



# Palaeo-environmental reconstruction of the Bhuban rocks of the Bhuban Formation, Surma Group exposed in the Midum Kham: an insight from ichnology

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The Bhuban rocks exposed in Midum Kham, Aizawl District of Mizoram, contains a rich ichnofossil assemblage. The present study aimed at establishing the palaeo-environmental conditions of the sedimentary rocks of the study area. The trace fossils recorded comprise 14 ichnospecies of 9 ichnogenera have been identified which include *Arenicolites carbonarius*, *Cochlichnus anguineus*, *Diplocraterion parallelum*, *Ophiomorpha nodosa*, *Palaeophycus tubularis*, *P. striatus*, *Planolites* isp., *Skolithos linearis*, *Skolithos verticalis*, *Skolithos* isp., *Teichichnus rectus*, *Thalassinoides horizontalis*, *T. suevicus* and *T. paradoxicus*. Ethologically these ichnogenera display dwelling and feeding activities of the infaunal organisms. *Arenicolites*, *Ophiomorpha*, *Diplocraterion*, *Skolithos* are the members of the *Skolithos* ichnofacies while *Palaeophycus*, *Planolites* and *Thalassinoides* are the members of the *Cruziana* ichnofacies. These ichnofacies indicate an upper shoreface to offshore transition shallow marine palaeoenvironment with fluctuating energy conditions during the deposition of the rocks of the Bhuban Formation of Mizoram.

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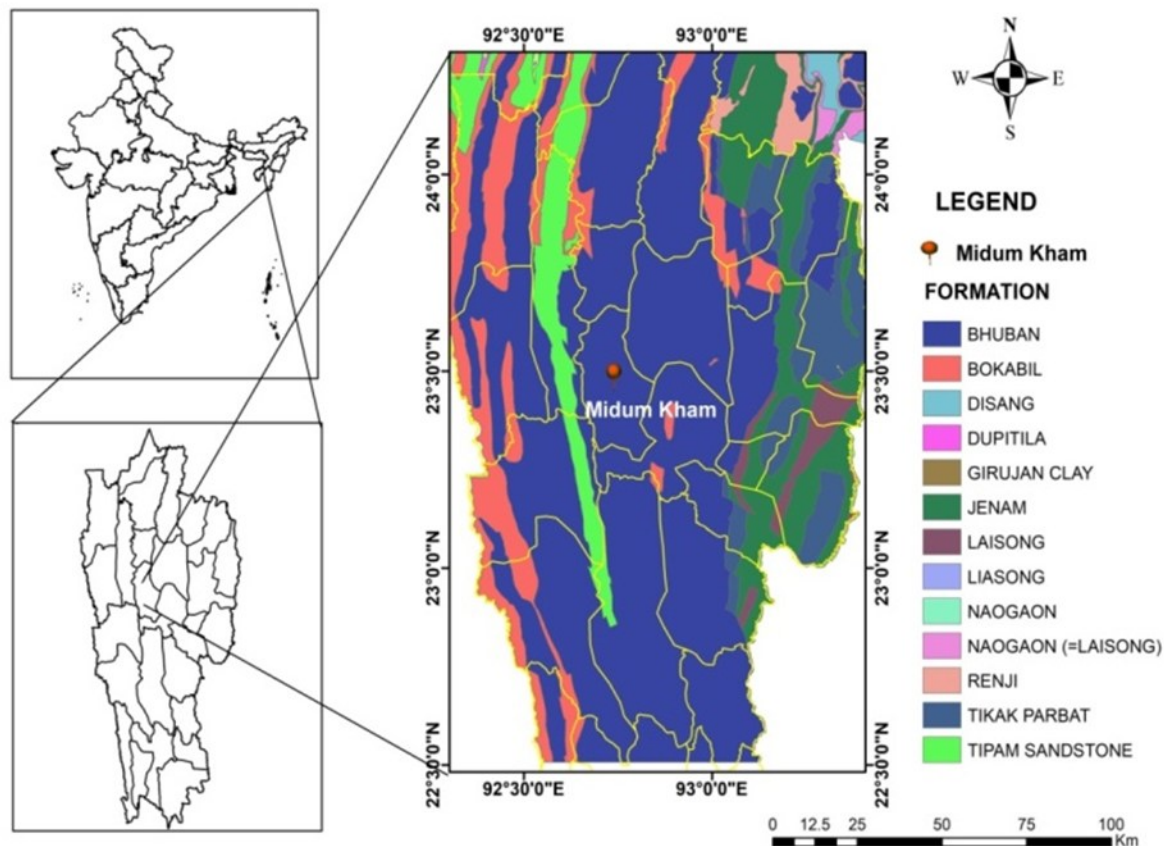
## Introduction

