Ichnology of the Early Cambrian Tal Group, Mussoorie Syncline, Lesser Himalaya, India

Meera Tiwari*, S K Parcha, Rajita Shukla and Harshita Joshi

Wadia Institute of Himalayan Geology, 33, General Mahadeo Singh Road, Dehradun 248 001, India.
**Corresponding author. e-mail: mtiwari@wihg.res.in, meeratiwari2@gmail.com*

The Lesser Himalayan sequence is considered as one of the best developed sections of Cambrian successions, exposed in five different synclines. Mussoorie Syncline, being one of the five synclines, exposes the Cambrian Tal Group. This paper describes nine ichnotaxa, viz., *Dimorphichnus* isp., ?*Diplichnites* isp., *Monomorphichnus* isp., *Nereites* isp., *Palaeopasichnus* isp., *Palaeophycus* isp., *Planolites montanus, Planolites* isp., *Skolithos* isp., *Treptichnus* isp. from the Dhaulagiri Formation of the Tal Group. A detailed analysis of the ichnofossils indicates that the entire succession of Tal Group reflects shallow marine conditions in general and Mussoorie Syncline in particular. The above ichnofossil assemblage along with earlier ichnofossils and other faunal occurrences substantiates the assignment of Early Cambrian age to the Dhaulagiri Formation.

1. Introduction

The Mussoorie Syncline is the most important area for understanding the Early Cambrian paleobiology of the Lesser Himalaya. The Tal Group of Mussoorie Syncline provides numerous Ediacaran to Cambrian transitional sections. Due to less susceptibility to taphonomic bias, particularly in areas dominated by siliciclastic sediments, trace fossils are considered as important palaeoenvironmental indicators and may trace the evolution of lifestyles of marine benthic organisms (Conway Morris 1993, 1998; Erwin *et al.* 1997; Droser *et al.* 1999; Jensen *et al.* 2000). A number of researchers described trace fossils including trilobite traces and body fossils from the Tal Group of Mussoorie Syncline (Banerjee and Narain 1976; Kumar *et al.* 1983; Singh and Rai 1983; Bhargava 1984; Singh *et al.* 1984; Rai 1987; Tiwari and Parcha 2006). Present work has yielded new ichnological data from the B member of Dhaulagiri (Upper Tal) Formation and the purpose of this paper is to describe and discuss the implications of trace fossils from this part of the Mussoorie Syncline.

2. Geology of the area

The topmost lithostratigraphic unit of the Krol Belt of Lesser Himalaya is represented by the Tal Group. Medlicott (1864) identified it for the first time in Nilkanth area of Garhwal Syncline. Subsequently, several other researchers proposed different schemes of classification (Middlemiss 1887; Auden 1934; Bhargava 1972; Shanker 1973, 1975; Valdiya 1975; Shanker *et al.* 1993). In the present work, the scheme proposed by Shanker *et al.* (1993) is followed. In Mussoorie Syncline, the Tal Group conformably overlies the Kauriala Formation of the Krol Group and is in turn overlain unconformably by the Shell Limestone Formation. The Tal Group is divisible into two formations, viz., Deo-ka-Tibba (Lower Tal) and Dhaulagiri (Upper Tal) (table 1). The Deo-ka-Tibba Formation consists of chert,

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Table 1. *Generalised stratigraphic succession of the area based on Shanker et al. (1993).*

Group	Formation	Member	Description
Tal	Dhaulagiri (Upper Tal)	E	Quartz-arenite, shale and siltstone
		D	Algal limestone and siltstone
		C	Felspathic quartz-arenite
		B	Black shale and quartz-arenite
		A	Quartz-arenite
	Deo-ka-Tibba (Lower Tal)	Calcareous	Calcareous, ferruginous siltstone, siliceous limestone
		Arenaceous	Banded siltstone
		Argillaceous	Black shale with calcareous bands
		Chert	Bedded chert with black shale and rock phosphate
Krol	Kauriala (Upper Krol)		Argillaceous limestone with interbedded calcareous shale
			Dolomitic limestone and shale bluish grey limestone
	Jarashi (Middle Krol)		Red to purple coloured shales with some intercalated green shale layers
	Mahi (Lower Krol)		Grey to greenish-grey calcareous shales to siltstones and argillaceous limestones
	Chambaghat		Sandstone, orthoquartzite and lenses of sandy units
Baliana	Infrakrol		Dark carbonaceous shales/siltstones
	Blaini		Conglomerate diamictite grading upward into carbonate bed

