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A Comparative Study of Ichnofossils from Upper and Middle Bhuban Unit of Bhuban Formation (Surma Group), Aizawl, Mizoram to Decipher the Depositional Environment

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Abstract

Objectives: The aim of the present study is to interpret and compare depositional environment of Upper and Middle Bhuban rocks from its trace fossil content. **Methods:** The trace fossils collected from the Upper and Middle Bhuban Formation are studied group wise up to species level for their systematic paleontological description with the help of type material and available literature in the laboratory. Distribution pattern of trace fossils in the sediments such as orientation, diversity, mode of preservation, relationship with the host sediments are also collected in order to interpret the depositional environment. **Findings:** Ichnological analysis of Upper Bhuban and Middle Bhuban Unit has been attempted to decipher the palaeo-environment. The Upper Bhuban Unit are represented by a diverse lithofacies comprises of sandstone, shale and silty-sandstone with the presence of wavy sedimentary structure and parallel lamination. A total of 12 ichnospecies found in Upper Bhuban Unit belongs to *Skolithos*, *Cruziana* and mixed *Skolithos* – *Cruziana* ichnofacies. *Phycosiphon* isp. is reported for the first time in North-East India. Middle Bhuban Unit exposed along Zuangtui section comprises ~40m thick sequence of sandstone, siltstone and shale. 17 ichnospecies belonging to *Skolithos*, *Cruziana*, *Teredolites* and mixed *Skolithos* – *Cruziana* ichnofacies has been identified along this section. *Diplopodichnus* is reported for the first time from the Surma rocks of Mizoram as well as other Miocene successions in India. Presence of *Teredolites* ichnofacies indicates marine margin environment, *Skolithos* ichnofacies indicate sandy shifting substrate and high energy conditions in foreshore zone while *Cruziana* ichnofacies indicate unconsolidated, poorly sorted soft substrate and low energy condition

in the shoreface/offshore zone. **Novelty:** Present study corroborate that Upper Bhuban rocks were deposited under shallow marine environment while Middle Bhuban rocks were deposited in a deeper, quiet water environment.

Keywords: Bhuban Formation; Surma Group; Ichnofacies; Depositional environment; Ichnofossils

1 Introduction

The Unit of Bhuban, especially the Middle and Upper Units of Bhuban Formation of Surma Group in Mizoram Fold belt does not have distinct lithological variations. Several workers attempted their differences in terms of sedimentology and body fossils so far however, the results have not yielded satisfactory. In this paper we compared their Ichnological differences, which is the first time for this kind of study in this area, highlighting how the depositional environments of these two units are changed. We took one section each, Zuangtui section for Middle Unit and Sakawtuichhun for Upper Bhuban Unit having rich ichnological assemblages diversity. One ichnospecies *Phycosiphon* from the Upper Bhuban Unit is reported for the first time in North-east India. *Diplopodichnus* from the Middle Bhuban Unit is reported for the first in Surma Group of North-east India as well as the Miocene rocks of India. The change over from older quieter to younger more hydrodynamic environments indicated in this study implore more studies to decipher the basin hinterland relationship, and eventually linking with the tectonic evolution of the fold belt.

Trace fossils play a very important role in the interpretation of palaeo environmental and stratigraphic framework especially where body fossils are poorly preserved and are long-ranging. Therefore, the main objectives of the present paper are to describe the trace fossil assemblage and to decipher and compare the depositional environment of Upper Bhuban and Middle Bhuban rocks exposed in the Aizawl district of Mizoram based on its ichnofossil content.

1.1 Location of study area

1.1.1 Ramrikawn – Sakawtuichhun Section

The study area lies between geographical co-ordinates 23°44'51" to 23°45'59" N and 92°40'47" to 92°40'04" E towards 12 km west of Aizawl city [Figure 1]. Upper Bhuban rocks are well exposed in three quarries at Sakawtuichhun area which comprises sandstone, shale, silty-sandstone and shale laminated sandstone bed. Sandstone are fine to medium grained, highly compacted and are grey in colour [Figure 2]. Majority of the ichnofossils are recorded from the sandstone bed while only few ichnofossils are recorded from shale-laminated sandstone and shale bed. A wavy and cross-stratified structures is developed at the shale laminated sandstone bed indicating deposition of sediments in subtidal high energy environments.

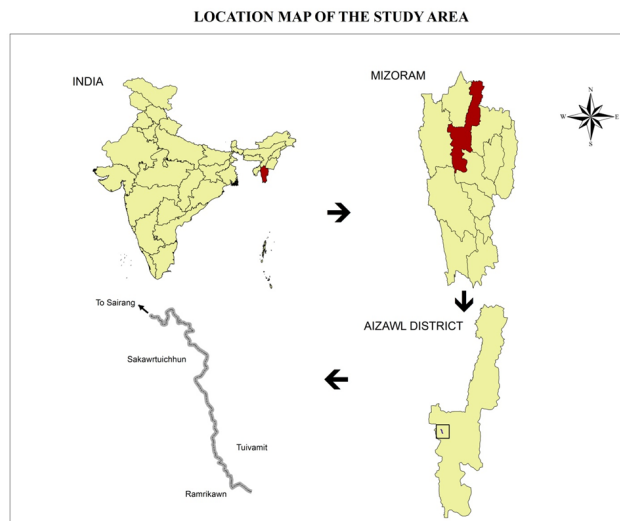


Fig 1. Location map showing the studied sections along Ramrikawn to Sakawrtuichhun area

1.1.2. Zuangtui Section

The study area is located in the northern part of Aizawl city latitude $23^{\circ}46'18.9''$ to $23^{\circ}46'21.36''$ N and longitude $92^{\circ}44'53.15''$ to $92^{\circ}44'53.43''$ E [Figure 1]. Rocks of Middle Bhuban Unit of Bhuban Formation is well exposed along a small road-cut section with a thickness of ~40m comprised of sandstone, siltstone, shale, mudstone and their admixtures in various proportions and a few pockets of shell limestone, calcareous sandstone and intra formational conglomerate is also observed [Figure 2]. Sedimentary structure such as ripple marks and mud clast are observed in the rock succession.