Trace fossils serve as indispensable proxies for interpreting paleoenvironments and stratigraphic frameworks, particularly in sedimentary successions where body fossils are poorly preserved or absent. In Mizoram, the Miocene Surma Group hosts a diverse ichnological assemblage that reflects highly dynamic marine condition.<sup>1</sup>

Despite its geological significance, the ichnology of Mizoram remains relatively understudied. The regional record began with Mehrotra et al.<sup>2</sup>, who identified *Palaeophycus* within the Barail Group of the Champhai area. Systematic documentation progressed when Tiwari et al.<sup>1</sup> reported the first ichnofossils from the Middle Bhuban unit at Bawngkawn and Ropaiabawk, Aizawl, Mizoram. This was followed by regional contributions from Rajkonwar et al.<sup>3,4</sup>, the latter providing a detailed

account of 18 ichnospecies from the Zuangtui locality.<sup>5</sup> More recent investigations include Fanai et al.<sup>6</sup>, who identified 9 ichnofossils in the South Hlimen area, and Rose et al.<sup>7</sup>, documented 11 ichnofossils from the Middle Bhuban Formation in the Siaha district. Lalawmpui et al.<sup>8</sup> documented trace fossils in Oligocene (Barail Group) of Champhai district.

The primary objective of this research is to systematically describe the ichnofossil assemblage of the Upper Bhuban succession at Midum Kham. By integrating these ichnological data with lithological observations, this study aims to refine the depositional models and reconstruct the prevailing paleoenvironmental conditions during the Miocene in this sector of the Surma Basin.



**Figure 1.** Location of the study area. (Source Geological Survey of India (GSI) Bhukosh portal. <https://bhukosh.gsi.gov.in/Bhukosh/Public>)

## Materials and Methods

A comprehensive laboratory study was conducted on the ichnofossils of the Bhuban Formation, focusing on their systematic description. By utilizing type materials and existing literature, field data and photo were collected, in terms of lithological variations, distribution, and occurrence of fossils bed-wise and sedimentary structures. The specimens were classified group-wise down to the species level. Simultaneously, ecological data such as fossil-sediment associations and spatial distribution were recorded to evaluate the environmental conditions prevalent during the time of deposition.

### Study Area and Geological Setting

The study area which is located between Thiak and Sumsuih Village is situated south of Aizawl, Mizoram (Figure 1), geographically bounded by coordinates  $23^{\circ}27'55''$  N and  $92^{\circ}44'20''$  E, encompassing the region between Thiak and Sumsuih villages. The investigated section

comprises a ~428 m thick stratigraphic succession characterized by sandstone, alternating sandstone-shale sequences, and siltstone. Notably, the majority of the recorded ichnofossils are hosted within the sandstone and silty sandstone facies, serving as an indicator of the prevailing paleoenvironmental conditions during deposition.

In Mizoram, the Tertiary succession is stratigraphically divided into three primary units: Barail Group (Oligocene), Surma Group (Lower to Middle Miocene) and Tipam Group (Upper Miocene to Early Pliocene). The Surma Group is further subdivided into the Bhuban and Bokabil Formations. Within this framework, the Bhuban Formation represents the most significant lithostratigraphic unit in the region and is categorized into three distinct members: Lower, Middle, and Upper. This stratigraphic succession is worked out by Ganju<sup>9</sup> and Karunakaran<sup>10</sup>. The lithology of the study area is defined by a cyclic sedimentary column featuring repetitive suites of arenaceous (sandy) and argillaceous (muddy) rocks. Specifically, the exposed succession belongs to the Bhuban Formation dominated by sandstone and siltstone, calcareous sandstone, and intraformational conglomerate (Figure 2).

