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Palaeoecological significance of ichnofossils from the Early Cambrian succession of the Spiti Valley, Tethys Himalaya, India

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The diverse assemblage of ichnofossils recorded from the Early Cambrian succession of the Kunzum La Formation in Spiti basin ranges in age from the Chiungchussuian stage of the Lower Cambrian to the Maochuangian stage of the Middle Cambrian. The trace fossil assemblage is dominated by *Cruziana*, *Skolithos* and partially by the *Nerites* ichnofacies, showing behavioural diversity from suspension to deposit feeders. Distribution of the observed ichnofacies variation is attributed to the availability of oxygen and nutrient influx. Ichnofossil studies of this area further indicate that the benthic palaeocommunity was dominated by annelids or similar worm-like animals living predominantly within the sediments, while the trilobites were trailing on the sea floor. The inferred palaeoecological distribution of ichnofossil assemblage is based on modern analogue of ocean slope and shelf zones. The litho and ichnofacies association indicates anaerobic to dysaerobic trends of the ichnofauna from *Nereites* to *Skolithos* ichnofacies. Three distinctive lithofacies association have been recognized and the stratigraphic disposition reflects a general upward coarsening of the sediments.

THE Tethys Himalaya extends north of the Himadri (Great Himalaya) along the northern margin of the Indian plate. The entire Tethyan sediments, divisible into five sub-basins, are represented predominantly by the Spiti and the Zanskar basin. The present work is restricted to the Spiti basin, which is flanked in the north by the Zanskar range and in the south by the Dhauladhar–Pir-Panjal range (Figure 1).

Various workers have worked out the stratigraphy and geology of the Spiti[1–9] and Parcha[10–12]. The Cambrian sediments of Spiti basin are well exposed in the Pin, Parahio valleys, and also around the Kunzum-La-Tackche area. The Lower Cambrian succession in the Spiti basin is rich in trace fossils; occurring in many horizons within siltstone, shale and sandstone. Trace fossil fauna from this area has also been reported by many researchers[10–17]. Since the body fossils are not reported/absent in the basal part of the Lower Cambrian particularly in the Spiti basin, the detailed study of trace fossils is of increased importance, particularly for deciphering the palaeoecology of the area. In the

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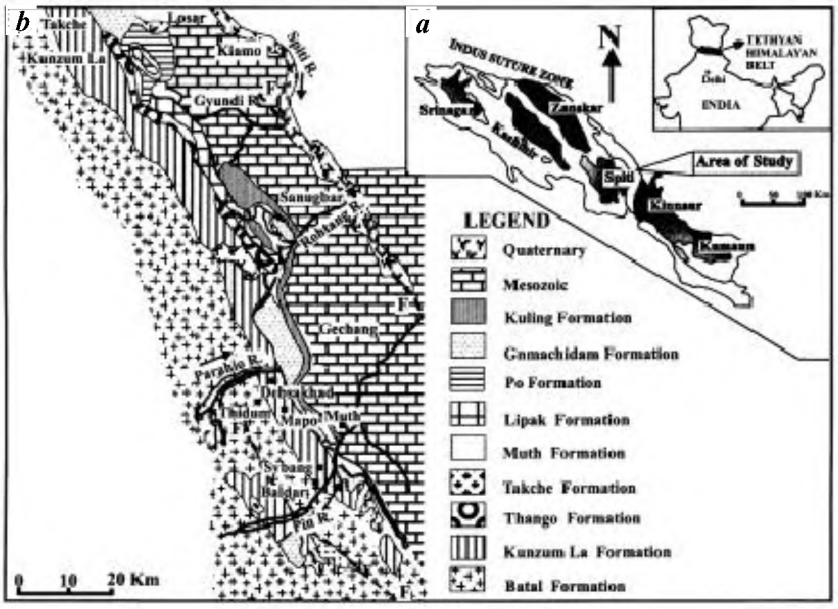

Figure 1. ***a***, Inset showing the distribution of Tethyan basins of the Himalayan regions. ***b***, Geological map of Spiti valley showing the Palaeozoic–Mesozoic rocks of the Spiti basin of Himachal Pradesh, India (modified after Bhargava *et al.*[9]).

present investigation, the trace fossil assemblage recorded from Pin–Parahio area is interpreted for revealing the palaeoenvironment and palaeoecology of the Early Cambrian succession in the Spiti Valley.