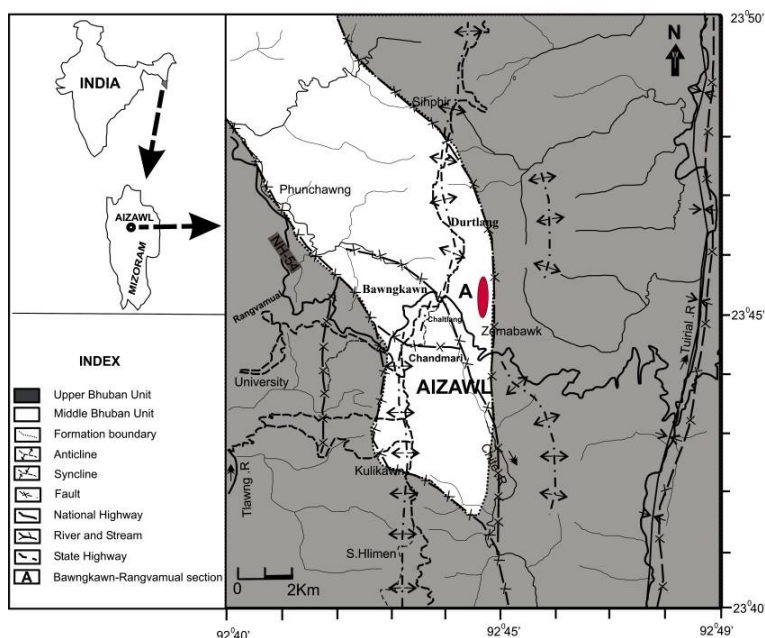


Fig 2. Geological map of Aizawl showing the location of the studied section along Zuangtui area

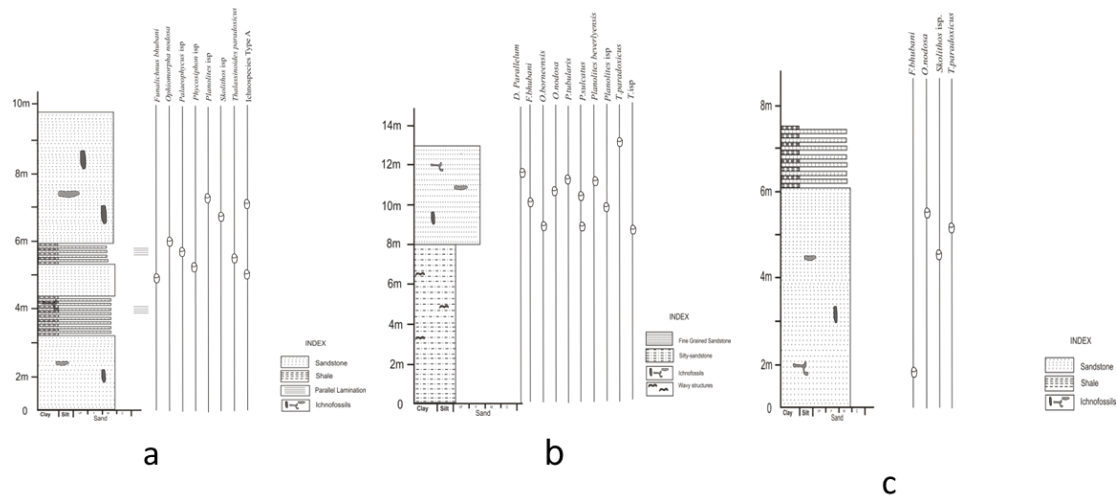


Fig 3. a): Lithocolumn of the Upper Bhuban Formation in Ramrikawn to Sakawrtuichhun Section (Quarry1). (b): Lithocolumn of the Upper Bhuban Formation in Ramrikawn to Sakawrtuichhun Section (Quarry 2). (c): Lithocolumn of the Upper Bhuban Formation in Ramrikawn to Sakawrtuichhun Section (Quarry 3).

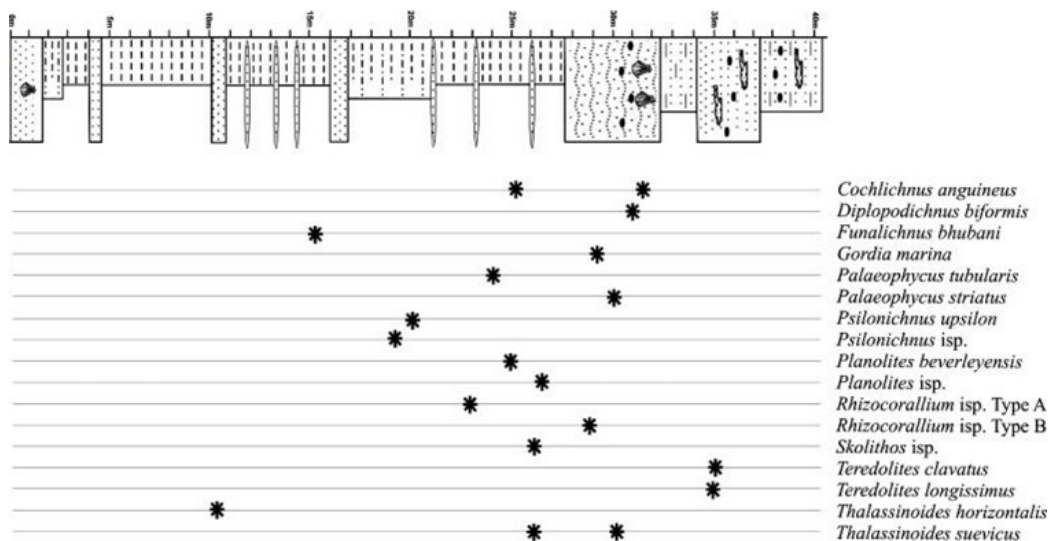


Fig 4. Lithocolumn of the Middle Bhuban Formation in Zuangtui Section

2 Methodology

2.1 Field Study

Extensive fieldwork has been carried out along Ramrikawn – Sakawrtuichhun and Zuangtui road sections. Field data were collected in terms of lithological variations, distribution, and occurrence of fossils bed-wise and sedimentary structures. Field photographs of those trace fossils which could not be collected were taken.

2.2 Laboratory Study

The collected trace fossils were cleaned in the laboratory followed by the identification and systematical description of both the collected and photographed trace fossils with the help of available published work. Ichnofacies and ethological grouping of the described trace fossils were accomplished. The depositional environment of the studied rock successions was worked out based

on ichno-assemblages and ethological groupings.