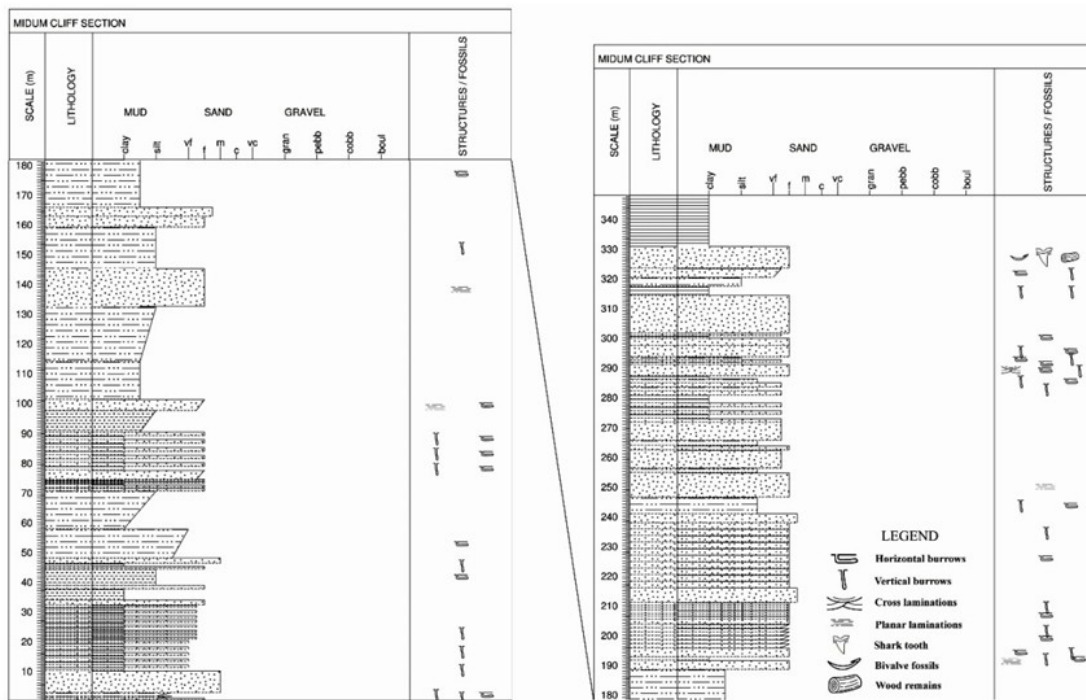


Figure 2. Litho-column of the study area

Results

Systematic Description

The collected ichnofossils are identified and described in the Palaeontology Laboratory of the Department of Geology, Mizoram University, Aizawl, Mizoram. The identified ichnospecies are named using the International Code of Zoological Nomenclature (ICZN) and described alphabetically.

**Ichnogenus: *Arenicolites* Salter (1857) (Figure 3A)**

**Ichnospecies: *Arenicolites carbonarius***

**Description:** Endichnial, full relief, vertical, slender, small, U-shaped burrow with no spreiten. Limbs closely spaced, circular in cross section parallel to each other. Width of the burrow as well as diameter of the limb are uniform throughout the height of the burrow. Burrow fills are distinct and different than the host sediments.

**Remarks:** The present specimen differs from the *A. tenuis* and *A. curvatus* in being slender and in non-inclined nature of the limbs. This ichnospecies is being recorded for the first time from the Surma succession of Northeast India by Rajkonwar et al.<sup>3</sup> *Arenicolites* has been considered as a dwelling and

