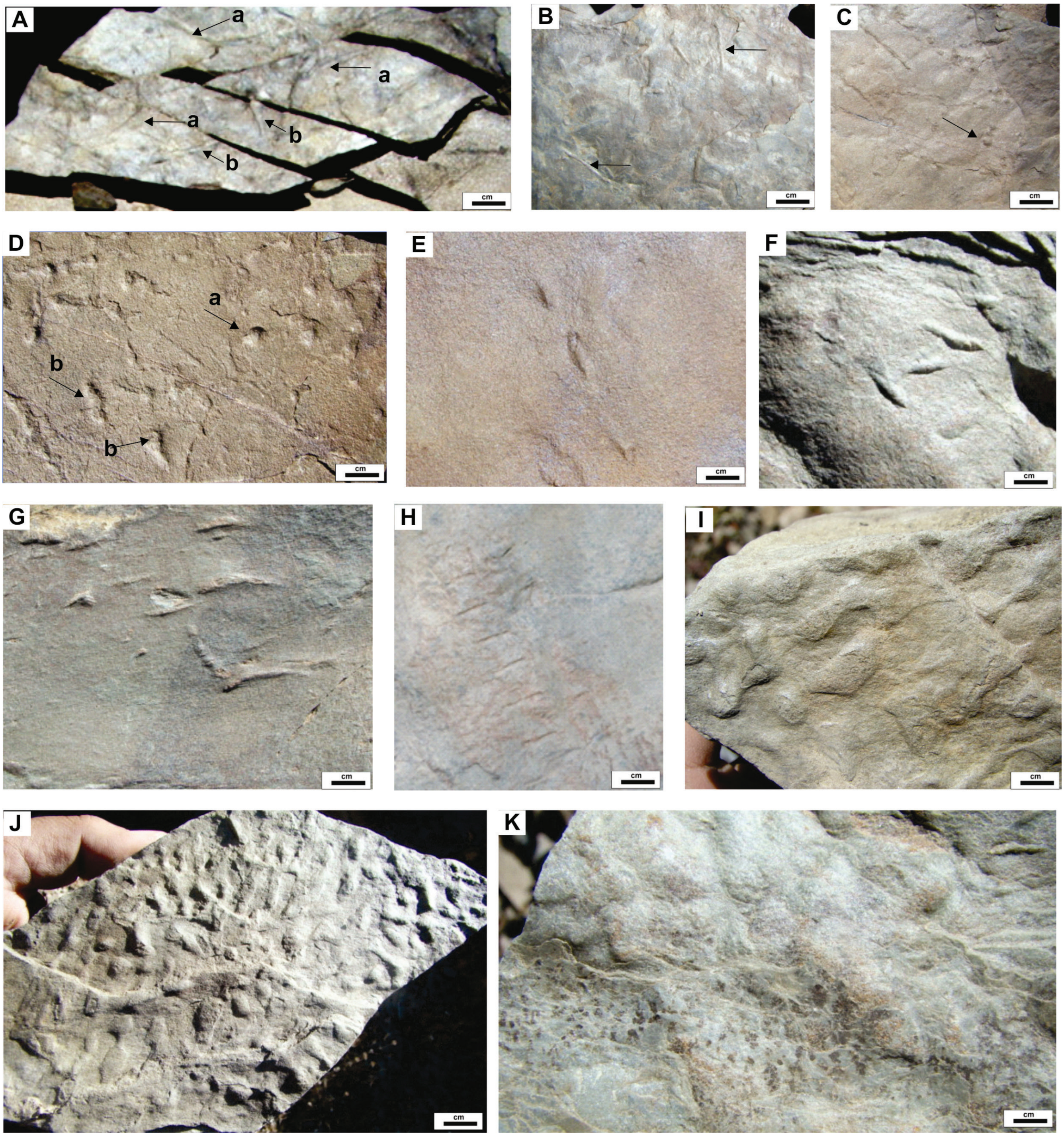

Fig. 4. Tracefossils from the early Cambrian succession of Chandratal section. A a, *Palaeophycus* isp. A b and B, *Planolites* isp. C and D a, *Skolithos* isp. D b, E and F, Burrow. G- H, Scratch marks. I- K, Microbially induced structure.

close resemblance to *Palaeophycus* in the outer morphological characters. *Palaeophycus* is regarded as a dwelling structure. The present specimen differs from *Palaeophycus* cf. *alternatus* reported by Pemberton and Frey (1982) and Gámez Vintaned *et al.* (2006**)** in the nature of constrictions.

Ichnogenus ***Planolites*** Nicholson, 1873

(*Type Ichnospecies*: *Planolites vulgaris* Nicholson and Hinde (1875) = (*Palaeophycus beverleyensis*) Billings, 1862).

Diagnosis: Unlined, rarely branching, straight to winding, smooth to irregularly walled, circular to elliptical in cross section and of variable dimensions; fill essentially structureless, mostly the same as the host rock but occasionally differing in lithology from the host rock (Pemberton and Frey, 1982; Fillion and Pickerill, 1990).