The Cambrian rocks conformably overlie the Precambrian rocks 'Vaikrita System'. The term 'Haimanta System' was given by Griesbach[2] for the Cambrian rocks but later on Srikantia[6] provided the term Haimanta Group. The Haimanta Group consists of Batal, Kunzum-La and Thango formations.

The Kunzum-La Formation overlies the Batal Formation. In the Kunzum-La–Tackche section of the Spiti Valley, the Kunzum-La Formation is well exposed and consists of greenish-grey siltstone, shale, slate, quartzite, sandstone, dolomite and local pebbly beds[6]. The Kunzum-La Formation passes upward unconformably into the Thango Formation.

Trace fossils were collected from the Kunzum-La Formation exposed in Kunzum-La–Tackche, Pin and Parahio sections of the Spiti Valley. Detailed lithologic set-up and distribution of their trace fossil bearing horizons is illustrated in Figure 2.

Sixteen genera of trace fossils were identified. The recorded genera include *Bergaueria*, *Cruziana*, *Chondrites*, *Diplichnites*, *Dimorphichnus*, *Gordia*, *Gyrochorte*, *Helminthopsis*, *Monomorphichnus*, *Planolites*, *Phycodes*, *Rusophycus*, *Skolithos*, *Trichophycus*, *Taphrhelminthopsis*, *Neonereites* and trilobites scratch marks. The trace fossil taxa *Phycodes*, *Trichophycus*, *Planolites* and *Chondrites* occurred simultaneously in the basal part of the Lower Cambrian rocks. The assemblage of recorded trace fossils shows change, both in abundance and diversity throughout the succession. The diversity increases upwards in the sections and is dominated by the trace fossils taxa of shallow-water neritic zone (shelf and slope) like *Diplichnites*, *Dimorphichnus*, *Rusophycus*, *Monomorphichnus*, *Phycodes*, *Trichophycus* and *Cruziana*. *Skolithos* ichnofacies occur in association with the trilobite scratch marks, higher in the succession. In all the sections of the Spiti basin, no early Cambrian trilobite has been reported so far immediately from the underlying and overlying strata or in association with the present trace fossil assemblages. The only trilobite of early Cambrian reported so far from the Pin valley section is *Redlichia noetlingi* by Hayden[3] and Parcha[10–12], but both have been collected from the float and not *in situ*. It seems that the *Pagetia*-bearing horizons, which occur well above the trace fossil-bearing horizons in the Kunzum-La Formation, may be younger than the *Redlichia noetlingi* bearing beds. Hence, the present trace fossil assemblage may represent the Chiungchussuian stage of the Lower Cambrian to the Maochuangian stage of the early Middle Cambrian.

The ichnofossil assemblage represents resting and grazing traces together with trails preserved in sandstone, siltstone and intercalated shale beds. Majority of the trace fossils represent trails and tracks on bedding planes. The parallel-elongated ridges with intermediate, narrow, V-shaped depression of *Cruziana* are preserved as positive hyporeliefs. Spiral markings of *Helminthopsis* are preserved in association with other trace fossil taxa as *Gyrochorte*, *Gordia*, *Neonereites* and *Taphrhelminthopsis*. Traces of trilobite activity in the form of *Diplichnites*, *Dimorphichnus*, *Mono-*

morphichnus and *Rusophycus* are also well preserved in shale and silt stone beds.

In all, three distinctive lithofacies associations are recognized on the basis of field characteristics and lithology. The vertical stratigraphic disposition reflects a general upward coarsening of the sediments in all the sections. The basal part in all the sections is marked by the presence of shale–sandstone facies association (facies association-1) deposited in the turbidity current dominant environment, while upsection siltstone–sandstone facies association (facies association-2) represents predominantly shelf-to-slope environment. The lithofacies association-2 appears deposited under sufficient water depth and where weak turbidity currents were active. The top part of all the sections is dominated by siltstone–quartzite lithofacies association (facies association-3), thereby indicating barrier-to-shelf environment of deposition.