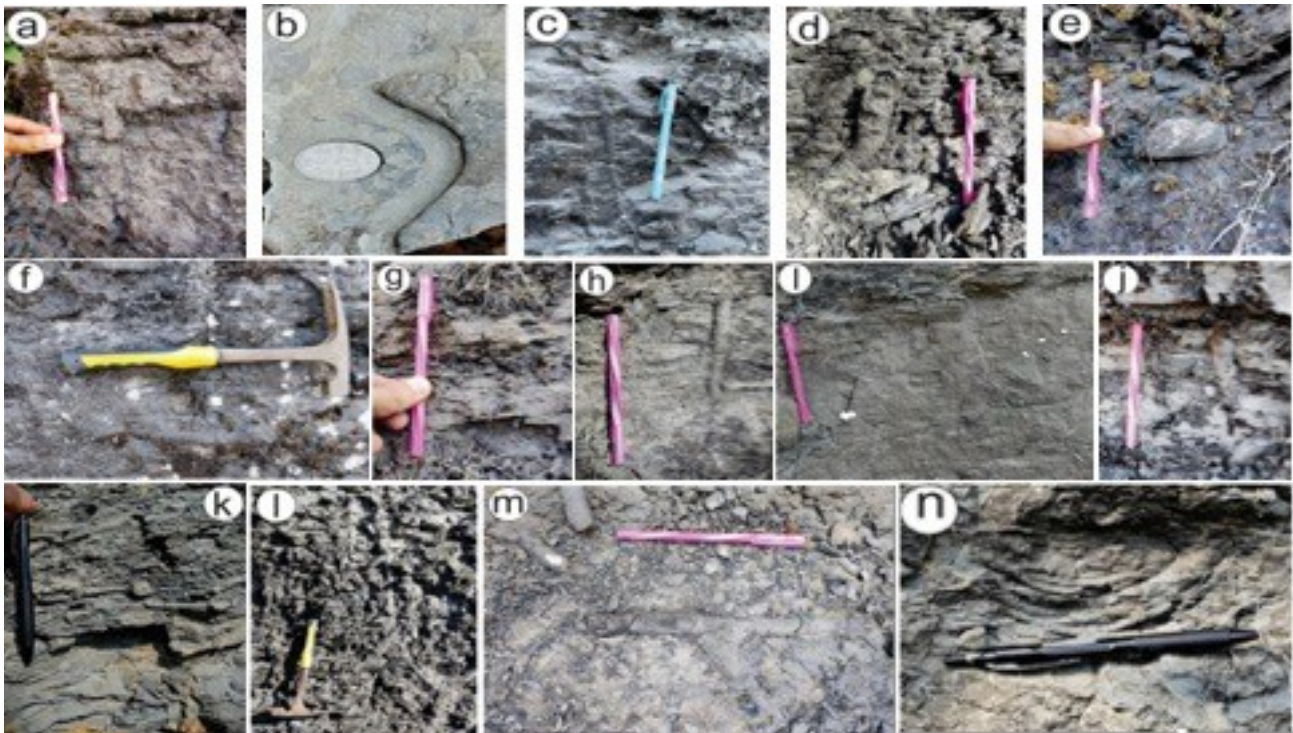
feeding structure of suspension-feeding annelids<sup>11</sup> or crustacean-like organisms.<sup>12</sup> Though known to occur in diverse environments including non-marine<sup>13</sup>, it is typical of shallow-marine.

**Ichnogenus: *Cochlichnus* Hitchcock, 1858 (Figure 3B)**

**Ichnospecies: *Cochlichnus anguineus* Hitchcock, 1858**

**Description:** Smooth, sinusoidal, horizontal, unlined and unbranched feeding trails, preserved as convex epirelief. The burrow filled is identical to the surrounding rocks.

**Remarks:** The present specimen shows regular sinuosity in structures which is similar to *C. anguineus* Hitchcock. *Cochlichnus* has been interpreted as a locomotion or grazing trace.<sup>14</sup> It has been traditionally suggested that the most likely producers of this trace are nematode worms.<sup>15</sup> Eager et al.<sup>16</sup> suggested that *Cochlichnus* are the crawling traces and probably are the feeding structures of small worms or worm like animals. Tiwari et al.<sup>1</sup> and Rajkonwar et al.<sup>3</sup> reported and described *Cochlichnus anguineus* from the Middle Bhuban Unit of Bhuban Formation, Surma Group.



