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Ordovician Ichnofossils and Microbially induced Sedimentary Structures from the Takche Formation, Tethyan Himalaya: Implications for Shallow Marine Palaeoecology and Palaeoenvironments

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Abstract: This study presents the first report of ichnofossils and MISS from the Ordovician Takche Formation exposed at its type section in the Spiti region of the Tethyan Himalaya, India. The ichnoassemblage comprises eleven ichnospecies belonging to nine ichnogenera, namely *Arthrophycus, Bergaueria, Chondrites, Lockeia, Palaeophycus, Planolites, Rosselia, Rugalichnus* and *Treptichnus*. The assemblage is dominated by horizontal and shallow-tier burrows and exhibits low to moderate bioturbation intensity, indicating deposition under low-energy distal shelf conditions below the intertidal zone. Ichnofabric attributes, tiering relationships and cross-cutting patterns further suggest fluctuating benthic oxygenation. The Deep-tier *Chondrites* reflects early colonisation under dysoxic substrate conditions, followed by improved oxygenation that allowed the expansion of shallow- and intermediate-tier burrowing activity. The occurrence of microbially induced sedimentary structures, represented by (*Rugalichnus*), within fine-grained siliciclastic intervals suggests episodic suppression of benthic metazoan activity and temporary microbial stabilisation of the substrate. Notably, despite siliciclastic deposition in a shelf setting, the absence of diagnostic arthropod traces such as *Cruziana* and *Rusophycus* supports interpretation of a low-energy, distal expression of the *Cruziana* ichnofacies rather than a proximal shoreface environment. These findings refine the palaeoenvironmental interpretation of the Takche Formation at its type section and contribute to a better understanding of Ordovician benthic ecosystem organisation along the Tethyan Himalayan margin.

Keywords: Takche Formation, Ordovician, Ichnofossils, Spiti, dysoxia, ichnofabric; tiering, Tethyan Himalaya.

INTRODUCTION

The lower Palaeozoic successions of northern India occur within the Tethyan Himalayan region in a tectonically significant setting. During Ordovician-Silurian time, this region formed part of the northern margin of the Gondwana palaeocontinent, and occupied relatively low southern palaeolatitudes, of about (~25° - 30° S), (Torsvik & Cocks 2009). The Tethyan sedimentary sequence, along with the adjoining Tibetan sedimentary successions extends along the northern margin of the Indian plate, north of the Greater Himalaya. These strata are traceable across the Himalayan arc from the western syntax at Nanga Parbat to the eastern syntax at Namcha Barwa. In the Indian Himalaya, they are preserved in various sub-basins, notably the Spiti-Zanskar, Kinnaur-Uttarakhand, and Kashmir basins, all lying south of the Indus-Tsangpo Suture Zone.

Among these, the Spiti region preserves an outstanding stratigraphic record, ranging from the Neoproterozoic to Cretaceous (Bhargava 2008a,b), making it an important natural laboratory for Himalayan stratigraphers and Palaeontologists. Together with the adjoining Zanskar Basin, the Spiti Basin forms the largest marine sub-basin in this sector of the Tethyan Himalaya and represents the southwestern extension of the greater Tethyan Tibetan Basin (Rao *et al*. 1984). In this context, the present study documents the trace fossil assemblage of the Takche Formation from its type locality in the Spiti region of Himachal Pradesh, India. The Takche Formation is well exposed in the Pin Valley, Parahio Valley, and around Takche within the Spiti Basin.

Ichnofossils records the biological activity of organisms and their behavioural response to changing ecological conditions, thereby constituting an important tool for reconstructing ancient sedimentary environments. Trace fossil studies, which encompass biogenic sedimentary structures such as burrows, dwelling structures and feeding traces, provide critical evidences for interpreting sedimentology, biostratigraphy, palaeoclimatology, sequence stratigraphy, palaeoecology and evolutionary palaeoecology (Buatois & Mángano 2011). In the Indian Himalaya, diverse ichnofossils have been reported from the late Precambrian and early Palaeozoic successions in the Kashmir, Zanskar, Spiti, Kinnaur and Kumaon regions, as well as from the Cambrian successions of the Lesser Himalaya (Shah & Sudan 1983; Parcha 1998; Shah *et al*. 1998; Sudan & Sharma 2001; Parcha *et al.* 2005; Parcha & Singh 2010; Upadhyay & Parcha 2012; Parcha & Pandey 2011, 2016).

Although the lower Palaeozoic sequence of the Spiti Basin has yielded numerous trace fossils, the published record