The important characteristics of the lithofacies associations, occurrence and distribution of the ichnofacies in them, and their significance in interpreting the bathymetry are illustrated below.

Facies association-1. Is represented by thick intercalation of shale and sandstone units. The trace fossils are mainly associated with sandstone facies. The grey-coloured sandstone is mainly bedded. The particles are of bimodal distribution dominated by medium grains and show concavo-convex contact. Angular polycrystalline quartz grains occur in association with muscovite flakes and clay matrix. The mica flakes are bent along the quartz grains and rock fragments give appearance of a pseudomatrix. The angular grains of quartz indicate their local supply from a nearby metamorphic provenance. This facies has undergone a high degree of compaction that is evident from bent micaceous flakes. This lithofacies is dominated by ichnofabrics of *Planolites*, *Chondrites*, *Trichophycus*, *Phycodes*, worm and burrows and *Helminthopsis* of shallow to deep slope *Nereites* ichnofacies (Figure 3). The mode of preservation of these ichnofabrics, the grey colour of sandstone, sufficient amount of matrix and wacke-type of composition of lithofacies suggest this lithofacies to be deposited under weakly oxidizing–weakly reducing environment and sediments were laid down by the turbidity currents.

Facies association-2 is marked by intercalations of laminated grey siltstone and grey sandstone. The trace fossils mainly occur in the siltstone facies. The siltstone contains silt-sized quartz grains in clay-rich matrix. The clay minerals and mica/chlorite grains are confined along the lamina planes. Alignment of the mica and chlorite grains seems related to their slow settling, either below the wave-base or under the weak current activity and weakly oxidizing–weakly reducing environmental conditions similar to associated sandstone. The ichnofabric of this facies is dominated by *Gyrochorte*, *Gordia*, *Phycodes*, *Planolites*, *Monomorphichnus*, *Dimorphichnus* and *Chondrites* of shallow to deep shelf *Cruziana* and *Arenocolite* ichnofacies (B, C; Figure 3).

Facies association-3 mainly consists of intercalations of thinly laminated siltstone and quartzite units. The trace fossils are mainly preserved in the quartzite facies. The quartzite (quartz–arenite) possesses sub-rounded to rounded particles and shows sub-parallel orientation with sutured contact. Polycrystalline quartz occurs along with muscovite, biotite and plagioclase. The quartz arenite seems to be deposited after sufficient transportation and reworking before sedimentation, and sutured contact suggests high depth of burial. This lithofacies is mainly dominated by *Skolithos*, *Bergaueria*, *Rusophycus* and trilobite scratch marks.

The trace fossil assemblage recovered from the analysis of the basal part of the Lower Cambrian succession of the Spiti basin permits a detailed interpretation of the palaeoecological conditions. The ichnocoenosis is dominated by a high behavioural diversity ranging from the suspension feeders to deposit feeders, displaying cubichinal, fodinichnial and domichinal behaviours. In the present study the *Cruziana*, *Skolithos* and *Nerites* ichnofacies have been recorded. In some horizons *Planolites*, *Chondrites* and *Skolithos* occur together on a single slab, demonstrating well-oxygena-