3 Result and Discussion

3.1 General Remarks

The collected ichnofossils are identified and described in the Palaeontology Laboratory of the Department of Geology, Mizoram University, Aizawl, Mizoram. The identified ichnospecies include *Cochlichnus anguineus*, *Diplopodichnus biformis*, *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Funalichnus bhubani* isp. nov., *Gordia marina*, *Ophiomorpha annulata*, *Ophiomorpha borneensis*, *Ophiomorpha nodosa*, *Palaeophycus striatus*, *Palaeophycus sulcatus*, *Palaeophycus tubularis*, *Palaeophycus* isp., *Phycosiphon* isp., *Planolites beverlyensis*, *Planolites* isp., *Psilonichnus upsilon*, *Psilonichnus* isp., *Rhizocorallium* isp. Type A, *Rhizocorallium* isp. Type B, *Skolithos* isp., *Teredolite clavatus*, *Teredolite longissimus*, *Thalassinoides horizontalis*, *Thalassinoides paradoxicus*, *Thalassinoides suevicus* and Ichnospecies Type A. Complex burrow systems, ichnogenera, and ichnospecies in the present studies are named according to I.C.Z.N. Rules, using the binomial system of nomenclature and described alphabetically.

3.2 Systematic Description

1. Ichnogenus: *Cochlichnus* Hitchcock, 1858

Ichnospecies: *Cochlichnus anguineus* Hitchcock, 1858 [Plate 1 a]

Description: Smooth, sinusoidal, horizontal, unlined, and unbranched feeding trails, preserved as convex epirelief. The burrow filled is identical to the host rocks. The maximum observed length is about 60 cm and the diameter ranges from 2 to 3 cm.

Remarks: The present specimen shows regular meandering structures suggest that *Cochlichnus* are the crawling traces and probably are the feeding structures of small worms or worm-like animals. Hakes reported *Cochlichnus* in sediments of supposedly low salinity palaeoenvironment.

Occurrence: Silty-sandstone bed of Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

2. Ichnogenus: *Diplopodichnus* Brady, 1947

Ichnospecies: *Diplopodichnus biformis* Brady, 1947 [Plate 2 d]

Description: Simple, smooth, straight to gently curved trails with distinct median furrow. Trails are parallel to the bedding plane and preserved as convex epirelief. The maximum observed length is about 8 cm and the diameter is 2 mm.

Remarks: The general morphology and orientation of the ichnogenera represent crawling trails of molluscan origin. *Diplopodichnus* is interpreted as a marine and non-marine Paleozoic trace fossil with possible range into the Late Proterozoic by previous workers. The present specimen is the first record of *Diplopodichnus* from the Surma rocks of Mizoram as well as other Miocene successions in India.

Occurrence: Sandstone bed of Middle Bhuban Unit, Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

3. Ichnogenus: *Diplocraterion* Torell (1870)

Ichnospecies: *Diplocraterion parallelum* Torell (1870) [Plate 4 a]

Description: Vertical U-shaped burrow with parallel tubes, cylindrical and circular in cross-section consisting of spreiten. Burrows are thinly lined and infill sediments are darker than the host sediments but spreiten is light colored. The diameters of burrow tubes are 0.8 cm to 1 cm and are 6 cm apart from each other. The burrow appears like a dumbbell in the cross-section.

Remarks: *Diplocraterion parallelum* differs from other *Diplocraterion* species by the parallel nature of the burrow tubes with an entire burrow distance. *Diplocraterion* is considered to be a sediment-feeding burrow of suspension feeders⁽¹⁾ and its spreite most probably reflects animal growth or adjustment to sedimentation and erosional processes.

Occurrence: Fine to medium-grained, grey-colored sandstone bed at Sakawrtuichhun Quarry 1 and Quarry 2 at the Upper Bhuban unit of Aizawl, Mizoram.

4. Ichnogenus: *Funalichnus* Pokorný (2008)

Ichnospecies: *Funalichnus bhubani* isp. nov. [Plate 1 c, Plate 4b]

Description: Endichnial, long, unbranched, vertical to steeply inclined, straight to gently curved, and unlined burrow. The burrow consists of several small cylindrical segments imparting a twisted rod-like structure to the burrow. The interspaces between the cylindrical bodies form curved depressions. The cylindrical bodies of the burrow mostly have uniform dimensions but also show slightly variable dimensions along the length and occasionally also display irregular forms which are usually parallel to the bedding plane and are inclined to the right or left sides. Burrow fill is identical to the surrounding sediments.

Remarks: The vertical nature and cylindrical segment form of *Funalichnus bhubani* indicate that the animal excavated the surrounding compact sediments to its body length and pushed the sediments periodically downward to maintain its position.

Occurrence: Fine to medium-grained, grey-colored sandstone bed at Sakawrtuichhun Quarry 1 and Quarry 2 at the Upper Bhuban unit of Aizawl, Mizoram; Silty sandstone bed at Middle Bhuban Unit of Bhuban Formation, Surma Group, Zuangtui. Aizawl.

5. Ichnogenus: *Gordia* Emmons, 1844

Ichnospecies: *Gordia marina* Emmons, 1844 [Plate 1 b]

Description: Long, smooth, straight to gently curved trail, unbranched and uniform thickness. The sediments that make the trail are identical to the host rocks.

Remarks: The present specimen differs from *Cochlichnus*, of *Helminthopsis* and *Cosmorhapse* as it does not possess regular meanders, loose meanders, and regular sinuously, therefore it is placed under *Gordia marina*. *G. marina* is considered as a scavenging or grazing trail of vermi form organisms by previous workers.

Occurrence: Sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

6. Ichnogenus: *Ophiomorpha* Lundgren (1891)

Ichnospecies: *Ophiomorpha borneensis* Keij (1965) [Plate 4 e]

Description: Full relief and endichnial burrows with long straight vertical shafts; lined and packed with the bilobate pellets. Rare to scattered ovoid or single pellets are also found. Burrow tubes have thick walls with smooth interior surfaces and distinctly irregular rugose exterior surfaces. The burrow fill is different from the surrounding sediment.

Remarks: The morphology of this form is like *O. nodosa* and *O. irregularie* which could be genetically related. *O. borneensis* is regarded to be a synonym of *Spongiliomorpha saxonica* but failed to consider the bilobate pellets.

Occurrence: Fine to medium-grained, grey-colored sandstone bed in all the Quarries of Sakawrtuichhun section, Upper Bhuban unit, Aizawl.