Planolites isp.
(Fig. 4 A b and B)

Material: Specimens are preserved in sandstone and siltstone as positive relief.

Description: Straight to slightly curved horizontal burrow, unbranched, unlined wall length of the individual burrow ranges from 1.2 to 2.3 cm and width from 0.3 to 0.6 cm. The burrow fill is identical to the matrix.

Remarks: Alpert (1975) gave a detailed analysis of *Planolites*. Pemberton and Frey (1982) suggested that a free moving, deposit -feeding organism could be responsible for *Planolites*. It is considered as a feeding structure, produced by a worm - like organism. The specimen somewhat resembles *Planolites corrugatus* Walcott (1889) in its outer features. The present form differs from *Planolites* isp. described by Parcha and Singh (2010) from the Zanskar Basin in the absence of curved and expande ends of the burrow and equally differs fromthe form described by Parcha and Pandey (2011) from the Spiti Basin.

Ichnogenus ***Skolithos*** Haldemann, 1840
(*Type Ichnospecies*: *Skolithos linearis* Haldemann, 1840)

Diagnosis: Subcylindrical, unbranched, lined or unlined, straight tubes or pipes perpendicular to bedding and parallel to each other. Burrow wall distinct or indistinct, smooth or rough, possibly annulated; burrow diameter may vary slightly along its length. Burrows fill structureless (Alpert, 1975).

Skolithos isp.
(Figs. 4 C and D a)

Material: Specimens are preserved in siltstone and in sandstone bed as full relief.

Description: Unbranched, with distinct burrow wall, with variable diameter of the tube, appears as vertical cylindrical to subcylindrical burrow on the bedding plane. The diameter of the burrow ranges from 0.4 to 0.7 cm. No vertical section has been observed in the present report.

Remarks: The present specimens are grouped under the ichnogenus *Skolithos* due to the presence of characteristic features much as subcylindrical. *Skolithos* is considered to be a dwelling burrow made by suspension-feeding vermiform organisms. It differs from *Monocraterion* Torell (1870) in lacking a prominent funnel- shaped aperture.. The specimen differs from *Skolithos* isp. described by Parcha and Singh (2010) from Zanskar and Parcha and Pandey (2011) from Parahio Valley.

Burrow
(Figs. 4 D b, E and F)

Material: Two specimens preserved in sandstone and one in siltstone bed.

Description: The specimens are straight to slightly curved, simple burrows with smooth surface. The length varies between 0.5 to 1.2cm and the width between 0.2 to 0.5 cm. Most likely a feeding structure produced by annelids, arthropods or polychaetes.

Scratch marks
(Figs. 4 G and H)

Material: Specimens preserved in siltstone as positive hyporelief.

Description: Straight to slightly curved ridges, parallel to the bedding plane; the infilled material is similar with the surrounding one. Ridges arranged in a row and of variable length (0.7 to 1.2 cm) and width (0.2 to 0.3 cm). The distance between two ridges varies between 0.8 and 1.3 cm. These marks are produced by grazing traces of trilobites or arthropods and are considered to be an isolated fragment of ichnogenus *Monomorphichnus.*

SIGNIFICANCE OF MICROBIALLY INDUCED SEDIMENTARY STRUCTURE

Along with the trace fossils, microbially induced sedimentary structures were also observed in the studied section which lie below the trace-fossil horizon. These structures are preserved in fine-grained sandstone. Microbially induced sedimentary structures (MISS) mostly formed in shallow marine settings by interaction of microbial mats with the physical dynamics of sediments. These structures exhibit a regular or irregular pattern. MISS have a distinctive morphology which represents changes in the depositional environment (Tang *et al*., 2011). Therefore, MISS can be used as an indicators of interaction between microbes and the depositional environment (Noffke *et al.*, 2001; Noffke, 2005, 2009; Noffke *et al.*, 2003, 2008; Shi *et al.*, 2008a, b). The present studied MISS exhibits an irregular pattern and occur as ridges with smooth, rounded to slightly curved tops of different sizes on the bedding plane (Fig. 4 I -K). The width of the individual ridge varies from 0.4 to 0.8 cm and the length from 0.7 to 1.3 cm. The sediment fill is identical to the host rock. They show similarity in structure and pattern with other reported MISS from the Vindhyan Supergroup by Banerjee and Jeewankumar (2005) as well as with the one reported by Chakraborty *et al.* (2012) from Rajasthan.