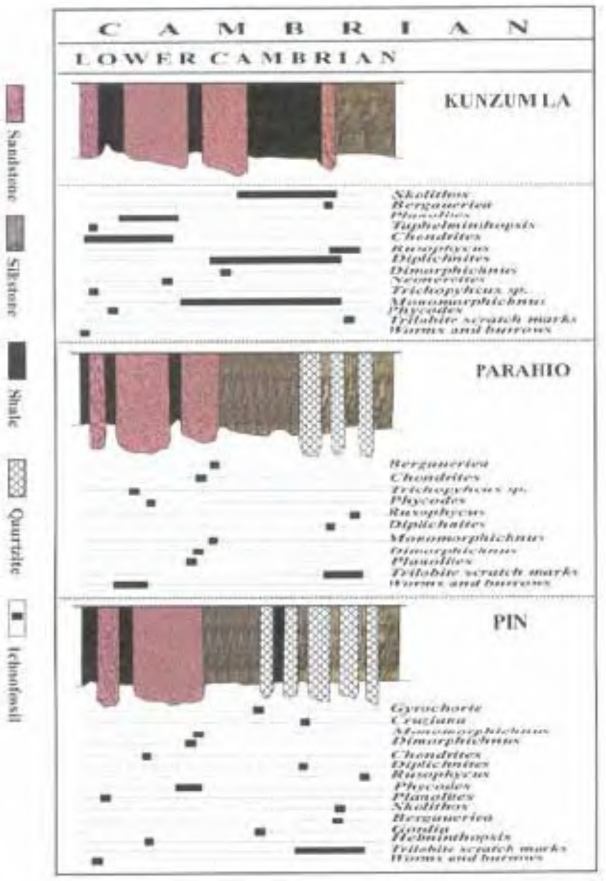

Figure 2. Ichnofossil distribution in the Lower Cambrian rocks of the Kunzum La, Parahio and Pin valley sections in the Spiti region of the Tethys Himalaya, India.

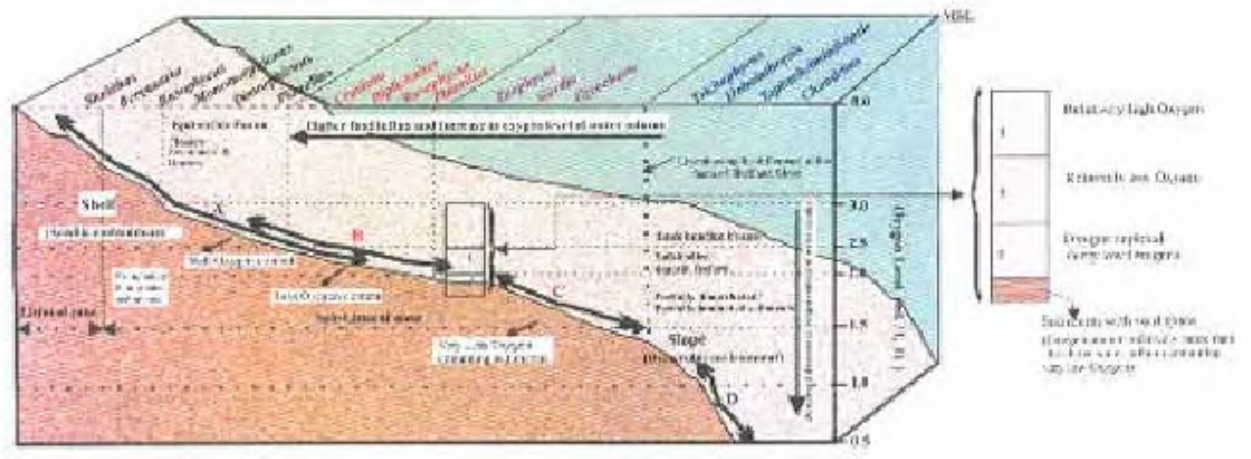

Figure 3. Ichnofacies and inferred palaeoecological set-up based on ichnofossils recorded from the Early Cambrian succession of the Spiti Valley, Tethys Himalaya. Ichnofacies: A, *Skolithos*; B, *Cruziana* and *Arenicolites*; C, *Cruziana* and *Zoophycus* and D, *Nereites* (based on Savrada and Bottjer[19], Ekdale and Mason[20], and Crimes *et al.*[21]).

ted high-energy condition, whereas *Chondrites* represent an oxygen-starved, low energy condition. The ichnofossil diversity is high in sediments deposited in shelf environment, probably due to an ecological disturbance. The abundance of *Diplichnites–Rusophycus* fossil assemblage reveals the shallow marine ichnofacies. The Lower Cambrian benthic palaeocommunity thus, was dominated by annelids or similar worm-like animals living principally within the sediments, whereas the trilobites were thrashing on the sea floor. The transition from an anaerobic to aerobic condition was distinctly marked by a faunal change from endobenthic, soft-bodied, deposit feeders to epibenthic grazers (Figure 3). Bromely and Ekdale[18] observed that the anaerobic environment of the ocean water impinges on slopes and upper bathyal zone not flushed by oxygen-rich current and assigned by typical trace fossils of the *Chondrites*. The presence of *Cruziana* ichnofacies in the Spiti basin revealed that during the Early Cambrian the region was probably subjected to rapid storm-generated, accreting sand deposition. Only a solitary freshwater trace fossil, *Scoyenia* has so far been reported from the Kinnaur sections of the Lahaul region by Bhargava and Bassi[15].

