Journal of The Palaeontological Society of India
Vol. 46, 2001, pp. 161-171

TRACE FOSSILS FROM THE CAMBRIAN ROCKS OF THE KUNZUM LA SECTION, SPITI, H.P., INDIA

C. S. SUDAN and U. K. SHARMA

P. G. DEPATRMENT OF GEOLOGY, UNIVERSITY OF JAMMU, JAMMU -180006

ABSTRACT

In the Kunzum La section of Spiti, there is a vertical increase in the abundance and diversity of trace fossils, i.e. from the TF1 horizon to the TF2 horizon. The TF1 horizon assemblage contains *Neonereites uniserialis*, *Phycodes palmatum*, *Treptichnus pedum* and *Planolites* sp. whereas the upper TF2 horizon assemblage represents a diversified range of trace fossils, i.e. *Cruziana pormensis*, *Monomorphichnus lineatus*, *Rusophycus* sp., *Protichnites* sp., *Diplichnites* sp.(arthropod traces), *Skolithos linearis*, *Laevicyclus* sp., *Chondrites* sp., *Cochlichnus* sp., *Didymaulichnus* sp. and *Bergaueria* aff. *B. perata*. The age of these ichnofossils may extend into rocks older than those described here, but the absence of arthropod traces in TF1 assemblage suggests a relatively rapid increase in diversity. The ichnofaunal evolution, as reflected from TF1 to TF2 horizons, make them an ideal group for understanding the behavioural evolution of primitive metazoans in the pre-trilobite Cambrian strata.

Key words: Spiti, Kunzum La section, ichnofossils, systematic description, Cambrian.

INTRODUCTION

The Kunzum La section of the Spiti Basin is one of the fascinating areas where Precambrian - Cambrian rocks are well exposed in the Tethyan Higher Himalayan belt. The Kunzum La section lies within the longitude range 77° 35' to 77° 40' and latitude range 32° 20' to 32° 27' and is included in the Survey of India topographic Sheet No. 52 H/11 (fig. 1 A, B).

The Spiti valley as a whole records a thick sequence of Precambrian-Cambrian sediments constituting the Batal and the Kunzum La formations which, according to Srikantia (1981), rest unconformably over the Rohtang Gneissic Complex and are unconformably overlain by the Thango Formation of ?Ordovician age (Kumar, 1984). The Batal Formation is characterised by grey to dark grey argillite and greenish grey quartzite, whereas the Kunzum La Formation which is divisible into a basal Debsa Khad Member made up dominantly of grey to greenish grey, thinly bedded quartzite, sandstone with subordinate grey shale, and an upper Parahio Member (Parahio Series, Hayden 1904) consisting of an alternation of greenish micaceous sandstone and shale with subordinate lenticular bands of limestone (Bhargava *et al.*, 1982; Kumar *et al.*, 1984).

In Spiti, the Cambrian trilobites and brachiopods are known from the Parahio and Pin valley sections (Hayden, 1904; Reed, 1910; Sahni and Sudan, 1996; Jell and Hughes, 1997). From the Parahio section, Bhargava *et al.* (1982) have reported some trace fossils, such as *Diplichnites* sp., *Dimorphichnus* sp., *Monomorphichnus* sp. (trilobite scratch marks), *Scolicia* sp., *Gyrochorte* sp., *Planolites* sp., *Gordia* sp. and *Skolithos* sp., from the upper part of the Debsa Khad Member.

The upper part of the Batal Formation in the Parahio secton and the basal part of the Debsa Khad Member of the Kunzum La Formation in the Kunzum La section respectively yielded *Anguloplanina* and *Pulvinomorpha* along with Chitinozoa - *Sphaerochitinozoa* (Kumar, 1984). These acritarchs are well known from the Vendian rocks of South-East Siberia, U.S.S.R. (Rudavskaya,1973).

As the earlier record of ichnofossils from the Kunzum La section is meagre (*Isopodichnus* sp., *Monomorphichnus* sp. and *Rusophycus didymus*) Bhargava and Srikantia, 1985), the present ichnological studies are of considerable significance for tracing out the biogenic record in the pre-trilobite Cambrian strata.

REPOSITORY

The trace fossil specimens described in this paper have been deposited in the Palaeontology Museum of the P. G. Department of Geology, University of Jammu, Jammu. The specimen numbers for each taxon are indicated in the explanation of Pl I.

SYSTEMATIC ICHNOLOGY

Ichnogenus ***Bergaueria*** Prantl, 1945

Bergaueria aff. *perata* Prantl, 1945

(Pl. I,i)

Unornamented, hemispherical trace, preserved as positive features on the sole of grey sandstone. Diameter of trace ranges from 4mm to 7mm. A central depression is well seen in some of the specimens. *Bergaueria* is generally considered to be a dwelling or resting burrow of actinarians (Pemberton *et al.*, 1988). Jensen (1997) suggested that the mere absence of central depression in *Bergaueria hemispherica* is not sufficient to separate *Bergaueria perata* from *Bergaueria hemispherica* as this small variation could be due to preservational variations.

Ichnogenus ***Chondrites*** von Sternberg, 1833

Chondrites sp.

(Pl. I, a)

Structures of feeding-grazing origin, characterised by a densely interwoven network of branches, preserved on the bedding surface. Trace consists of asymmetrical tracks of biogenic origin dominantly in dendritic pattern. The tracks are of varying width, ranging from 1mm to 3mm, each branch of approximately constant width, but sometimes narrowing towards the ends.

Ichnogenus ***Cochlichnus*** Hitchcock, 1858

Cochlichnus sp.

(Pl. I, l)

Horizontal sinuous trails, preserved on the bedding surface. The maximum length and width of the trail is 110 mm and 4 mm respectively whereas wave length and amplitude of the curve is 30 mm and 6 mm respectively. The trace represents the cast which results from the activity of worm-like deposit feeders. Webby (1970) has reported *Cochlichnus serpens* from the Precambrian of New South Wales, Australia. Goldring and Jensen, (1996) have described *Cochlichnus* sp. from the Zovkhan Basin Mongolia. *Cochlichnus* have been recorded from wide range of environments and stratigraphical horizons (Seilacher, 1955b,1963). Annelids, especially nematodes, have been suggested to be the producers of such traces (Moussa, 1970).

Ichnogenus ***Cruziana*** d'Orbigny, 1842

Cruziana pormensis Crimes, Legg, Marcos and Arboleya, 1977

(Pl. I, m)

Elongate band-like plough pattern ridges in which internal lobes have fine v-markings and the external lobes are represented by a series of ridges running parallel to the length of the trace and continuing up the side wall to the edge. The maximum length and width of the trace is 130 mm and 23 mm respectively. Such traces are thought to be produced by the furrowing of the trilobite through the sediment. The V-markings, as is seen in the present specimens, are dug by the endopodites with movement inwards and backwards (Seilacher, 1955a; Crimes, 1970b).