**Figure 3.** Trace fossil from the Midum Kham section.

**A.** *Arenicolites carbonarius*. **B.** *Cochlichnus anguineus*. **C.** *Diptocraterion parallelum*. **D.** *Ophiomorpha nodosa*. **E.** *Palaeophycus tubularis*. **F.** *Palaeophycus striatus*. **G.** *Planolites* isp. **H.** *Skolithos linearis*. **I.** *Skolithos verticalis*. **J.** *Skolithos* isp. **K.** *Thalassinoides horizontalis*. **L.** *Thalassinoides suevicus*. **M.** *Thalassinoides paradoxicus*. **N.** *Teichichnus rectus*.

**Ichnotaxonomy:** **Ichnogenus: *Diptocraterion* Torell, 1870 (Figure 3C)**

**Ichnospecies: *Diptocraterion parallelum* Torell, (1870)**

**Description:** Vertical, u-shaped burrow, consisting of spreiten. The tubes are parallel, lined and are circular in cross section. The sediment fill of the burrow is darker than the host rock but spreiten is light colour.

**Remarks:** *Diptocraterion parallelum* is a feeding burrow of suspension feeders<sup>17,18</sup> and its spreite most probably reflects animal growth or adjustment to sedimentation of erosional process.<sup>19</sup> Fanai et al.<sup>6</sup> also described the same species from the Upper Bhuban Unit of Bhuban Formation, Mizoram.

**Ichnotaxonomy:** **Ichnogenus *Ophiomorpha* (Figure 3D)**

**Ichnospecies: *Ophiomorpha nodosa* Lundgren (1891)**

**Description:** Endichnial, lined, branched to unbranched, vertically or inclined to the bedding plane, burrow wall consisting of a regularly distributed discoid pellets. The in-fill material of the burrow is identical to the host rock but pellet-lined structures consist of darker material than the

host sediment.

**Remarks:** The morphological characters of the present burrows are similar to *O. nodosa*.<sup>20</sup> Different ichnospecies of *Ophiomorpha* are differentiated based on variations in burrow configuration, shape, and distribution of the pellets. Fanai et al.<sup>21</sup> reported *O. nodosa* from the Upper Bhuban Unit of Bhuban Formation, Mizoram.

**Ichnotaxonomy:** **Ichnogenus: *Paleophycus* Hall, 1847 (Figure 3E)**

**Ichnospecies: *Paleophycus striatus* Hall, 1852**

**Description:** Burrow is endichnial, unbranched, horizontally disposed to the bedding plane, thinly lined burrow having faint striations. The burrow material is same as the host rock.

**Remarks:** *P. striatus* differs from other ichnospecies of *Paleophycus* in having the continuity and parallelism of its striations.<sup>22</sup> The ichnospecies is also associated with shallow marine low energy tidal zone in the studied section. Rajkonwar et al.<sup>5</sup> described the same species from the Middle Bhuban Unit of Zuangtui, Mizoram.

**Ichnotaxonomy:** **Ichnogenus: *Palaeophycus* Hall (1847) (Figure 3F)**

**Ichnospecies: *Palaeophycus tubularis* Hall (1852)**

**Description:** Endichnial, full relief, long, smooth, straight and cylindrical tube. Burrow is unbranched, unornamented, and lined disposed horizontal to the bedding plane. The maximum observed length of the burrow is 8 cm. the burrow is compressed, appears as elliptical in cross-section, and is filled with the same sediment as the host rock.

**Remarks:** The distinction between *Palaeophycus*, *Planolites*, and *Macaronichnus* is partially controversial. *Palaeophycus* is an eurybenthic facies -crossing form produced probably by polychaetes or annelids.<sup>23</sup> The present form is classified as *P. tubularis* on account of the horizontal smooth, straight, long, and unbranched burrows with distinct lining character.<sup>24</sup> The collapsing nature of the burrow is restricting species-level identification. *Palaeophycus* is a eurybenthic, facies - crossing form produced by polychaetes or annelids. *P. tubularis* is also described by Rajkonwar et al.<sup>5</sup> from the Middle Bhuban Unit of Zuangtui, Mizoram.

**Ichnogenus: *Planolites* Nicholson (1873) (Figure 3G)**

**Ichnospecies: *Planolites* isp.**

**Description:** Epichnial, long, cylindrical smooth-walled, unlined, unbranched burrow and oriented parallel to the bedding plane. The burrow fill is different from the host sediments.