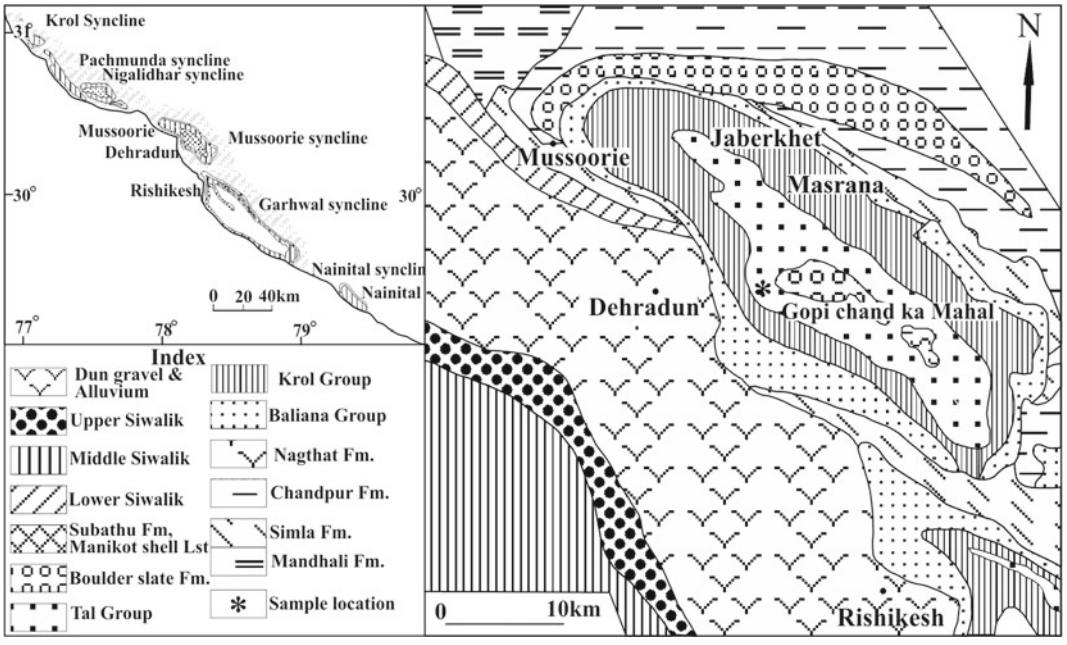

Figure 1. Geological map of the area showing fossil locality.

black shale, siltstone and siliceous limestone and is subdivided into four informal members, viz., Chert, Argillaceous, Arenaceous and Calcareous members. The Dhaulagiri Formation consists of quartz arenite, with minor felspathic arenite, shale, siltstone and limestone. It is divisible into five informal members, viz., A, B, C, D and E (Bhargava 1972; Shanker 1973, 1989; Shanker *et al.* 1993). The present fossil assemblage occurs within member B of the Dhaulagiri Formation. Trace fossils were collected from a well-bedded section of greyish-black siltstone with minor intercalation of silty shale layers, occurring below thin quartz arenite, exposed along the Maldeota–Dhaulagiri road section, approximately 4 km from Dhaulagiri (30°20′39.5″:78°09′39.1″) (figures 1 and 2).