Ichnogenus ***Didymaulichnus*** Young,1972

Didymaulichnus sp.

(Pl. I, n)

Bilobate elongate trace bisected by a shallow central furrow, preserved as convex hyporelief on the sole of grey sandstone. The maximum length and width of the trace is 115 mm and 10 mm respectively. The present specimen differs from *Cruziana* in the absence of V-shaped markings on the surface of the lobes. Trace makers of *Didymaulichnus* may be the molluscs (Glaessner, 1969), trilobites (Crimes, 1970a) and gastropods (Hakes, 1977).

Ichnogenus **Diplichnites** Dawson, 1873

Diplichnites sp.

(Pl. I, c)

Diplichnites have been interpreted as the result of arthropods walking /striding across the sediment surface (Radwanski and Roniewicz, 1963). The trace consists of parallel series of fine ridges of varied types depending upon the nature of the activity of the organism. The maximum length and thickness of the ridges is 12 mm and 4 mm respectively and the maximum gap between the two ridges is 4 mm.

Ichnogenus **Laevicyclus** Quenstedt, 1879

Laevicyclus sp.

(Pl. I, j)

The vertical burrows occur as cylindrical bodies across the bedding plane with a central perforation representing the vertical canal. On the bedding plane, the trace is slightly oval in shape and its diameter ranges from 2 mm to 5 mm. The present trace can be regarded as feeding and dwelling cavity constructed by worms across the soft stratum. *Laevicyclus* have been reported from the Garbyang Formation (Banerjee *et al.*, 1975) and from the Lower Cambrian of Salt Range, Pakistan (Seilacher, 1955b).

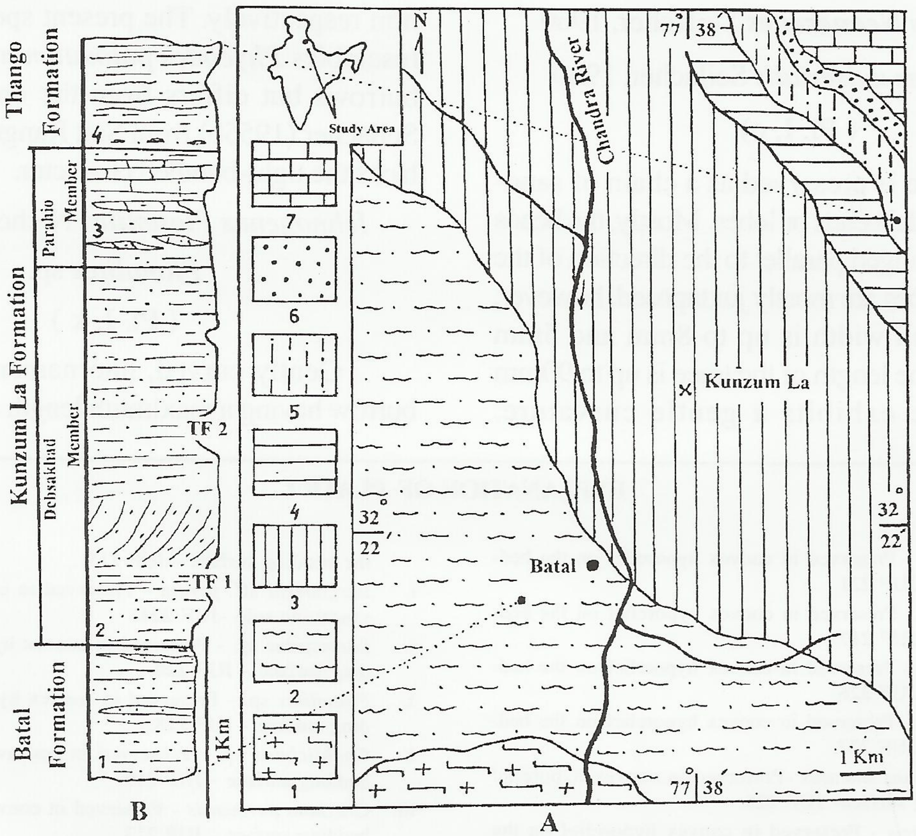


Fig. 1. A. Geological map showing different lithological units in the Batal-Kunzum La Section of Spiti (Modified after Bhargava and Srikantia, 1985) 1. Rohtang Gneisses, 2. Batal Formation, 3-4. Kunzum La Formation, 3. Debsakhad Member, 4. Parahio Member, 5. Thango Formation, 6. Muth Formation, 7. Lipak Formation. **B.** Lithocolumn showing the stratigraphic position of trace-fossil horizons in the Kunzum La Section. 1. Shale-siltstone-quartzite, 2. Cross-bedded sandstone with subordinate shale, 3. Micaceous sandstone-siltstone with limestone lenses, 4. Conglomerate with cross-rippled sandstone.

Ichnogenus ***Monomorphichnus*** Crimes, 1970

Monomorphichnus lineatus Crimes, Legg, Marcos & Arboleya, 1977

(Pl. I, e)

Sets of slightly sigmoidal to gently curved, nearly parallel asymmetrical ridges preserved on the bedding surface. The maximum length and width of the individual ridge is 8 mm and 1 mm respectively. The maximum number of ridges in a set is seven and the maximum width of a ridge set is 9mm. Individual ridge set repeats laterally without any intervening markings. *Monomorphichnus lineatus* could be produced by the swimming or grazing activity of arthropods; during the current they raked the sediment surface at intervals with endopodite claws (Crimes, 1970b).

Ichnogenus ***Neonereites*** Seilacher, 1960

Neonereites uniserialis Seilacher, 1960

(Pl. I, o)

The trace is preserved as a chain of sand-infilled ellipsoidal beads or lobes. Mostly, the beads or lobes are arranged parallel to the direction of the trail. Beads / lobes are mostly juxtaposed, however, their length and width is up to 8mm and 5mm respectively. The length of the trace is up to 90mm and the trace exhibits a gentle curvature. *Neonereites uniserialis* has been reported from Lias of Germany (Häntzschel and Reineck, 1968); from the Upper Precambrian (Vendian) Valdai Series of the Onega Peninsula, U.S.S.R. (Fedonkin,1976) and from Lower Cambrian of the Nama Group, Southwest Africa - Namibia (Crimes and Germs,1982).