7. Ichnospecies: *Ophiomorpha nodosa* Lundgren (1891) [Plate 4c, d]

Description: Endichnial, lined, branched to unbranched, vertically or inclined to the bedding plane, burrow wall consisting of a regularly distributed discoid pellets. The depths of the burrows are ranges from 20 cm in observed specimens but it also penetrates to more depth. The diameter of the burrow and pellets ranges from 1.5 to 25 cm and 05 to 1 cm respectively. 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* Lundgren⁽¹⁻³⁾. Different ichnospecies of *Ophiomorpha* are differentiated based on variations in burrow configuration, shape, and distribution of the pellets.

Occurrence: Fine to medium-grained, grey-colored sandstone in Sakawrtuichhun section of Upper Bhuban unit, Aizawl.

8. Ichnogenus : *Paleophycus* Hall, 1847

Ichnospecies: *Paleophycus striatus* Hall, 1852 [Plate 1 g]

Description: Burrow is hypichnial, full relief, unbranched, horizontally disposed to bedding plane, thinly lined burrow having faint striations. The observed length is 18 cm and the diameter is 1.8 to 2 cm. The burrow material is same as the host rock.

Remarks: The gross morphology of the ichnospecies resembles *Palaeophycus striatus* described Elita Rose, Lalchawimawii, A. Lalrammuana, J. Malsawma, Paul Lalnuntluanga, R. P. Tiwari⁽²⁾. Ichnofossils from the Middle Bhuban Unit, Bhuban Formation of Pachhy Lokah near Maubawk, Siaha District, Mizoram, India from the Surma succession of Northeast India. *P. striatus* differs from other ichnospecies of *Paleophycus* in having striations.

Occurrence: Sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

9. Ichnogenus: *Palaeophycus* Hall (1847)

Ichnospecies: *Palaeophycus tubularis* Hall (1852) [Plate 1 h, Plate 4 f]

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 7 cm and the diameter is 0.8 to 1.3 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. The present form is classified as *P. tubularis* on account of the horizontal smooth, straight, long, and unbranched burrows with distinct lining.

Occurrence: Sandstone and shale in Sawlartuichhun Quarry 3 section, Upper Bhuban unit, Aizawl, Mizoram.

10. Ichnospecies: *Palaeophycus sulcatus* Miller and Dye (1878) [Plate 4 h]

Description: Endichnial, horizontal, straight to gently sinuous, cylindrical, lined burrow. The burrow shows enlargement at some distance and varies in diameter. The observed length of the burrow is 6cm and the diameter is 1.2 cm. The sediment that fill the burrow is similar to that of the host rock.

Remarks: *Palaeophycus sulcatus* differs from *P. striatus* by anastomosing rather than longitudinal striations and from *P. alternatus* in having consistent rather than alternating striations.

Occurrence: Fine to medium-grained grey color sandstone bed of Upper Bhuban unit in Sakawrtuichhun Quarry 2 section, Aizawl, Mizoram.

11. Ichnospecies: *Palaeophycus* isp. [Plate 4 i]

Description: Burrows sub-cylindrical, horizontal, unbranched, disposed parallel to the bedding plane. Burrows are semicircular in cross-section and color of the burrows is similar to the host rock.

Remarks: The present burrow is identified as *Palaeophycus* because of its essentially horizontal, lined, and unbranched character. The collapsing nature of the burrow is restricting species-level identification. *Palaeophycus* is a eurybenthic, facies-crossing form produced by polychaetes or annelids.

Occurrence: Fine to medium-grained, buff color sandstone-shale alternation bed of Upper Bhuban unit at Sakawrtuichhun quarry 1 and Ropaibawk section, Aizawl, Mizoram.

12. Ichnospecies: *Phycosiphon* isp. [Plate 4 h]

Description: Extrusive small-scale, spreiten-rich trace composed of repeated narrow U-shaped lobes extending from central spreiten. Lobes are parallel or oblique to bedding. The diameter of the tube is less than 1mm and lobes several millimeters to about 1cm wide.

Remarks: The size range of *Phycosiphon* and *Anconichnus* are virtually identical and their highly recurved shapes are similar. Both have protrusive spreite lobes but the plane of these lobes is different. *Anconichnus* is supposed to be vertical to oblique and less commonly horizontal whereas *Phycosiphon* is horizontal to oblique and seldom vertical.

Occurrence: Sandstone bed at Sakawrtuichhun Quarry, Upper Bhuban Unit, Aizawl, Mizoram.

13. Ichnogenus: *Planolites* Nicholson (1873)

Ichnospecies: *Planolites beverleyensis* Billings (1862) [Plate 1f, Plate 5 a]

Description: Horizontal, full relief, sub-cylindrical, unlined, straight to gently curved, unbranched burrow, oriented parallel to the bedding plane. Some striations are observed along the burrows. The color of this burrow is darker than the host rock indicating that the burrow fill material is not the host sediments. The diameter is about 0.9-1.1cm and the length is about 12 cm. Burrow occurs as a single isolated specimen.

Remarks: *Planolites* is a broad ichnogenus ranging from Precambrian to Recent. *Planolites beverleyensis* is a eurybenthic, extremely facies crossing form, interpreted as Pascichnia and referred to as polyphyletic vermiform deposit-feeders producing active back-filling. As the burrow fill is different from that of the host rock and burrows are straight to tortuous, they are identified as *Planolites beverleyensis*^(1,3,4). The genus *Planolites* is commonly recognized from shallow water marine environments.

Occurrence: Grey-colored sandstone bed in Sakawrtuichhun of Upper Bhuban unit, Aizawl, Mizoram.

14. Ichnospecies: *Planolites* isp. [Plate 1e, Plate 5 b-c]

Description: Endichnial, 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. Species-level identification is not attempted due to the lack of more detailed morphologic features and hence is kept under open nomenclature.

Occurrence: Fine to medium, grey-colored sandstone bed at Sawkartuichhun Quarry, Upper Bhuban Formation, Aizawl, Mizoram.

15. Ichnogenus : *Psilonichnus* Fursich, 1981

Ichnospecies: *Psilonichnus upsilon* Frey et al. 1984 [Plate 4 a & b]

Description: Burrows are inclined, I-shaped, and shows branching at the lower part. The branches differ from each other in terms of size and shape. Dimensions of the burrows vary but are constant in a present fossil specimen. The maximum observed length is 28 cm. The burrow fill is identical to the host rocks.