**Remarks:** The morphological character of the present burrow resembles that of *Planolites* Nicholson.<sup>34</sup> Species-level identification is not attempted due to the lack of more detailed morphologic features. *Planolites* is also described from the Bhuban Formation of Mizoram by Fanai et al.<sup>6,21</sup>, Rajkonwar et al.<sup>5</sup>, Lalawmpui et al.<sup>8</sup>.

**Ichnogenus: *Skolithos* Haldemann (1840) (Figure 3H)**

**Ichnospecies: *Skolithos* isp.**

**Description:** Burrows occur as isolated, cylindrical, thinly lined, unbranched tubes disposed perpendicular to the bedding plane. The burrows appear as circular to semi-circular openings at the surface. The diameters of the burrows are ranges from 1 to 1.5 cm.

**Remarks:** Present specimens are placed under *Skolithos* as these exhibit isolated, unbranched, cylindrical tubes, perpendicular to the bedding plane. *Skolithos* burrows are widely recognized in shallow water, intertidal deposits and various shallow marine environments, and the probable producers are annelids and orphoronids.<sup>25,22</sup> Rajkonwar et al.<sup>4,5</sup> also described *Skolithos* from the Bhuban Formation of Mizoram.

**Ichnogenus: *Skolithos* Haldemann (1840) (Figure 3I)**

**Ichnospecies: *Skolithos linearis***

**Description:** Vertical or steeply inclined, unbranched, straight to slightly curved, cylindrical or sub-cylindrical, thinly lined burrow perpendicular to the bedding plane with a structureless fill. It occurs as closely spaced tubes on bedding planes.

**Remarks:** Morphologically, this specimen clearly falls within the range of *Skolithos linearis* as described by Alpert<sup>25</sup>, Curran and Frey<sup>26</sup> and Curran<sup>27</sup>. *Skolithos* may have been dwelling burrows of suspension feeding polychaetes.<sup>25,22</sup> Tiwari et al.<sup>28</sup> described *Skolithos linearis* from the Bhuban Formation of Mizoram.

**Ichnogenus: *Skolithos* Haldeman, 1840 (Figure 3J)**

**Ichnospecies: *Skolithos verticalis***

**Description:** Vertical or steeply inclined, unbranched, straight to slightly curved, cylindrical or sub-cylindrical with a funnel-shaped top.

**Remarks:** Ethologically, *Skolithos verticalis* is interpreted as a dwelling or feeding trace. The possible producers are polychaetes or phoronids.<sup>25</sup> *Skolithos* appears in a variety of shallow marine environments; it has been documented from normal marine settings to lagoons, bays, mouth-bars and fluvial channels.<sup>29</sup> Rajkonwar et al.<sup>5</sup> described *Skolithos verticalis* from the Bhuban Formation of Mizoram.

**Ichnogenus: *Thalassinoides* Ehrenberg, 1944 (Figure 3K)**

**Ichnospecies: *Thalassinoides horizontalis* Myrow, 1995**

**Description:** Endichnial, smooth-walled, unlined, three-dimensional, horizontal burrow system showing Y/T-shaped branching. Tunnels are straight to curves disposed of parallel to the bedding plane and bifurcate at an angle of 95° -125°. The diameter of the burrows varies from 2.2-3.5 cm.

**Remarks:** *Thalassinoides horizontalis* can be differentiated from the other ichnospecies of *Thalassinoides* in lack of the vertical component and as occurring underneath the bedding plane. The morphological features of the present specimen resemble very well the form described as *T. horizontalis*. Rajkonwar et al.<sup>5</sup> described *T. horizontalis* from the Bhuban Formation of Mizoram.

**Ichnogenus: *Thalassinoides* Ehrenberg (1944) (Figure 3L)**

**Ichnospecies: *Thalassinoides paradoxicus* Rieth (1932)**

**Description:** Endichnial, full relief, three-dimensional burrow system. The shaft of the burrows is generally vertical to inclined connected to the surface; commonly with irregular, very extensive horizontal burrow network, occurring at several levels, connected by vertical shafts short blind tunnels very common. Surface covered with longitudinal ridges. Generally, occurs associated with erosion surfaces.