Ichnogenus ***Phycodes*** Richter, 1850

Phycodes palmatum (Hall, 1852)

(Pl. I, g)

Sand-infilled, straight to slightly curved burrows exhibiting branch-like appearance but branches do not intersect each other. The branches, though slightly diverging, are aligned in the same direction. The maximum length and width of the individual curved burrow is up to 112 mm and 9 mm respectively. The present specimen closely resembles *Phycodes palmatum* in the pattern of burrows but differs from the one recorded by Seilacher (1955b) from Salt Range, Pakistan as it lacks the tight-bundled character.

Ichnogenus ***Planolites*** Nicholson, 1873

Planolites sp.

(Pl. I, k)

Gently curved, unornamented horizontal burrow having a maximum length and width of 35

EXPLANATION OF PLATE I ⟶

a. *Chondrites* sp. - Preserved in convex hyporelief on the bedding surface - JUF 221.

b. *Rusophycus* sp.- Preserved in convex hyporelief on the bedding surface - JUF 217.

c. *Diplichnites* sp.- Preserved in convex hyporelief on the bedding surface - JUF 226.

d. *Protichnites* sp.- Preserved in convex hyporelief on the bedding surface - JUF 227.

e. *Monomorphichnus lineatus* -Preserved in convex hyporelief on the bedding surface- JUF 225.

f. *Skolithos linearis* - Preserved in convex hyporelief on the bedding plane, in the vertical section inclined burrow tubes visible - JUF 216.

g. *Phycodes palmatum* - Preserved in convex hyporelief on the bedding surface - JUF 214.

h. *Treptichnus pedum* - Preserved in convex hyporelief on the bedding surface - JUF 215.

i. *Bergaueria* aff. *perata* - Preserved in convex hyporelief on sandstone sole -JUF 224.

j. *Laevicyclus* sp. - Preserved in convex hyporelief on the bedding surface - JUF 220.

k. *Planolites* sp. - Preserved in convex hyporelief on the bedding surface - JUF 218.

l. *Cochlichnus* sp. - Preserved in concave hyporelief on the bedding surface - JUF 219.

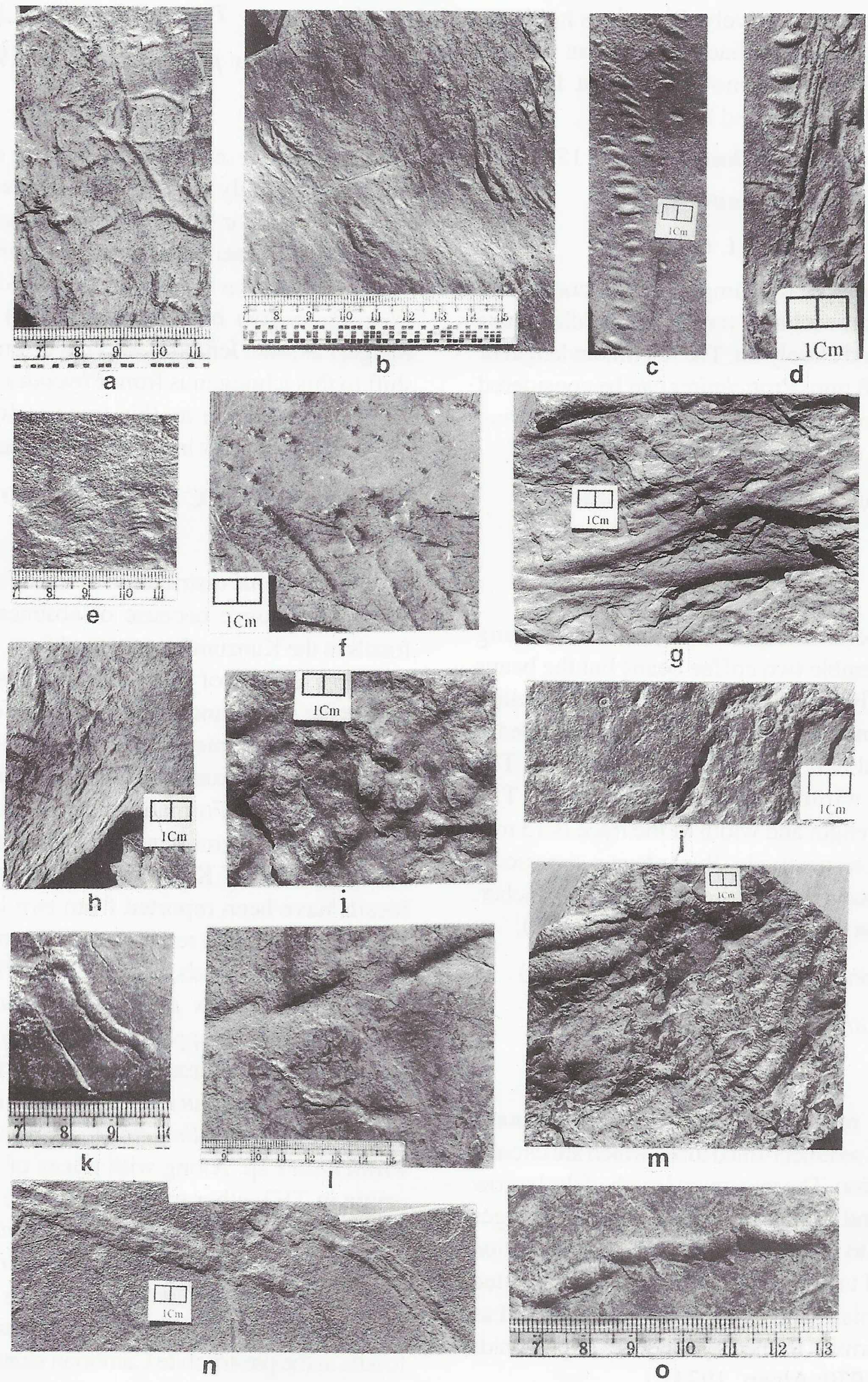
m. *Cruziana pormensis* - Preserved in convex hyporelief on the bedding surface - JUF 213.

n. *Didymaulichnus* sp. - Preserved in convex hyporelief on sandstone sole - JUF 222.

o. *Neonereites uniserialis*-Preserved in convex hyporelief on the bedding surface-JUF 223.

Journal of the Palaeontological Society of India
Vol. 46, 2001

Plate I



SUDAN AND SHARMA

mm and 4 mm respectively. *Planolites* has been attributed to the active backfilling of an interim burrow formed by a mobile deposit feeding organism (Pemberton and Frey, 1982).

Ichnogenus ***Protichnites*** Owen, 1852

Protichnites sp.