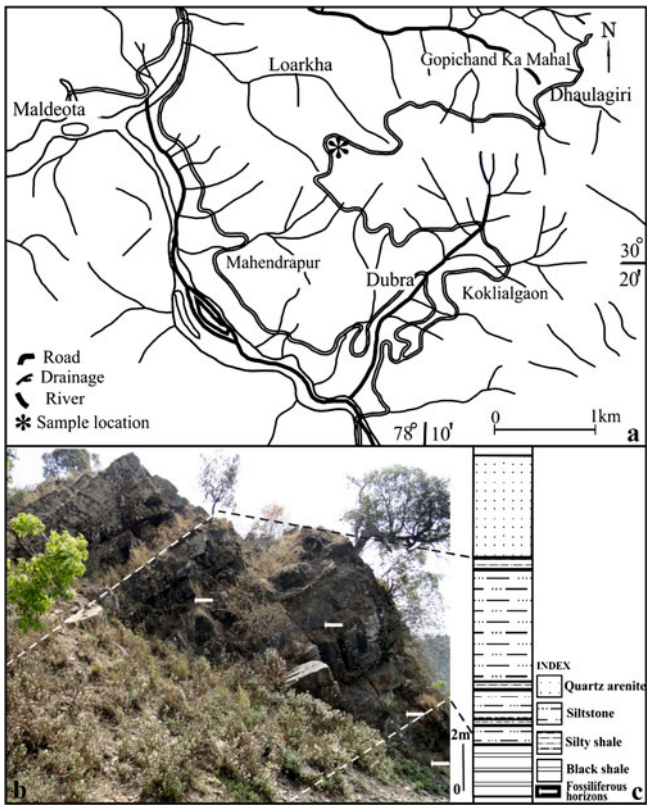

Figure 2. (**a**) Road map of the area. (**b**) Field photograph of the area, arrows point to sample location. (**c**) Litholog of the area showing sample location.

3. Trace fossil occurrences

In Mussoorie Syncline, the Arenaceous member of Deo-ka-Tibba (Lower Tal) Formation has yielded considerable number of trace fossils. Banerjee and Narain (1976) were the first to report trace fossil *Aulichnites* from the Arenaceous member. The reported trace fossils mainly belong to *Skolithos* and *Cruziana* ichnofacies with an abundance of arthropod traces like *Diplichnites*, *Merostomichnites*, *Dimorphichnus*, *Monomorphichnus*, *Protichnites* and *Tasmanadia* (Kumar *et al.* 1983; Singh and Rai 1983; Bhargava 1984; Singh *et al.* 1984; Rai 1987). In contrast, there are limited reports of trace fossil from the Dhaulagiri Formation. The published reports include trace fossils *Paleophycus* and *Skolithos* along with arthropod traces of Lower Cambrian affinity from member A of Dhaulagiri Formation (Bhargava 1984; Rai 1987; Bhargava *et al.* 1998). The lowermost part of Dhaulagiri Formation on the Mussoorie–Dhanaulti road section has yielded Early Cambrian trace fossils similar to those of the Arenaceous member of the Deo-ka-Tibba Formation. The reported trace fossils are *Monomorphichnus* isp., *Dimorphichnus* isp., *Diplichnites* isp. *A*, *Planolites* isp., *Skolithos* isp., *Merostomichnites* isp., ?*Neonereites* isp., along with various scratch marks and burrows (Tiwari and Parcha 2006). The member B of Dhaulagiri Formation contains nine new ichnotaxa (this paper) identified as *Dimorphichnus* isp., ?*Diplichnites* isp., *Monomorphichnus* isp., *Nereites* isp., *Palaeopasichnus* isp., *Palaeophycus* isp., *Planolites montanus*, *Planolites* isp., *Skolithos* isp., *Treptichnus* isp. along with some meandering trails.

The ichnogenera described here are housed in the repository section of the Wadia Institute of Himalayan Geology Museum, Dehradun, India and bear the catalogue numbers WIHG/A/1921–WIHG/A/1935.

4. Systematic ichnology

Ichnogenus *Dimorphichnus* Seilacher (1955)
Dimorphichnus isp.
Figure 3(h)
Material: One specimen is preserved as a hyporelief.
Repository: WIHG/A/1925.
Description: Two sets of asymmetrical, small, unbranched, wedge and rib-shaped markings of varying size. Each individual wedge is set 3–6 mm apart from the other; length of the individual markings varies from 6–10 mm and width from 2–4 mm. Some of the markings are shifted towards the other side, suggesting changes in the movement of the animal. The infilled material in the markings is same as the host material.
Remarks: The present specimen is comparable to the ichnogenus *Dimorphichnus* due to its curved and sub-parallel ridges. The specimen differs from *Dimorphichnus* isp. reported from the Cambrian sequences of the Tethyan Himalayan region, in nature and pattern of wedge markings (Shah and Sudan 1983; Bhargava and Bassi 1988; Parcha 1998; Parcha and Singh 2010; Parcha and Pandey 2011). It equally differs from the ichnospecies *Dimorphichnus* described by Singh and Rai (1983) and by Tiwari and Parcha (2006) from the Lesser Himalaya and also with the species described by Kumar and Pandey (2010) from Rajasthan. This ichnogenus is also known from the Lower Cambrian successions of Salt Range (Seilacher 1955, 1967).