**Remarks:** *Thalassinoides* isp. is the most characteristic biogenic structure produced by arthropods in the marine geological record<sup>17</sup>. The lack of, or a very thin lining are characteristic of fine grained, coherent ground, in which burrows do not need additional strengthening of their walls.<sup>24</sup> Structureless fill often represents passive way of sedimentation constrained by gravitation.<sup>30</sup> They are most typically registered in shallow-marine environment, usually oxygenated, soft but fairly cohesive substrates<sup>19</sup>. The main enlarged bulbs may act as breeding chambers, but the ending tips which are bulged may be due to the turn back of the organism to avoid further burrowing. Tiwari et al.<sup>1</sup> also described *T. paradoxicus* from the Bhuban Formation of Mizoram.

**Ichnogenus:** *Thalassinoides* Ehrenberg (1944) (Figure 3M)

**Ichnospecies:** *Thalassinoides suevicus* Bromley & Frey, 1974

**Description:** Profusely branched, showing Y to T-shaped bifurcations in horizontal system, essentially cylindrical large burrow systems; unornamented, and irregular burrows passively filled. Sediment fill is different from the host sediment.

**Remarks:** *Thalassinoides* is a domichnial and fodinichnial structure produced by crustaceans, mostly decapods.<sup>31</sup> It occurs in a great variety of marine environments, yet is most typical of the shelf *Cruziana* ichnofacies. The *Thalassinoides suevicus* is distinguished from other ichnospecies of this ichnogenus by predominantly horizontal, more or less regularly dichotomous. Tiwari et al.<sup>1</sup> also described *T. suevicus* from the Bhuban Formation of Mizoram.

**Ichnogenus:** *Teichichnus* Seilacher (1955) (Figure 3N)

**Ichnospecies:** *Teichichnus rectus* Seilacher (1955)

**Description:** Endichnial, straight to sinuous unbranched gently horizontal stacked spreiten shift laterally as well as vertically. The stacked tubes are bend and shows oblong nature at its initial part and after that displays the uniform dimensions. Burrow filled is identical to host sediments.

**Remark:** Seilacher<sup>32</sup> interpreted *Teichichnus* as the result of the vertical shift of horizontal burrow which might be U-shaped with pipe at the top. *T. rectus* has straight walled and generally having a higher width-depth ratio (approximately 1:1). Seilacher<sup>32</sup> compared these forms to the modern structures made by the recent polychaete *Nereis diversi-color*. Fanai et al.<sup>6</sup> described *Teichichnus rectus* from the Bhuban Formation of Mizoram.

## Discussions

The recorded trace fossil assemblage from the sedimentary succession exposed in Midum Kham section is moderately diverse, belonging to 14 ichnospecies of 9 ichnogenra. The trace fossils from the study were found to be occurred along with some wood fossil, mollusk and shark teeth (Figure 2). Traces are relatively abundant, belonging to *Skolithos* and *Cruziana* ichnofacies. The *Skolithos* ichnofacies is represented by *Arenicolites carbonarius*, *S. verticalis*, *S. linearis*, *Diplocraterion parallellum*, *Ophiomorpha nodosa*, *Teichichnus rectus* and *Thalassinoides suevicus*. *Skolithos* ichno-assemblage has been reported from environments characterized by frequent high-energy and high rate of sedimentation.<sup>33-39</sup> The presence of *Diplocraterion* has been interpreted as an indicator of a high-energy environment.<sup>40,41</sup> Heinberg and Birkelund<sup>23</sup> has reported *Diplocraterion* from shallow marine environments, suggesting agitated water conditions. *Ophiomorpha* and *Skolithos* are also reported from the environment dominated by frequent high energy events and changes in sedimentation rate.<sup>38,39</sup> According to MacEachern et al.<sup>36</sup> Such conditions generally occur on the shoreface and sheltered foreshore, but similar conditions may be found in a wide range of high-energy shallow water environments. Thus, the dominantly vertical traces are typical members of the *Skolithos* ichnofacies, representing foreshore-middle shoreface environments with sandy substrate. The *Cruziana* Ichnofacies is dominated by deposit feeders, represented by *Thalassinoides horizontalis*, *T. suevicus*, *T. paradoxicus*, *Palaeophycus tubularis*, *P. striatus*, *Planolites* isp. These traces typify poorly sorted, unconsolidated muddy substrates in shallow marine settings of consistent salinity and moderate energy, positioned below fair-weather wave base but above storm wave base.<sup>30,34,35,36,38,42</sup> *Planolites* is a facies-crossing genus and has been reported from a wide range of environments from littoral to slope.<sup>43</sup> However, according to Tiwari et al.<sup>1</sup>, the presence of *Planolites* indicates unconsolidated substrate with moderate to low energy shoreface/offshore conditions. The presence of endobenthos, such as *Thalassinoides*, suggests that the bottom water was well-oxygenated. The trace fossils typical of the *Cruziana* ichnofacies show that at least some parts of these deposits were accumulated very close to or below fair-weather wave-base.<sup>44</sup> The horizontal biogenic structures (*Thalassinoides*, *Planolites*, *Palaeophycus*) indicates a shallow marine environment with occasional deep-water