(Pl. I, d)

Two rows of bifid imprints and a commonly narrow intermittent drag trail in the middle, tracks irregularly and closely set. The maximum length of the trail is 48 mm. *Protichnites* can be considered to be of arthropod origin, possibly produced during its crawling on the surface of the sediment.

Ichnogenus ***Rusophycus*** Hall, 1852

Rusophycus sp.

(Pl. I, b)

The specimens preserved on the bedding surface resemble two coffee beans but the beans are generally parallel and come closer together along the central line, sometimes occurring fused at the one end and parallel at the other end. The beans are without any ornamentation. The maximum length and width of the trace is 15 mm and 11 mm respectively. *Rusophycus* represents a resting excavation of trilobite origin (Seilacher, 1953, 1955a; Crimes, 1970a; Young, 1972).

Ichnogenus ***Skolithos*** Haldeman, 1840

Skolithos linearis Haldeman, 1840

(Pl. I, f)

Trace represents vertical to inclined, unbranched sediment-filled tubes which are circular in cross section. The maximum length of the burrow is 40 mm and the diameter of the burrows ranges from 1 mm to 2 mm. These tubes in vertical section are parallel to each other. The burrows are filled with brownish sands. *Skolithos* is interpreted as dwelling burrows formed by annelides or phoronids (Osgood, 1970; Alpert, 1974).

Ichnogenus ***Treptichnus*** Miller, 1889

Treptichnus pedum (Seilacher, 1955)

(Pl. I, h)

The trace preserved on the bedding surface as straight to slightly curved, sand-infilled burrow branching occasionally to give minor branches; the branching segments are arranged in a nearly straight succession. Similar traces were described earlier as *Phycodes pedum* by Seilacher (1955b) from Salt Range, Pakistan. Jensen (1997) has given a generic shift to this ichnogenus from *Phycodes pedum* to *Treptichnus pedum* as this trace is formed by addition of segments in a treptichian manner.

STRATIGRAPHIC DISTRIBUTION AND ECOLOGY

Stratigraphic distribution of trace fossils is of much importance because of absence of body fossils in the Kunzum La section of Spiti. Although in almost all parts of the world, trace fossils occur before the appearance of mineralised fossils, the horizons rich in trace fossils are devoid of body fossils. In the Kunzum La section of Spiti, the Batal and Kunzum La Formations constitute the Late Precambrian - Cambrian rocks. From the Debsa Khad Member of Kunzum La Formation, trace fossils have been reported from two levels, the lower horizon (TF1) represents traces produced by the vermiform animals, i.e. *Planolites*, *Treptichnus pedum*, *Phycodes palmatum*, *Neonereites uniserialis* and the upper horizon (TF2) marks the first appearance of traces of arthropod origin, i.e. *Cruziana pormensis*, *Diplichnites* sp., *Monomorphichnus lineatus*, *Rusophycus* sp. and *Protichnites* sp. Along with traces of arthropod origin in TF2, other trace fossils have also been reported, i.e. *Skolithos linearis*, *Laevicyclus* sp. *Bergaueria* aff. *perata*, *Chondrites* sp., *Didymaulichnus* sp. and *Cochlichnus* sp. In the Kunzum La section of Spiti, the diversity of trace fossils in the pre-trilobite Cambrian strata increases

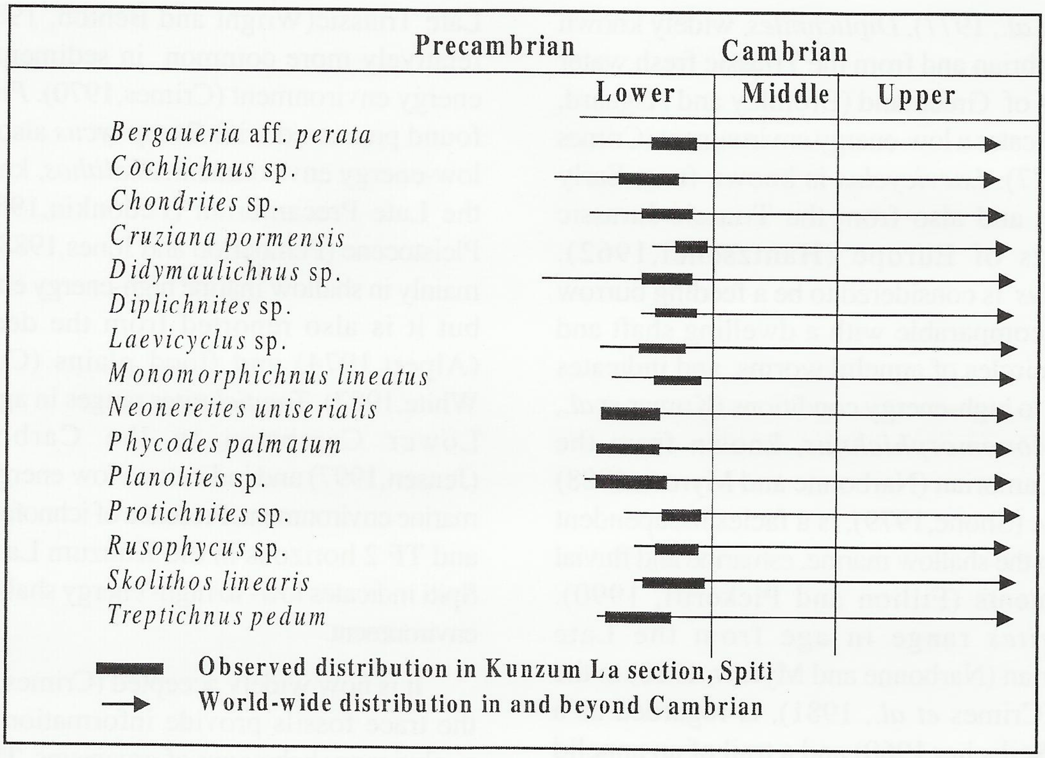


Fig. 2. Stratigraphic range chart of the ichnospecies recorded from the Kumzum La Section.

from TF 1 to TF 2; such proliferation of ichnofauna from TF 1 to TF 2 could be the result of evolutionary changes due to extensive competition, which is consistent with patterns described from many world- wide sections (Crimes, 1987, 1992, Narbonne *et al.*, 1987). The stratigraphical position of presently described trace fossils is summarised in fig.-2.

The Lower Cambrian trace fossils have also been reported from the Tal Formation (Singh and Rai,1983; De *et al.*, 1994; Bhargava *et al.*,1998 and Sudan and Sharma *in press*), Zanskar (Hughes and Droser,1992; Parcha, 1998 and Shah *et al.*, 1998), Kashmir (Shah and Sudan, 1983), Spiti (Bhargava *et al.*, 1982; Bhargava and Srikantia, 1985 and Sudan *et al.*, 2000) and Kumaun (Banerjee *et al.*, 1975 and Sudan and Sharma, 2000).