Ichnogenus *Diplichnites* Dawson (1873)
?*Diplichnites* isp.
Figure 3(g)
Material: Specimen preserved as hyporelief.
Repository: WIHG/A/1927.
Description: Well-preserved markings in a single row; markings curved and parallel to each other. The individual length of the markings varies from 8–13 mm and width from 2–3 mm. The distance between two parallel markings is 3–4 mm.

Figure 3. (**a**, **c**) *Monomorphichnus* isp., (**b**) *Skolithos* isp., (**d**) *Planolites* isp., (**e**) *Palaeopasichnus* isp., (**f**) *Treptichnus* isp., (**g**) ?*Diplichnites* isp., and (**h**) *Dimorphichnus* isp.

The markings indicate crawling activity of an arthropod on the soft sediments.

Remarks: The present specimen is grouped under the ichnogenus *Diplichnites* because of the presence of serial markings and curved nature. The specimen differs with *Diplichnites* ichnospecies described from the Lesser, Spiti and Zanskar Himalaya in the absence of two parallel, equally spaced rows (Parcha 1998; Tiwari and Parcha 2006; Parcha and Singh 2010; Parcha and Pandey 2011).

Ichnogenus *Monomorphichnus* Crimes (1970)
Monomorphichnus isp.
Figure 3(a, c)

Material: Two slabs of coarse-grained sandstone showing two specimens on the sole of the bed. The specimens are preserved as positive relief.

Repository: WIHG/A/1929, 1930.

Description: Series of isolated, slightly curved ridges repeated laterally, moderately spaced from each other; ridges vary in length from 8–10 mm, in width from 1.5–2 mm and are 2–3 mm apart from each other.

Remarks: The present specimen differs from *Monomorphichnus monolinearis* described from Kashmir by Shah and Sudan (1983) and with the species of *Monomorphichnus* described from Zanskar (Parcha 1998; Parcha and Singh 2010) and Spiti (Parcha and Pandey 2011) in the nature and pattern of the ridges. The present specimens equally differ from *Monomorphichnus* species described from member A of the Dhaulagiri Formation of the Lesser Himalaya (Tiwari and Parcha 2006), *Monomorphicnus lineatus* described from Calcareous member of Deo-ka-Tibba and A, B members of Dhaulagiri Formation in Nigalidhar Synform (Desai *et al.* 2010) and from *Monomorphichnus* isp. described from Rajasthan, in nature, size and pattern of ridges (Kumar and Pandey 2010). The ichnogenus *Monomorphichnus* is recorded from almost all the Cambrian successions of the Tethyan Himalayan regions.

Ichnogenus *Nereites* Macleay (1839)
Nereites isp.
Figure 4(f)

Repository: WIHG/A/1923.

Material: One specimen preserved in siltstone as positive relief.

Description: Simple, irregular, meandering trail with numerous irregular pellets; meanders of variable dimensions and touching the neighbouring segments. The total length of the trail is 35 mm; length of the individual lobe varies from 6–8 mm whereas the width varies from 3–4 mm.

Remarks: The specimen shows close similarity with the ichnogenus *Nereites* in its meandering pattern of the trail. The present form differs from the *Nereites* isp. described from the Spiti Basin in having a single row of claw markings as compared to two rows in the latter (Parcha and Pandey 2011).

Ichnogenus *Palaeopasichnus* Palij (1976)
Palaeopasichnus isp.
Figure 3(e)

Material: One specimen preserved in coarse-grained sandstone as positive relief.

Repository: WIHG/A/1931.

Description: Bars arranged in a single row; bars closely spaced, wide in the middle and elongated towards the margins. The number of bars in a row is 12. The total length of the row is 85 mm; length of individual bar varies from 6–15 mm and width varies from 3–7 mm; the distance between two successive bars varies from 4–6 mm.