conditions within shoreface setup.<sup>36</sup> Intense bioturbation and rich trace fossil assemblage indicate good oxygenation and food availability. Distribution of the trace fossils in the Bhuban rocks of the study area through time depicts a definite trend changing from *Cruziana* ichnofacies of lower shoreface-offshore marine to *Skolithos* ichnofacies corresponding to upper-middle shoreface.<sup>33,45</sup> Sediments at the lower stratigraphic level are dominated by *Cruziana* ichnofacies, suggesting a reduced energy level away from the shoreline corresponding to lower shoreface offshore marine settings. The idealized shoreface models for ichnofacies by Frey et al.<sup>33</sup> and Pemberton and Mac Eachern<sup>46</sup> show that the *Skolithos* ichnofacies generally grades seaward into *Cruziana* ichnofacies. The same pattern of ichnofossil distribution is also observed in the study area. The dominance of *Skolithos* ichnofacies at the higher stratigraphic levels indicates an agitated environment with sandy substrate near the shoreline. The presence of wave ripples and hummocky cross-stratification also corroborate the above view.<sup>47</sup> Thus, it also corresponds to the increase in the energy conditions. Such an increase of the energy or shifting of the environment factor from low-energy to high-energy offshore environment suggests a regression in the study area. The presence of various ichnofacies indicated that the bottom water was well-oxygenated which had allowed the sustenance of life. Terrestrial plant debris, robust bivalve/gastropod shells and shark teeth, together with bioclastic carbonate cement within the calcareous sandstone bed also represent deposition within a middle- to upper-shoreface environment characterized by high-energy, well-oxygenated nearshore conditions proximate to coastal or deltaic sources (Figure 2).<sup>48</sup> This is sharply overlain by a thick, structureless shale facies comprising massive mudstone devoid of primary sedimentary structures interpreted as rapid suspension fallout in a low-energy distal offshore or pro-delta realm below storm wave base following transgression. The absence of structures likely reflects fluid mud behavior or homogenized subtle bioturbation under dysoxic bottom waters, marking a basinward shift during maximum flooding.<sup>49</sup>

The geological framework of Northeast India has been predominantly governed by subduction-related tectonic processes, wherein the Indian Plate has undergone subduction beneath the overriding Burmese Plate. This persistent subduction dynamic has not only induced lateral migrations of depocenters but has also resulted in fluctuations of sea levels and associated energy regimes within the sedimentary basin.<sup>1,50</sup> Such tectonically driven oscillations in sea level account for the distribution pattern of the ichno-assemblage in the studied section.<sup>51</sup>

## Conclusion

Ichnological analysis shows that the Bhuban

rocks exposed in the Midum Kham were deposited in an upper shoreface-offshore shallow marine paleoenvironment, indicating a tectonically controlled fluctuating environmental regime under dominantly regressive phase with occasional transgression. There was a progressive decrease in energy across the shelf resulting in development of *Cruziana* type settings. It may also be concluded that siltstone sandstone facies represent the upper shoreface, while mudstone facies correspond to the lower shoreface-offshore environment. Fluctuations in the sea level could have been the result of the tectonics of the region.

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