Bergaueria, known from intertidal to muddy bottoms of shore face (Crimes *et al.*, 1977) and from deep water sediments (Ksiazkiewicz, 1977), ranges in age from the basal Cambrian (Narbonne *et al.* 1987) to the Pleistocene (Pemberton and Jones, 1988). *Chondrites* ranges in age from Cambrian to Tertiary (Simpson,1957), being abundant in the Early Cambrian (Alpert,1975) and is a low-energy ichnotaxa (Fürsich,1998). *Cochlichnus*, a facies crossing trace (Pickerill, 1981), ranges in age from the Late Vendian (Fedonkin, 1983) and continues throughout the Phanerozoic (Jensen, 1997). *Cruziana* ranges in age from the Cambrian to the Triassic (Bromley and Asgaard,1979) and is mostly found in sediments of high-energy environment in which *Diplichnites* are absent (Crimes, 1970b) but the co-occurrence of *Diplichnites* and *Cruziana* indicates low-energy environment. *Didymaulichnus,* known from the Late Vendian to the Early Cambrian (Palij *et al.*, 1983; Fritz and Crimes, 1985; Fedonkin, 1988; Narbonne and Myrow, 1988), Ordovician (Baldwin, 1977), Devonian (Garcia Romas,1976) and Cretaceous (Vossler *et al.*, 1989), indicates intertidal transitional environment of deposition

(Kumar *et al.*, 1977). *Diplichnites,* widely known from Cambrian and from the Triassic fresh water sediments of Greenland (Bromley and Asgaard, 1979), indicates a low-energy environment (Crimes *et al.*, 1977). *Laevicyclus* is known from Early Cambrian and also from the Triassic-Jurassic sediments of Europe (Häntzschel,1962). *Laevicyclus* is considered to be a feeding burrow which is comparable with a dwelling shaft and scraping circles of annelid worms, and indicates moderate to high-energy conditions (Kumar *et al.*, 1977). *Monomorphichnus,* known from the Earliest Cambrian (Narbonne and Myrow, 1988) to Triassic (Shone,1979), is a facies independent form from the shallow marine, estuarine and fluvial environments (Fillion and Pickerill, 1990). *Neonereites* range in age from the Late Precambrian (Narbonne and Myrow, 1988) to the Eocene (Crimes *et al.*, 1981), is regarded as a burrow (Seilacher,1960) and a trail of an annelid (Hakes,1976). *Neonereites* has been described from both the shallow and the deep water deposits (Seilacher,1960; Häntzschel and Reineck, 1968 and Tanaka,1971). Shallow water *Neonereites* can be relatively straight or more commonly curved, whereas tight meandering forms are often preserved in deep water conditions, particularly by the end of the Palaeozoic (Delgado, 1910 and Seilacher, 1974). *Phycodes* is widely found in the Lower Cambrian strata (Clausen and Vilhjalmsson,1986) and Triassic (Pollard, 1981). It is indicative of low energy, subtidal or mud flat environment of Cambrian - Ordovician sea (Crimes *et al.*, 1977). It is also produced in shallow marine environment with strong wave action. It is, hence, inferred that the trace makers had a considerable range of energy toleration (high to low) limit. *Planolites,* known from the Late Precambrian (Narbonne and Hofmann, 1987) as well as from the Pleistocene sediments (Wetzel, 1981), is a facies independent form (Crimes, 1970a). *Rusophycus* ranges in age from the Early Cambrian (Crimes,1970b) to the Late Triassic(Wright and Benton, 1987) and is relatively more common in sediments of low-energy environment (Crimes,1970). *Protichnites* found preserved with *Rusophycus* also indicates low-energy environment. *Skolithos,* known from the Late Precambrian (Fedonkin,1985) to the Pleistocene (Pemberton and Jones,1988), is found mainly in shallow marine high-energy environment but it is also reported from the deep waters (Alpert,1974) and flood plains (Curran and White,1987). *Treptichnites* ranges in age from the Lower Cambrian to the Carboniferous (Jensen,1997) and indicates a low energy, shallow marine environment. Presence of ichnofauna in TF1 and TF 2 horizons in the Kunzum La section of Spiti indicates low- to high- energy shallow marine environment.

It is now widely accepted (Crimes,1994) that the trace fossils provide information about the evolutionary behaviour of organisms. The absence of body fossils in trace fossil-rich horizons suggests that arthropods initially developed as soft-bodied forms, could not be preserved, and they were followed in the later stages by the arthropods which developed hard parts. The interval between the first appearance of the trace fossils and that of the trilobite body fossils marks a major event in the history of evolution of arthropods during which skeletalization of arthropods may have taken place.

ACKNOWLEDGEMENTS

Authors are grateful to Prof. S. K. Shah for going through the manuscript of this paper and providing valuable suggestions. We also thank Dr. N. Hughes and Dr. S. Jensen for critically reviewing the manuscript and providing useful suggestions for improving the same. The financial aid provided by the D.S.T. and UGC (UKS) for the present work is gratefully acknowledged. Thanks are due to the Head of the Geology Department, University of Jammu for providing the necessary facilities.

REFERENCES

Alpert, S. P. 1974. Systematic review of the genus *Skolithos*. *Jour. Palaeont.* **48** : 661-669.

Alpert, S. P. 1975. *Planolites* and *Skolithos* from the Upper Precambrian-Lower Cambrian, White-Inyo Mountains, California. *Jour. Pal.* **49** : 508-521.

Baldwin, C. T. 1977. The stratigraphy and facies association of trace fossils in some Cambrian and Ordovician rocks of north-western Spain, p. 9-40. In : *Trace fossils* 2 (Eds. Crimes, T. P. and Harper, J. C.), *Geol. Jour.* (Spec.Issue), **9**.

Banerjee, D. M., Tandon, S. K. and Sinha, A. K. 1975. Trace fossils in the Tethyan sucession in a part of Northern Kumaun Himalaya. *Proc. Symp. Sed. Sedimentation and Sed. Environments, Delhi,* 177-185.

Bhargava, O. N., Kumar, G. and Gupta, S. S. 1982. Late Lower to Early Middle Cambrian Trace fossils, Spiti valley, Himachal Himalaya. *Jour. Geol. Soc. India,* **23** : 183-191.