Remarks: Present ichnospecies resemble very well with *Psilonichnus upsilon* reported by Singh from the Bokabil Formation of Manipur. This ichnospecies has also been reported by Frey and Kundal, Dharashivkar

Occurrence: Silty-sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

16. Ichnospecies: *Psilonichnus* isp. [Plate 4 c]

Description: A simple, isolated, I-shaped, unbranched, unlined, and disposed vertical to incline to the bedding planes. The burrow material is almost similar to the host rock.

Remarks: The overall morphological character of the present burrow has resembled the ichnogenus *Psilonichnus*. The species-level identification has not been attempted due to a lack of a more detail morphological characters.

Occurrence: Silty-sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

17. Ichnogenus: *Rhizocorallium* Zenker, 1836

Ichnospecies: *Rhizocorallium* isp. Type A [Plate 3 d]

Description: Epichnial, semi-relief, straight, unbranched, U-shaped burrow containing spreiten preserved horizontal to the bedding. The limbs of the burrow are filled with fine to medium-grained sediments identical to the host rock. The distance between the two limbs is 3.5 cm; the maximum observed length of the burrow is about 9 cm.

Remarks: The present specimen is partly weathered due to exposure to the environment. Due to the presence of spreiten and horizontal to the bedding plane, the morphological character is similar as described by Aenia Ozukum. S K. Srivastava, Bhawanisingh G. Desai from Botsa, Kohima District of Nagaland⁽⁵⁾ and is placed under the ichnogenus *Rhizocorallium*.

Occurrence: Silty-sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

18. Ichnospecies: *Rhizocorallium* isp. Type B [Plate 3 e]

Description: The burrow is endichnial, sinuous, unbranched, U-shaped tubes containing spreiten and disposed parallel to the bedding plane. The burrow is poorly preserved and the maximum observed length is 5.5 cm, the marginal tubes are 1 to 1.2 cm apart from each other and the tube diameter is 0.2 cm.

Remarks: The present burrow is a U-shaped burrow with spreiten and occurs parallel to the bedding plane, therefore it is placed under the ichnogenus *Rhizocorallium* Zenker. Although the overall morphology of the burrow resembles *Rhizocorallium*, it is very small in overall dimension and poorly preserved, therefore, identification at the species level has not been attempted.

Occurrence: Sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

19. Ichnogenus: *Skolithos* Haldemann (1840)

Ichnospecies: *Skolithos* isp. [Plate 2 d & e; Plate 5d]

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^(3,5,6) and various shallow marine environments, and the probable producers are annelids and orphoronids.

Occurrence: Fine-grained and grey color sandstone bed Sakawrtuichhun 1 & 2 section, Upper Bhuban Unit, Aizawl, Mizoram.

20. Ichnogenus : *Teredolites* Leymerie, 1842

Ichnospecies: *Teredolites clavatus* Leymerie, 1842 [Plate 2 g, h & i]

Description: Clavate-shaped borings predominantly perpendicular to the grain in woody substrates, varying in length between 2-10 mm and width between 3-5 mm. The bores are round to oval, occasionally club-shaped occurs as clusters having a length-width ratio- usually less than 5.

Remarks: Present ichnofossils exhibit similar morphological characteristics described by Leymerie. *Teredolites* are restricted to borings in xylitic material whereas *Gastrochaenolites* are for equivalent borings in lithic material. *T. clavatus* was reported by several workers from various Cretaceous and Tertiary sediments of the world.

Occurrence: Silty-sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

21. Ichnospecies: *Teredolites longissimus* Kelly and Bromley, 1984 [Plate 2 f, g & h]

Description: Specimens are preserved as grouped or isolated sand-filled tubes, incompletely and variably preserved. Tubes are commonly elongated, sinuous to contorted, and densely packed. The lengths of the tubes are ranges from 15-52 mm and the mean diameter of tubes is 3-5 mm. The clavate shape is noted to indicate its distinct feature, however, in general, it is poorly preserved.

Remarks: The present specimens are similar to *Teredolites longissimus* described by Kelly, Bromley. This ichnospecies predominantly develops parallel to the wood grain, having a length-width ratio usually greater than 5.

Occurrence: Silty-sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

22. Ichnogenus : *Thalassinoides* Ehrenberg, 1944

Ichnospecies: *Thalassinoides horizontalis* Myrow, 1995 [Plate 3 a]

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*⁽³⁾.

Occurrence: Sandstone bed at Middle Bhuban Unit of Bhuban Formation, Surma Group, Aizawl, Mizoram.

23. Ichnogenus: *Thalassinoides* Ehrenberg (1944)

Ichnospecies: *Thalassinoides paradoxicus* Rieth (1932) [Plate 5 e]

Description: Endichnial, full relief, three-dimensional irregular burrow system spread on the bedding plane horizontal to sub-horizontal. The shaft of the burrows is generally vertical to inclined connected to the surface; commonly shows T/Y shaped bifurcations and also show swelling at the junction. The length of the branch varies from 15 to 42 cm and the diameter from 2.5 to 5cm. The burrow fill is different from the host rock.

Remarks: Present specimen resembles closely with the specimen of *Thalassinoides paradoxicus* described and figured by Rieth. *T. paradoxicus* corresponds to branching, box work burrows highly irregular in size and geometry. *Thalassinoides paradoxicus* is different than *T. horizontalis* consisting of a vertical or inclined shaft and branch dichotomous.

Occurrence: Grey color sandstone-shale bed in MZU Road section; Fine to medium-grained, grey color sandstone bed in three quarries of Sakawrtuichhun section, Upper Bhuban unit, Aizawl, Mizoram.

24. Ichnospecies: *Thalassinoides suevicus* Rieth, 1932 [Plate 3 b & c]

Description : Profusely branched, Y-shaped, unornamented, and irregular burrows passively filled and disposed horizontal to oblique spreading over the bedding plane. The main burrow is 4 to 8 mm in diameter. Sediment fill is different from the host sediment.

Remarks: The present burrows are very densely branched and thereby placed under *Thalassinoides suevicus*. Aeinia Ozukum, S K. Srivastava, Bhawanisingh G. Desai⁽⁴⁾.

Occurrence: Sandstone, Middle Bhuban Unit of Bhuban Formation, Surma group of Zuangtui area, Aizawl, Mizoram.

25. Ichnospecies: Type-A [Plate 5 g]

Description: Burrows sub-horizontal to the bedding plane, unbranched and thinly lined. The burrow fill is different from the host rock. The maximum observed length of the burrow is about 30 cm and the diameter of the burrow ranges from 1.5 to 2.5 cm. Due to a lack of detailed morphological character, the present specimen is kept under an open nomenclature.