Remarks: The present specimen shows close similarity with the ichnogenus *Palaeopasichnus* in nature and pattern of bars. The specimen differs from *Palaeopasichnus* from the Cambrian of Spiti Basin in its unbranching nature (Parcha and Pandey 2011).

Ichnogenus *Palaeophycus* Hall (1847)
Palaeophycus isp.
Figure 4(b)

Material: One specimen preserved in coarse-grained sandstone.

Repository: WIHG/A/1928.

Description: Smooth and curved bulbous burrow with faintly preserved constrictions. The length of the burrow is 12 mm and the maximum width is 3 mm. Infilling material of the burrow is same as that of the host rock.

Remarks: The specimen differs with *Palaeophycus tubularis* Hall (1847) and that described by Desai *et al.* (2010) from the Tal Group in the length–width ratio. The specimen differs with the form described from Spiti in the absence of short ridges on the surface (Parcha and Pandey 2011). The specimen also differs with *Palaeophycus bolbitermilus* described by Kim *et al.* (2000) in the absence of terminal bulbs.

Ichnogenus *Planolites* Nicholson (1873)
Planolites montanus Richter (1973)
Figure 4(e)

Material: Two well-preserved specimens preserved as hyporelief.

Repository: WIHG/A/1935.

Description: Simple, horizontal, unbranched smooth burrows varying from 4–5 mm in diameter and up to 60 mm in length. The sediment fill of the burrow is of the same material in which they are preserved.

Remarks: The present specimen shows close resemblance in morphology to *Planolites montanus*

Figure 4. (**a**, **c**) *Planolites* isp., (**b**) *Palaeophycus* isp., (**d**) winding trails, (**e**) *Planolites montanus* and (**f**) *Nereites* isp.

Richter described by Metz (1995), hence assigned to the same ichnospecies.

Ichnogenus *Planolites* Nicholson (1873)
Planolites isp.
Figure 4(a, c)
Material: Two slabs of coarse-grained sandstone containing five well-preserved specimens preserved as hyporelief.
Repository: WIHG/A/1933–1934.
Description: Straight to slightly curved, horizontal, short, smooth burrows of varying shapes and diameters, lacking wall lining. The individual length of the burrow varies from 20–35 mm, whereas, the width varies from 5–8 mm. Burrows are slightly expanded at one end. The sediment filling of the burrows is of the same material as the host rock.

Remarks: The present specimens closely resemble ichnogenus *Planolites* in their unbranched nature. The present form differs with the *Planolites* described from the Cambrian of Zanskar Valley (Parcha and Singh 2010) and Spiti in the absence of closely spaced striae (Parcha and Pandey 2011). It shows some affinity with the species described from the A member of Dhaulagiri Formation but differs with it in the nature of burrow (Tiwari and Parcha 2006). It is often difficult to make a distinction between morphologically similar ichnogenera *Planolites* and *Palaeophycus*, apart from the nonbranching nature of the burrow. However, the specimen differs with all the known ichnospecies of *Planolites* in nature and pattern of burrow. It is the most common ichnogenus found in the Lesser and Tethyan Himalayan regions.

Ichnogenus *Skolithos* Haldemann (1840)
Skolithos isp.
Figure 3(b)
Material: The specimens are preserved on three slabs of micaceous sandstone.
Repository: WIHG/A/1922–1926.
Description: Small, straight, unbranched, vertical burrows occurring as circular to sub-circular bodies on the surface of the bedding plane; diameter of the burrows ranges from 2–7 mm, the inner circle of the burrow ranges from 2–5 mm; space between burrows is wide; burrow is filled with same sediment as the host rock. Vertical section is also well-preserved.
Remarks: The present ichnospecies shows some similarity with *Skolithos linearis* Haldemann (1840), but differs with it in pattern and nature of burrow. Similar type of trace fossils were reported from the Dhaulagiri Formation (Tiwari and Parcha 2006). The present specimen differs from the *Skolithos* isp. described from Zanskar and Spiti in the absence of inner circle (Parcha and Singh 2010; Parcha and Pandey 2011). In the described specimens, slight inclination of burrow is seen in vertical section.