Bhargava, O. N., Singh, I., Hans, S. K. and Bassi, U. K. 1998. Early Cambrian trace fossils from the Nigali Dhar Syncline (Sirmaur District, Himachal Pradesh), lithostratigraphic correlation and trace fossil contents of Tal Group. *Jour. Him. Geol.* **19(1)** : 89-108.

Bhargava, O. N. and Srikantia, S. V. 1985. Trilobite and other trace fossils from the Kunzum La Formation, Eastern Lahaul Valley, Himachal Himalaya. *Jour. Geol. Soc. India,* **26** : 880-886.

Bromley, R. G. and Asgaard, U. 1979. Triassic freshwater ichnocoenesis from Carlsberg Fjord, East Greenland. *Palaeogeog. Palaeoclimatol. Palaeoecol.* **28** : 39-80.

Clausen, C. K. and Vilhjalmsson, M. 1986. Substrate control of Lower Cambrian trace fossils from Bornholm, Denmark., *Palaeogeog., Palaeoclim., Palaeoecol.* **56**:51-68.

Crimes, T. P. 1970a. Trilobite tracks and other fossils from the Upper Cambrian of North Wales. *Geol. Jour.* **7** : 47-68.

Crimes, T. P. 1970b. The significance of trace fossils in sedimentology, stratigraphy and palaeoecology with examples from Lower Palaeozoic strata, p. 101-126. In : *Trace fossils.* (Eds. Crimes, T. P. and Harper, J.C.), *Geol. Jour. Spl. Issue,* **3**.

Crimes, T. P. 1987. Trace fossils and correlation of Late Precambrian and Early Cambrian strata. *Geol. Mag.* **124**: 97 - 119.

Crimes, T. P. 1992. Changes in the trace fossil biota across the Proterozoic-Phanerozoic boundary. *Jour. Geol. Soc. London,* **149** : 637-646.

Crimes, T. P. 1994. The period of early evolutionary failure and the dawn of evolutionary success : The record of biotic changes across the Precambrian-Cambrian Boundary, p. 105-133. In : *The Palaeobiology of Trace Fossils* (Ed. Donovan, S.K.), J. Wiley & Sons, England.

Crimes, T. P. and Germs, G. J. B. 1982. Trace fossils from the Nama Group (Precambrian-Cambrian) of Southwest Africa (Namibia). *Jour. Pal.* **56** : 890-907.

Crimes, T. P., Goldring, R., Homewood, P., Stuijvenberg, J. Von and Winkler, W. 1981. Trace fossil assemblages of deep-sea fan deposits, Gurnigel and Schliereri Flysch, Cretaceous-Eocene, Switzerland. *Eclog. Geol. Helvet.* **74** : 953-955.

Crimes, T. P., Legg, I., Marcos, A.and Arboleya, M. 1977. ?Late Precambrian-Lower Cambrian Trace fossils from Spain. In : *Trace fossils* 2 (Eds. Crimes, T. P. and Harper, J.C.) *Geol. Jour. Spl. issue* **9** : 91-138.

Curram, H. A. and White, B. 1987. Trace fossils in carbonate upper beach rocks and eolianites : recognition of the backshore to dune transition, p.243-254. In : *Proceedings of the 3rd Symposium on the Geology of the Bahamas* (Ed. Currram, H.A.), Fort Lauderdale, Florida. CCFL Bahamian Field Station.

Dawson, J. W. 1873. Impressions and footprints of aquatic animals and imitative markings on Carboniferous rocks. *Am. Jour. Sci. Ser.* 3, **5** : 16-24.

De, C., Das, D. P. and Raha, P. K. 1994. Ichnostratigraphic and Palaeoenvironmental significance of Trace fossils from Tal Formation of Nigalidhar Syncline, Sirmur district, Himachal Pradesh, India. *Ind. Jour. Geol.* **66 (2)** : 77 - 90.

Delgado, J. F. N. 1910. Terrains Palaeozoiques du Portugal. Étude sur les fossiles des Schistes a *Nereites* de san Domingos et des Schistes à *Nereties* et à Graptolites de Barancos. *Surv. Géol. Portugal,* **56.**

Fedonkin, M. A. 1976. Traces of multicellur animals from the Valdai Series. *Izvestiya Akad. Nauk. S.S.S.R., Ser. Geol.* **4** : 129-132.

Fedonkin, M. A. 1983. Besskeletnaya fauna podol'skogo pridnestrov'ya. [Non-skeletal fauna of Podolia (Dniestr River Valley).] In: Velikanov, V. A., Aseeva, M. A. & Fedonkin, M. A.: Vend Ukrainy, 128-139. Naukova Dumka, Kiev.

Fedonkin, M. A. 1985. Palaeoichnology of Vendian Metazoa, p. 112-116. In: *The Vendian System : Historic, Geological and Palaeontological basis,* I. (Eds. Sokolov, B.S. and Ivanorsky, A.A.), Nauka, Moscow, (in Russian).

Fedonkin, M. A. 1988. Palaeoichnology of the Precambrian-Cambrian transition in the Russian platform and Siberia, p 12. In : *Trace fossils, Small shelly fossils and the Precambrian boundary proceedings* (Eds. Landing, E., Narbonne, G.M. and Myrow, P.), New York State Museum Bulletin, 463. (abstract).

Fillion, D. and Pickerill, R. K. 1990. Ichnology of the Upper Cambrian ? to lower Ordovician, Bell Island and Wabaria Group of Eastern Newfoundland, Canada. *Palaeontographica Canadiana,* **7** : 1-119.

Fritz, W. H. and Crimes, T. P. 1985. Lithology, trace fossils and correlation of Precambrian-Cambrian boundary beds. Cassiar Mountains, North-Central British Columbia. *Geol. Surv. Canada Paper,* **83** : 13-24.

Fürsich, F. T. 1998. Environmental distribution of trace fossils in the Jurassic of Kachchh (western India). *Facies,* **39** : 243 - 272.

Garcia-Ramos, J. C. M. 1976. Morfologia de trazoa fossils endos afloramientos de " Arenise de Naranco" (Devonica media) de Austuriag (NW de Espana). *Trabajos de Geologia-universided de Oviedo,* **8** : 131-171.

Glaessner, M. F. 1969. Trace fossils from the Precambrian and basal Cambrian. *Lethaia,* **2** : 369-393.

Goldring, R. and Jensen, S. 1996. Trace fossils and biofabrics at the Precambrian-Cambrian boundary interval in Western Mongolia. *Geol. Mag.* **133** : 403 -415.