Occurrence: Grey-colored sandstone bed, Upper Bhuban unit, Sakawrtuichhun, Aizawl, Mizoram.

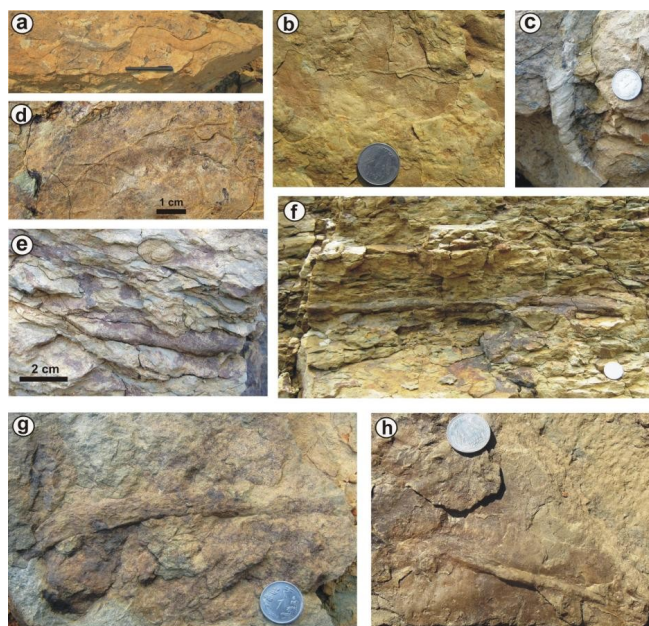


Plate 1: a. *Cochlichnus anguineus*, b. *Gordia marina*, c. *Funalichnus bhubani*, d. *Diplopodichnus biformis*, e. *Planolites isp.*, f. *Planolites beverleyensis*, g. *Palaeophycus striatus*, h. *Palaeophycus tubularis*

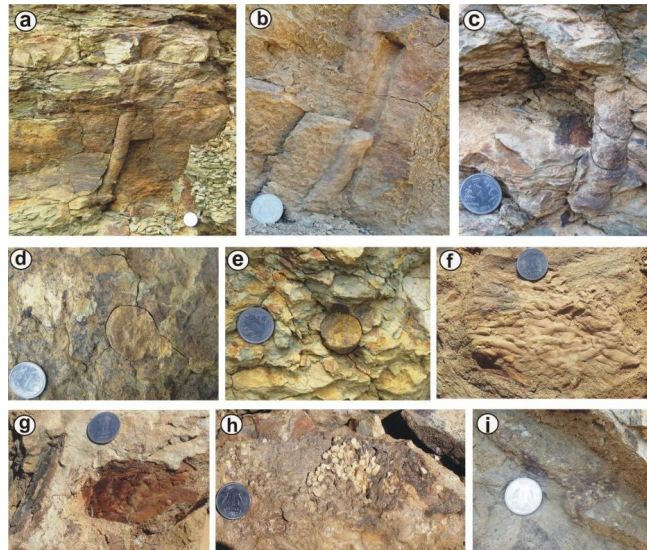


Plate 2: **a.** *Pylonichnus upsilon*, **b.** *Pylonichnus upsilon*, **c.** *Pylonichnus isp.*, **d.** *Skolithos isp.*, **e.** *Skolithos isp.*, **f.** *Teredolites longissimus*, **g.** *Teredolites clavatus* and *T. longissimus*, **h.** *Teredolites clavatus* and *T. longissimus*, **i.** *Teredolites clavatus*

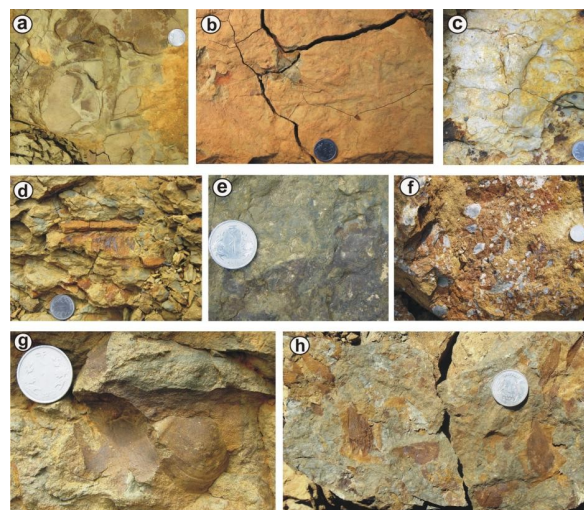


Plate 3: **a.** *Thalassinoides horizontalis*, **b.** *Thalassinoides suevicus*, **c.** *Thalassinoides suevicus*, **d.** *Rhizocorallium isp.* Type-A, **e.** *Rhizocorallium isp.* Type-B, **f.** Mud clast in brown coloured, medium grained sandstone, **g.** Bivalve cast (*Apolymetis sp.*) preserved in the bottom most medium grained sandstone, **h.** Bivalve Pinna preserved in grey sand stone

3.3 Discussion

3.3.1 Upper Bhuban Formation

The Upper Bhuban Unit of Bhuban Formation, Surma Group (Lower to middle Miocene) is well exposed in 24 m successions of Ramrikawn - Sakawrtuichhun section. The dominant lithologies are sandstone, shale, silty sandstone and shale laminated sandstone bed. The majority of the ichnofossils are recorded from the sandstone bed while only a few ichnofossils are recorded from shale-laminated sandstone and shale bed. A wavy and cross-stratified structure is developed at the shale-laminated sandstone bed indicating the deposition of sediments in subtidal high-energy environments.