Ichnofossil assemblage recorded from the Spiti region suggests that the availability of nutrients strongly influenced their distribution, as well as abundance. The assemblage was also influenced by the presence of oxygen in both water column as well as in unconsolidated sediments. It seems that the trace fossil assemblages in this region have been affected by the concentration of oxygen level in the water column. Such features have also been studied by Savrada and Bottjer[19] from Niobrara Formation, Colorado. Higher concentration of oxygen and nutrient influx along the sea shelf influences the behaviour (fodinichina, dominichina) and increased bioturbation, diversity and abundance of trace fabrics[20,21].

In the Spiti region the transition of pascichnial to domichinal activity has been observed at the middle part of the Lower Cambrian (Tsanglangpuian) stage. Further it has been noticed that the diversity is increasing upward in the succession from Lower to late Middle Cambrian (Maochuangian) stage. So far, there is no record of body fossil along with the trace fossils; it seems to be a worldwide phenomenon, which makes the presence of trace fossil interpretation useful for the constraint of palaeoenvironmental and palaeoecological analysis at this level in the region.

The characteristic trace fossil, *Trichophycus pedum* formerly *Phycodes pedum*, has not been reported in the present investigation, though the trace fossil genera, *Trichophycus* has been recorded from the Kunzum-La, Pin and Parahio sections. The genus is considered as a horizon marker for the beginning of the Cambrian though it extends upwards, but does not occur below the Lower Cambrian. So the boundary can be marked essentially at the level where *Trichophycus* first appears in these successions. In fact, the biostratigraphy of the Lower Cambrian succession of this region is presently based on the trace fossil assemblage. The typical Precambrian–Cambrian boundary marker, *Trichophycus pedum* is reported from the worldwide Cambrian sections of Australia[22], Norway[23] and in the Zanskar region of Ladakh Himalaya[11]. Thus in the absence of body fossils in these successions at this level, the Lower Cambrian biostratigraphy of the region can be marked mainly on the basis of trace fossil assemblage only.

The characteristic trace fossils collected from the lower part of the Kunzum-La Formation indicate that the lower part of the formation was deposited in the deep-to-shallow shelf setting. Hence, this diverse assemblage of trace fossils is useful to elucidate the temporal palaeoenvironment and palaeoecological conditions, which existed in the Tethyan region of the Spiti basin during the Lower Cambrian. These

studies further suggest that there existed a low energy depositional environment at this level of sedimentation.

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Multiplex PCR in diagnosis and characterization of bovine viral diarrhoea virus isolates from India

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Bovine viral diarrhoea (BVD) is one of the most economically important infectious diseases in cattle worldwide and the causative agent, BVD Virus (BVDV) is a pestivirus in the family Flaviviridae. Though prevalence of BVDV antibodies in Indian cattle has been established by serology, information on the use of multiplex PCR for diagnosis and characterization of BVDV isolates at genomic level is lacking. In this study, we report development of a multiplex polymerase chain reaction (PCR) assay using primers of 5′ untranslated region (UTR) and structural glycoprotein (E1–E2) region, which generated two different amplicons (288 bp and 784 bp) in a single tube when 13 Indian BVDV isolates were tested. Both the amplicons were found specific when restriction enzyme analysis and subsequent nucleotide sequencing of three selected isolates representing different geographic areas of India were performed. The sequence analysis of both the regions grouped them into BVDV 1b genotype. The study demonstrated that multiplex PCR can be used for identification and subsequent genotyping of BVDV isolates.

PESTIVIRUSES are important pathogens of cattle, sheep and pigs and cause significant economic losses throughout the world[1]. The genus pestivirus in the family Flaviviridae contains Bovine Viral Diarrhoea Virus (BVDV), Classical Swine Fever Virus (CSFV) and Border Disease Virus

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