Hakes, W.G.1976. Trace fossil and depositional environment of four clastics units, Upper Pennsylvanian Megacyclothemes, north-east Kansas. *Paleont. Contr. Univ. Kans.* no. **63.**

Hakes, W. G.1977. Trace fossils in Late Pennsylvanian cyclothems, Kansas, p. 209-226. *Trace fossils* 2 (Eds. Crimes, T.P. and Harper, J.C.), *Geol. Jour. Spl. Issue*, **9**.

Haldeman, S. S. 1840. Supplement to number one of 'A monograph of the Limniades, and other freshwater univalve shells of North America', containing description of apparently new animals in different classes, and the names and characters of the subgenera in Paludina and Anculosa : 3 (Philadelphia).

Hall, J. E. 1852. *Palaeontology of New York.* C. Van. Benthusyen, Albany, **2** : 358.

Häntzschel, W. 1962. Trace fossil and Problematica, p. W 177-W 245. In: *Treatise on Invertebrate Paleontology* (Eds. Moore, R.C.and others), Part-W. *Geol. Soc. Am. and Univ. Kans. Press, Lawrence.*

Häntzschel, W. and Reineck, H. E. 1968. Fazies - untersuchungen im Hettangium von Helmstedt (Niedersachen). Mitteilngen aus dem Geologischen Staatsinstut in Hamburg, **37** : 5-39.

Häntzschel, W. 1975. Trace fossils and Problematica, p. W1-W269. In : *Treatise on Invertebrate Palaeontology* (Ed. Teichert. C.), Part W. Miscellanea, supplement **1** *Geol. Soc. Amer. and University of Kansas Press, Lawrence.*

Hayden, H. H. 1904. The Geology of Spiti with parts of Bashahr and Rupshu. *Mem. Geol. Surv. India*, **36** : 1-121.

Hitchcock, E. 1858. *Ichnology of New England. A report on the Sandstone of the Connecticut Valley, especially its footprints.* W. White (Boston).

Hughes, N. C. and Droser, M. L. 1992. Trace fossils from the Phe Formation (Lower Cambrian), Zanskar Valley, north western India. *Mem. Queens Mus. Brisbane*, 139-144.

Jell, P. A. and Hughes, N. C. 1997. Himalayan Cambrian Trilobites. *Palaeont. Assoc. London, Spl. Pap. Palaeont.* **50**: 1-113.

Jensen, S. 1997. Trace fossils from the Lower Cambrian Mickwitzia sandstone , south - central Sweden. Fossils & Strata, Lethaia, International. *Jour. Palaeont. and Strat.* **40** : 1-111.

Ksiazkiwicz, M. 1977. Trace fossils in the flysch of Polish Carpathians. *Palaeontol. Polon.* **36** : 112-208.

Kumar, G. 1984. The Precambrian-Cambrian boundary beds, Northwest Himalaya, India and boundary problem. *Proc. V Indian Geophyt. Conf., Lucknow* (1983), *Spl. Pub.*, 1984 : 98-111.

Kumar, G., Raina, B. K., Bhargava, O.N., Maithy, P. K. and Babu, R. 1984. The Precambrian-Cambrian boundary and its prospects, Northwest Himalaya, India. *Geol. Mag.* **121** : 211-219.

Kumar, S., Singh, I. B. and Singh, S. K. 1977. Lithostratigraphy, structure, depositional environment, Palaeocurrent and trace fossils of the tethyan sediments of Malla Johar area, Pithoragarh-Chamoli districts, Uttar pradesh, India. *Jour. Pal. Soc. India*, **20** : 396-435.

Miller, S. A. 1889. *North American Geology and Palaeontology for the use of amateurs, students and scientists*, Western Methodist Book Concern (Cincinnati, Ohio).

Moussa, M. T. 1970. Nematode fossil trails from the Green River Formation (Eocene) in the Uinta Basin. *Jour. Pal.* **44** : 304 - 307.

Narbonne, G. M. and Hofmann, H. J. 1987. Edicaran biota of the Wernecke Mountains, Yukon, Canada. *Palaeontol.* **30** : 647-676.

Narbonne, G. M. and Myrow, P. 1988. Trace fossil biostratigraphy in the Precambrian-Cambrian boundary interval, In : *Trace fossils Small shelly fossils and the Precambrian-Cambrian boundary proceedings*, (Eds. Landing, E., Narbonne, G. M. and Myrow, P.), *New York State Museum Bull.* **463**: 72-76.

Narbonne, G. M., Myrow, P. M.,Landing, E. and Anderson, M. M.1987. A candidate stratotype for the Precambrian - Cambrian boundary, Fortune Head, Burin Peninsula, southeastern Newfoundland. *Canadian Jour. Earth Sci.* **24** : 1277-1293.

Nicholson, H. A. 1873. Contributions to the study of the errant annelids of the older Palaeozoic rocks. *Royal Soc. London, Proc.* **21** : 228-290 (Also *Geol. Mag.* **10** : 309-310).

d' Orbigny, A. 1842. In : *Treatise on Invertebrate Palaeontology-W (Supplement-1, Trace fossils) Teichert. Geological Society of America, University of Kansas*, W234-W235.

Osgood, R. G. 1970. Trace fossils of the Cincinnati area. *Palaeontographica Americana,* **6 : 41**, 281-444.

Owen, R. 1852. Description of the impressions and footprints of the *Protichnites* from the Potsdam Sandstone of Canada. *Geol. Soc. London, Quart. Jour.* **8** : 214 - 225.

Palij, V. M., Posti, E. and Fedonkin, M. A. 1983. Soft-bodied Metazoa and animal trace fossils in the Vendian and Early Cambrian, p. 56-94. In: *Upper Precambrian and Cambrian Palaeontology of the East European Platform* (Eds. Urbanek, A. and Razanov, A.Y.), Wydawnictwa Geologizne Publishing House. Warszawa.

Parcha, S. K. 1998.Trace fossils from the Cambrian of Zanskar (Ladakh Himalaya) and their stratigraphic significance. *Jour. Geol. Soc. India*, **51** :635-645.

Pemberton, S. G. and Frey, W. F. 1982.Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma. *Jour. Pal.* **56** : 843-881.

Pemberton, S. G., Frey, R. W. and Bromley, R. G. 1988. The ichnotaxonomy of *Conostichnus* and other plug-shaped ichnofossils. *Canadian Jour. Earth Sci.* **25** : 866-892.

Pemberton, S. G. and Jones, B. 1988. Ichnology of the Pleistocene Iron Shore Formation, Grand Cayman Island. British West Indies. *Jour. Pal.* **62** : 495-505.

Pickerill. R. K. 1981. Trace fossils in a Lower Palaeozoic submarine canyon sequence-the Siegas Formation of northwestern New Brunswick, Canada. *Maritime sediments and Atlantic Geology*, **17** : 36-59.