This section yielded a trace fossil assemblage of 14 ichnospecies belonging to 7 ichnogenera. These include *Diplocraterion parallelum*, *Funalichnus bhubani*, *Ophiomorpha borneensis*, *Ophiomorpha nodosa*, *Palaeophycus tubularis*, *Palaeophycus sulcatus*, *Palaeophycus isp.*, *Phycosiphon isp.*, *Planolites beverleyensis*, *Planolites isp.*, *Skolithos isp.*, *Thalassinoides paradoxicus*,

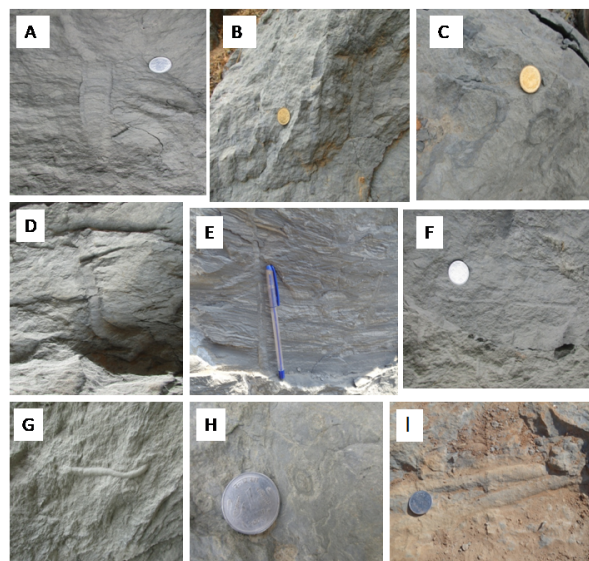


Plate 4: a. *Diplocraterion parallelum*. b. *Funalichnus bhubani*. c, d. *Ophiomorpha nodosa*. e. *Ophiomorpha borneensis*. f. *Planolites beverleyensis*. g. *Palaeophycus sulcatus*. h. *Phycosiphon* isp. i. *Palaeophycus* isp.

Thalassinoides isp. and Ichnospecies Type A.

The ichnotaxa described from the studied succession are typical for the *Skolithos* and the *Cruziana* ichnofacies. The members of *Skolithos* ichnofacies are *Diplocraterion parallelum*, *Funalichnus bhubani*, *Ophiomorpha borneensis*, *Ophiomorpha nodosa*, and *Skolithos* isp. *Cruziana* ichnofacies is represented by *Palaeophycus tubularis*, *Palaeophycus sulcatus*, *Palaeophycus* isp., *Phycosiphon* isp., *Planolites beverleyensis*, *Planolites* isp., *Skolithos* isp., *Thalassinoides paradoxicus*, *Thalassinoides* isp. and Ichnospecies Type A. Ethologically, the assemblage belongs to domichnia and fodichnia groups. Domichnian signature is reflected in ichnospecies of *Diplocraterion parallelum*, *Funalichnus bhubani*, *Ophiomorpha borneensis*, *Ophiomorpha nodosa*, and *Skolithos* isp. Fodichnian signature reflected by *Palaeophycus sulcatus*, *Palaeophycus tubularis*, *Palaeophycus* isp., *Planolites beverleyensis*, *Planolites* isp., *Thalassinoides paradoxicus* and *Thalassinoides* isp. The *Skolithos* and *Cruziana* ichnofacies indicate a foreshore to shoreface/offshore shallow-marine environment, with occasional high-energy depositional conditions⁽⁷⁾. The ichnospecies *Phycosiphon* isp. are being reported for the first time from the Miocene succession of North-East India.

Skolithos, *Cruziana*, and mixed *Skolithos/Cruziana* ichnofacies indicate variable hydrodynamic conditions as low wave and current energy conditions with intervening periods of high wave and current energy conditions and an intermediate period of stressful environment. The *Cruziana* ichnofacies reflect a marine environment of permanently subtidal, poorly sorted, and unconsolidated (muddy) substrates in shallow marine settings characterized by uniform salinity. Conditions typically range from moderate energy levels lying below fair-weather (minimum) wave base but above storm wave base, to lower energy levels in deeper, quieter waters. Thus, it can be concluded that rocks of Upper Bhuban Formation, Surma Group of Mizoram were deposited under the sandy shifting substrate and high energy conditions in foreshore to unconsolidated, poorly sorted soft substrate and low energy condition in shoreface/offshore zone of shallow marine environment with occasion storm events.

3.3.2. Palaeo-environment, palaeo-ecology, and ethological diversity of trace fossil in the studied section of Middle Bhuban Unit:

The Middle Bhuban Unit of Bhuban Formation, Surma Group (lower to middle Miocene) is well exposed in 40 m thick successions of Zuangtui section. Vertical burrows of *Funalichnus bhubani*, *Psilonichnus upsilon*, and *Skolithos* occur in silty-shale

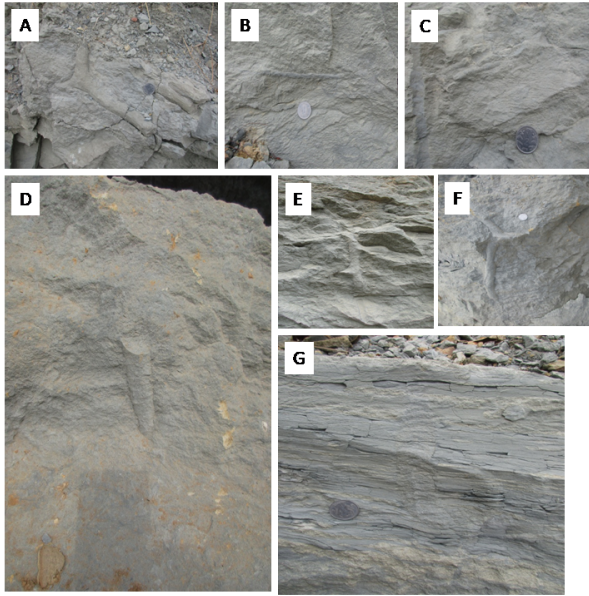


Plate 5: a. *Planolites beverleyensis* and *Thalassinoides* isp., b –c. *Planolites* isp., d. *Skolithos* isp., e. *Thalassinoides paradoxicus*, f. *Thalassinoides* isp., g. Ichnospecies Type A.

and shale beds exposed in the middle part of the succession are a typical member of *Skolithos* ichnofacies. *Psilonichnus upsilon* are inclined, sparsely branched, sub-vertical burrows that occur in back-beach and lower coastal dune facies⁽⁸⁾. The *Skolithos* ichnofacies indicate the unconsolidated and shifting nature of the substrate, high energy conditions, and a rapid change in the sedimentation rate and erosion of surface sediments. *Funalicchnus bhubani* indicates the changes in the colonization pattern of the benthic community.

The high abundance of horizontal deposit feeding traces namely, *Cochlichnus*, *Planolites*, *Palaeophycus*, *Rhizocorallium*, and *Thalassinoides suevicus* are indicative of extremely quiet water conditions with less reworking where organic matter was being deposited along with the sediments. This assemblage represents a transitional zone to a lower shoreface environment, somewhat quieter offshore conditions; most probably the lowest energy levels. The *Thalassinoides* are frequently related to the oxygen-at situations and soft but fairly cohesive substrates.