Ichnogenus *Treptichnus* Miller (1889)
Treptichnus isp.
Figure 3(f)
Material: The present specimen is preserved as epirelief.
Repository: WIHG/A/1932.
Description: Short, curved burrows having branches; the burrows vary in width from 3–6 mm and length from 8–18 mm. Alternating set of burrows bifurcate to give rise to branches.
Remarks: The specimen shows close resemblance with the ichnogenus *Treptichnus*, but differs from all known species of this genus in the nature of burrow. It shows some resemblance with *Treptichnus pedum* in nature and pattern of the burrow but due to poor preservation the present specimen could not be grouped with this species.

Winding Trails
Figure 4(d)
Material: The present specimen is preserved as epirelief.
Repository: WIHG/A/1924.
Description: Thin trail more or less straight, tapering at one end; the diameter of the trail ranges from 2–3 mm and varies in length from 20–35 mm; the in-filled sediment is same as that of the host rock.

5. Discussion and conclusion

The Tal Group contains a variety of trace fossils, most of which are facies independent. The studied assemblage of trace fossils is found in the form of tracks, burrows, grooves along with scratch marks, whereas trails occur as grooves and ridges with positive epireliefs. The present ichnofossil assemblage is dominated by surface trails along with simple forms like vertical to horizontal burrows having distinct lined walls.

The detailed analysis of the earlier described trace fossils by different researchers and those from the present study area indicates that there exist two distinct levels of trace fossils, one in the Arenaceous member of the Deo-ka-Tibba Formation and the other in the A and B members of the Dhaulagiri Formation. Earlier, Rai (1987) assigned a Lower Cambrian age to the Arenaceous member of the Deo-ka-Tibba Formation, exposed in Mussoorie Syncline on the basis of ichnogenera *Rusophycus*, *Cruziana*, *Skolithos*, *Plagiogmus* and *Diplichnites*. A lower Cambrian age was also suggested for lower part of Dhaulagiri Formation (=Sankholi Formation) exposed in Nigalidhar Syncline (Bhargava 1984; De *et al.* 1994; Desai *et al.* 2010). Similarly, a trace fossil assemblage comprising *Monomorphichnus* isp., *Dimorphichnus* isp., *Diplichnites* isp. A, *Planolites* isp., *Skolithos* isp., *Merostomichnites* isp. and ?*Neonereites* isp. was reported from member A of the Dhaulagiri Formation (Tiwari and Parcha 2006), whereas, member B contains a much diverse and better preserved assemblage consisting of *Nereites* isp., *Palaeopasichnus* isp., *Palaeophycus* isp., *Planolites montanus, Skolithos* isp., *Treptichnus* isp., *Dimorphichnus* isp., ?*Diplichnites* isp., *Monomorphichnus* isp., and *Planolites* isp. Similar ichnogenera have also been reported from the Lower Cambrian successions of the Tethyan Himalayan sequences exposed in Parahio section of Spiti and in Zanskar basin, where the ichnofossil-bearing horizon is overlain by definite Lower Cambrian and Middle Cambrian trilobite-bearing horizons (Parcha and Singh 2010; Parcha and Pandey 2011). In Mussoorie Syncline, presence of inarticulate brachiopods from member B of the Dhaulagiri Formation further suggests Atdabanian (=Qiongzhusian/Chiungchussu) age (Early Cambrian) for the Dhaulagiri Formation (Tripathi *et al.* 1984). Therefore, the ichnofossil assemblage and the body fossils indicate an Early Cambrian age to the Dhaulagiri Formation.

The traces described here are interpreted to be dwelling traces made by filter feeding organisms. The traces are moderately crowded on bedding plane and are restricted to the thinly laminated sandy and silty layers only, thereby indicating substrate preference of the trace making organisms. This indicates low to moderate oxygenated conditions. The dominance of deposit feeding traces indicates presence of abundant food resources along

with low to moderate energy and low turbidity conditions. The detailed analysis of the trace fossils indicates fluctuating energy conditions with fluxes of turbid water. The studied ichnofossils indicate shallow marine depositional conditions for the entire succession of the Dhaulagiri Formation.

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