Pollard, J. E. 1981. A comparison between the Triassic trace fossils of Cheshire and south Germany. *Palaeont.* **24** : 555-588.

Prantl, F. 1945. Dvé Zahadné Zklamenéliny (Stopy). Z vrstev Chrustenickch - d 2, Rozpravy 2, Tridy Ceske Akad. **55** : 3 - 8.

Quenstedt, F. A. 1879. Petrefactenkunde Deutschlands. 1. Abth., **6** : Korallen. Die Rohren - und Steinkorallen : 1093 p., L. F. Fues (Leipzig).

Radwanski, A. and Roniewicz, P. 1963. Upper Cambrian trilobite ichnocoensis from Wielka Wisniowka (Holy Cross Mountains, Poland). *Acta. Palaeont. Pol.* **8** : 259 - 280.

Reed, F. R. C. 1910. Cambrian fossils of Spiti. *Pal. Ind. Series* **15**, Mem 7, **1** : 7 - 9.

Richter, R. 1850. Aus der thiiringischen Grauwacke. *Deutsch. Geol. Gesell., Zeitschr.* **2** : 198 - 206.

Rudavskaya, V. A. 1973. Acritarchs of the Riphean-Cambrian boundary deposits in south-eastern Siberia, p. 17-21. In : *Microfossils in the most ancient deposits (in Russian)*, Nauka, Moscow (Ed. Vozzhennikova, T.A.)

Sahni, A. K. and Sudan, C. S. 1996. Agnostid fauna from the Cambrian of Spiti. *Jour. Geol. Soc. India,* **48** : 653 - 662.

Seilacher, A. 1953. Studien Zur Palichnologie I I. Die fossilen Ruhespuren (Cubichnia). *Neues Jb. Geol., Palaeont. Abh.* **98**: 87 - 124.

Seilacher, A. 1955a. Spuren und Lebensweise der Trilobiten, p. 373-399. In: *Beitrage Zur Kenntnis des Kambriums in der Salt Range (Pakistan), Akademie der Wissenschaften und der Literatur, Mainz.* (Eds. Schindewolf, O.H. and Seilacher, A.) Abhandlungen der Mathematisch-Naturwissenschaftlichen Klasse 1955.

Seilacher, A. 1955b. Spuren und Fazies im unterkambrium, p. 373-399. In : (Eds. Schindewolf, O. H. and Seilacher, A. *Beitrage Zur Kenntnis des Kambriums in der Salt Range (Pakistan), Akademie der Wissenschaften und der Literatur, Mainz. bhandlungen der Mathematisch-Naturwissenschaftlichen Klasse* 1955.

Seilacher, A. 1960. Lebenspuren als Leitfossilien : *Geol. Rundschau,* **49** : 41-50.

Seilacher, A. 1963. Lebenspuren and Salinitätsfazies. *Fortschritte in der Geologie von Rheinland und Westfalens,* **10** : 81-94.

Seilacher, A. 1974. Flysch trace fossils : Evolution of behavioural diversity in the deep sea. *Neues Jb. Geol. Palaeont.* Mh. **4 :** 233.

Shah, S. K., Kumar, A. and Sudan, C. S. 1998. Trace fossils from the Cambrian sequence of Zanskar (Ladakh Himalaya). *Jour. Geol. Soc. India,* **51** : 777-784.

Shah, S. K. and Sudan, C. S. 1983.Trace fossils from the Cambrian of Kashmir and their stratigraphic significance. *Jour. Geol. Soc. India,* **24** : 194 - 202.

Shone, R. W. 1979. Giant *Cruziana* from the Beaufort Group. *Geol. Soc. South Africa. Trans.* **82** : 371-375.

Simpson, S. 1957. On the trace fossil *Chondrites. Quart. Jour. Geol. Soc. London,* **112** : 475 - 499.

Singh, I. B. and Rai, V. 1983. Fauna and biogenic structures in Krol - Tal succession (Vendian-Early Cambrian), Lesser Himalaya: their biostratigraphic and palaeoecological significance. *Jour. Pal. Soc. India,* **28** : 67 - 90.

Sudan, C. S. and Sharma, U. K. 2000. Trace fossil distribution and stratigraphic setting of Garbyang Formation in the Girthi-Ganga Section of Kumaun. *Jour. Geol. Soc. India,* **55** (2) : 175-182.

Sudan, C. S. and Sharma, U. K. (*in Press*). Ichnocoenoses from the Tal Formation of Mussoorie and Rishikesh, Lesser Himalaya, India. *Jour. Ind. Asso. Sedi.*

Sudan, C. S., Sharma, U. K., Sahni, A. K. and Shah, S. K. 2000. Trace fossils from the Pin section of Spiti Valley, Himachal Pradesh and their Stratigraphic significance. *Jour. Geol. Soc. India,* **55**(**6**) : 649 - 654.

Srikantia, S. V. 1981. Lithostratigraphy, Sedimentation and Structure of Proterozoic - Phanerozoic Formations of Spiti basin in Higher Himalaya of Himachal Pradesh, India, p. 32-48. In: *Contemporary Geoscientific Researches in Himalaya,* (Ed. Sinha, A. K.).

Sternberg, K. M. Graf. Von. 1833.Versuch einer geognostisch - botanischen Darstellung der Flora der Vorwelt. Fr. Fleischer - Leipzig, Prague, **1** : 1-80.

Tanaka, K. 1971. Trace fossils from the Cretaceous flysch of the Ikushumbetsu area, Hokkaido, Japan. *Geol. Surv. Japan, Rep.* **236**, 102 p.

Vossler, S. M., Magwood, J. P. A. and Pemberton, S. G. 1989. The youngest occurrence of the ichnogenus *Didymaulichnus* from the Upper Cretaceous (Turonian) *Cardium* Formation. *Jour. Pal.* **63** : 384-386.

Webby, B. D. 1970. Late Precambrian Trace fossils from New South Wales. *Lethaia,* **3** : 79-109.

Wetzel, A. 1981. Okologische and Stratigraphische Bedeutung Biogener Gefuge in quartaren sedimenten am NW-afrikanischen Kontinentalrand. *"Meteor" Forschungs-Ergebnisse, Reihec,* **34** : 1-47.

Wright, A. D. and Benton, M. J. 1987. Trace fossils from Rhaetic shoreface deposits of Staffordshire. *Palaeont.* **30** : 407 - 428.

Young, F. G. 1972. Early Cambrian and older trace fossils from the Southern Cordillera of Canada. *Canadian Jour. Earth Sci.* **9** : 1-17.

Manuscript accepted July 2001