MISS have been reported by Hagadorn and Bottjer (1997) from Vendian - Cambrian strata of North America; by Noffke *et al.* (2006) from Upper Neoproterozoic rocks of South Africa; by Calner and Eriksson (2011) from Paleozoic strata of southern Sweden, and Tang *et al.* (2011) from siliciclastic Proterozoic rocks of southern North China. In India, Sarkar *et al.* (2006) reported MISS from Chorhat Sandstone, Vindhyan Supergroup; Banerjee and Jeewankumar (2005) from the Palaeoproterozoic Koldaha Shale, Central India; Kumar and Pandey (2007) from Neoproterozoic rocks of Rajasthan; and Chakraborty *et al.* (2012) from Mesoproterozoic of the Chhattisgarh and Khariar basins. Hagadorn and Bottjer (1997) stated that the presence of microbial mat structures along with trace fossils help to understand the interaction between the biota and early life. The presence of the MISS in the basal part of the early Cambrian succession is ascribed to the absence of grazing organisms during that time. The presence of microbial mats in the fine-grained sandstone reflects that deposition has taken place within the photic zone (Chakraborty *et al.*, 2012). The presence of these structures plays a significant role in order to understand the microbial processes present in the ancient siliciclastic facies.

STRATIGRAPHIC SIGNIFICANCE OF TRACE FOSSILS

The trace fossils described in the present study are useful as depth indicators for interpreting the palaeoenvironmental conditions. Seven ichnogenera have been reported from the Early Cambrian succession of the Chandratal section. The present trace fossil assemblage reflects diversified behavior (feeding, grazing and dwelling) with trails preserved in sandstone, siltstone and shale beds. Majority of the trace fossils represent trails and tracks on bedding planes. The benthic palaeocommunity preserved in the Chandratal section shows dominance of arthropods, annelid and polychaetes, all living principally within the sediments. The transition from an anaerobic to aerobic condition was distinctly marked by a faunal change from endobenthic, soft-bodied, deposit feeders to epibenthic grazers (Parcha *et al*., 2005). The present assemblage of trace fossils indicates that the Kunzum La Formation was deposited in deep to shallow shelf setting. The present study further suggests that there existed a low-energy depositional environment at this level of sedimentation. The trace fossil assemblage was also influenced by the presence of oxygen in both the water column as well as the unconsolidated sediments on see floor. It seems that the trace fossil assemblages in this region may have been affected by the concentration of oxygen in the water column (Parcha *et al*., 2005). Their distribution shows low to moderate energy level. The present trace fossil assemblage indicates *Cruziana* ichnofacies. Their abundance and diversity indicates that there was a slight fluctuation in energy conditions which allowed development of *Cruziana* ichnofacies during the deposition of Early Cambrian succession in this region. The *Cruziana* mainly occurs below the normal wave base. The availability of nutrients have strongly increased their distribution as well as abundance in the Chandratal section.

In the Chandratal section, trace fossils are reported from the basal part of the Kunzum La Formation Stage 3 of Series 2 and goes up to Stage 4 of Series 2 of the Cambrian System, whereas, so far, trilobites from the Spiti Basin are reported from the Stage 4, Series 2 of the Cambrian System to the Guzhangian Stage up to the top of Series 3 (Peng *et al*., 2009; Singh *et al*. 2014). Fuchs (1982) and Srikantia (1981) considered deposition of the Cambirian sediments in a relatively deep setting dominated by turbidites, whereas Bhargava and Bassi (1998) and Bhargava (2011) interpreted deposition in subtidal to intertidal environments. Myrow *et al*. (2006) interpreted a siliciclastic deltaic setting containing numerous medium-scale shoaling cycles ranging from storm-influenced offshore deposits to thick trough cross-bedded fluvial facies. Parcha *et al*. (2005) suggested barrier-to-shelf and slope environment. Hughes (2002) and Hughes *et al*. (2013) suggested that the trace fossils occur throughout the marine deposits of the Cambrian in the Himalaya, and are not localized to particular zones or levels in the pre-trilobitic Cambrian. Based on ichnofossils from the Cambrian successions of the Parahio Valley, Parcha and Pandey (2011) suggested anaerobic to aerobic environment which was distinctly marked by a faunal change from endobenthic, soft - bodied deposit feeders to epibenthic grazers. In the Chandratal section, the presence of *Cruziana* ichnofacies reflects low to high-energy environment, whereas microbially induced structures present in the fine-grained sandstone reflects deposition under shallow marine conditions within the photic zone.

CONCLUSIONS

In the present study, the trace fossils are used to define the palaeoenvironmental conditions of the Kunzum La Formation, in which trilobites and other body fossils are missing. In the Spiti as well as the Zanskar basins, most ichnofossils do not occur in association with body fossils, but usually occur below the trilobite-bearing horizons in Early Cambrian. Throughout the sequence, the described trace fossils reflect the presence of suspension and deposit feeding animals. These traces mostly belong to arthropods, annelids and polychaetes. The presence of burrow, scratch marks and trails reflects change in depositional regime. The *Cruziana* ichnofacies indicates that deposition has taken place in shallow marine conditions which reflect low to high energy environment. The distribution of trace fossils reflects gradual increase in complexity. Whereas the presence of microbially induced structures in the fine sandstone indicates deposition under shallow marine conditions within the photic zone, the prolific growth of microbial mats in the basal unit of the Kunzum La Formation suggests lack of the grazing activity of organisms; it equally reflects the organism development patterns during this period. So the presence of trace fossils and microbial mats in the Chandratal section can be used to correlate the succession with other Early Cambrian succession of Spiti and other Tethyan Himalayan successions.

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