Overall trace fossil assemblage of Middle Bhuban rocks at the Zuangtui section consists of dominant horizontal feeding structures suggesting low to moderate energy conditions, and unstable, soft, unconsolidated substrates of the shoreface environment. The presence of *Teredolites* is interpreted to have either been carried down by shallow distributary channels and trapped on flanking sand flats or was stranded on flats during the transgressive phase that generated the flooding surfaces.

Table 1. Table showing the occurrence and distribution pattern of Ichnofossil in the Upper Bhuban Unit and Middle Bhuban Unit of Bhuban Formation, Surma Group, Aizawl, Mizoram (A = Absent, P=Present)

Ichnospecies	Nature of Ichnofossil	Upper Bhuban Unit	Middle Bhuban Unit
<i>Funalicchnus Bhubani</i>	Vertical burrow	P	P
<i>Diplocaterion Parallellum</i>	Vertical burrow	P	A
<i>Ophiomorpha borneensis</i>	Vertical burrow	P	A
<i>Psilonichnus upsilon</i>	Vertical burrow	A	P
<i>Ophiomorpha nodosa</i>	Vertical burrow	P	A
<i>Skolithos</i> isp.	Vertical burrow	P	A

Continued on next page

Table 1 continued

<i>Psilonichnus</i> isp.	Vertical burrow	A	P
<i>Palaeophycus striatus</i>	Horizontal burrow	P	P
<i>Palaeophycus</i> isp.	Horizontal burrow	P	A
<i>Phycosiphon</i> isp.	Horizontal	P	A
<i>Planolite beverleyensis</i>	Horizontal burrow	P	P
<i>Planolites</i> isp.	Horizontal burrow	P	P
<i>Palaeophycus sulcatus</i>	Horizontal burrow	P	A
<i>Palaeophycus tubularis</i>	Horizontal burrow	P	P
<i>Cochlichnus anguineus</i>	Crawling traces	A	P
<i>Diplopodichnus biformis</i>	Crawling traces	A	P
<i>Gordia marina</i>	Crawling traces	A	P
<i>Rhizocorallium</i> isp. Type A	Sub-horizontal burrow	A	P
<i>Rhizocorallium</i> isp. Type B	Sub-horizontal burrow	A	P
<i>Teredolites clavatus</i>	Wood Boring	A	P
<i>Teredolites longissimus</i>	Wood Boring	A	P
<i>Thalassinoides horizontalis</i>	Sub horizontal burrow	A	P
<i>Thalassinoides paradoxicus</i>	Sub horizontal burrow	P	A
<i>Thalassinoides suevicus</i>	Sub horizontal burrow	A	P
<i>Thalassinoides</i> isp.	Sub horizontal burrow	P	A

4 Conclusions

4.1 Upper Bhuban Unit of rock succession along Ramrikawn- Sakawrtuichhun Section

Distribution of the trace fossils in the studied sections depicts a definite trend changing from *Cruziana* ichnofacies of lower shoreface-offshore marine to *Skolithos* ichnofacies corresponding to upper-middle shoreface. Sediments at the lower stratigraphic level are dominated by *Cruziana* and mixed *Skolithos*-*Cruziana* ichnofacies, suggesting a reduced energy level away from the shoreline corresponding to lower shoreface -offshore marine settings. *Skolithos* ichnofacies dominated at the higher stratigraphic levels in the studied sections indicating high water energy environment with sandy substrate near the shoreline. Thus, it can be inferred that the studied successions of Upper Bhuban Formation, Surma Group of Mizoram were deposited under sandy shifting substrate and high energy conditions in foreshore to unconsolidated, poorly sorted soft substrate and low energy condition in shoreface/offshore zone of shallow marine environment with occasion storm events.

4.2 Middle Bhuban Unit of rock succession along Zuangtui Section

Vertical endichnial burrows of *Funalichnus bhubani*, *Psilonichnus upsilon* and *Skolithos* occur in silty-shale and shale beds exposed in the middle part of the succession are typical member of *Skolithos* ichnofacies indicating the unconsolidated and shifting nature of the substrate, high energy conditions and a rapid change in the sedimentation rate and erosion of surface sediments. *Funalichnus bhubani* indicates the changes in the colonization pattern of the benthic community. Abundance of these biogenic structures and sedimentary characteristics may be attributed to a relatively moderate to high wave and current energy conditions and shifting of substrate exploited by the opportunistic animals in the foreshore/shoreface environments. Moreover, associated genera are intimately related to high energy shoreface environment. The high abundance of horizontal deposit feeding traces namely, *Cochlichnus*, *Planolites*, *Palaeophycus*, *Rhizocorallium* and *Thalassinoides suevicus* are indicative of extremely quiet water conditions with less reworking where organic matter was being deposited along with the sediments. This assemblage represents transitional zone to lower shoreface environment, somewhat quieter offshore conditions; most probably the lowest energy levels the oxygenated situations and soft but fairly cohesive substrates. Overall this assemblage consists of dominant horizontal feeding structures suggests the low to moderate energy conditions, unstable, soft, unconsolidated substrate of the shoreface environment. *Cochlichnus* is a crawling trace and probably the feeding structures of small worms or worm-like animals and reported in sediments of low salinity palaeoenvironment. The xylic material which hosts the *Teredolites* is interpreted to have either been carried down shallow distributary channels and trapped on flanking sand flats or was stranded on flats during the transgressive episodes that generated the flooding surfaces. During the Lower Miocene time the rocks formed in Mizoram area were deposited in shallow marine setup, whereas this area has now turned into a positive land mass as a result of the withdrawal of the sea.

5 Declaration

Presented in 4th Mizoram Science Congress (MSC 2022) during 20th & 21st October 2022, organized by Mizoram Science, Technology and Innovation Council (MISTIC), Directorate of Science and Technology (DST) Mizoram, Govt. of Mizoram in collaboration with science NGOs in Mizoram such as Mizo Academy of Sciences (MAS), Mizoram Science Society (MSS), Science Teachers' Association, Mizoram (STAM), Geological Society of Mizoram (GSM), Mizoram Mathematics Society (MMS), Biodiversity and Nature Conservation Network (BIOCON) and Mizoram Information & Technology Society (MITS). The Organizers claim the peer review responsibility.

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