PALAEOENVIRONMENTAL SIGNIFICANCE OF THE ICHNOFOSSIL ASSEMBLAGES FROM OLIGOCENE, BARAIL GROUP, CHAMPHAI DISTRICT, MIZORAM

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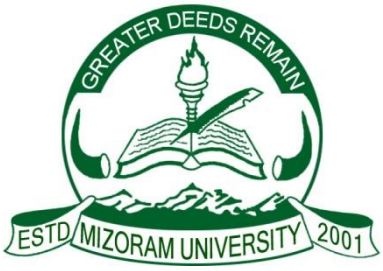

DEPARTMENT OF GEOLOGY

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PALAEOENVIRONMENTAL SIGNIFICANCE OF THE ICHNOFOSSIL ASSEMBLAGES FROM OLIGOCENE, BARAIL GROUP, CHAMPHAI DISTRICT, MIZORAM

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CERTIFICATE

This is to certify that the thesis entitled " Palaeoenvironmental Significance of the Ichnofossil Assemblages from Oligocene, Barail Group, Champhai District, Mizoram" submitted to Mizoram University for the award of the Degree of Philosophy in Geology is a research work carried out by Ms.Lalawmpuii, Research Scholar, in the Department of Geology, Mizoram University, under my supervision and it has not been previously submitted for the award of any research degree to any other University/Institute.

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DECLARATION

I Lalawmpuii, hereby declare that the subject matter of this thesis is the record of work done by me, that the content of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/ Institute.

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Place : Aizawl

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CHAPTER-1

IN TRODUCTION

1.1 GENERAL REMARKS

Mizoram is situated on the north-east end of the country. It shares almost 70% of its border with Bangladesh and Myanmar. It is also surrounded by Manipur, Tripura and Assam. Its geographical borders with Assam, Manipur and Tripura extend over 123 km, 95 km and 66 km. respectively. It covers an area of about 21,081 sq.km. The length of the state from north to south is about 277 km. At the broadest from the east to west its width is about 121 km. It is situated between latitudes 21˚58' and 24˚29' N and longitudes 92˚29' and 93˚22' E. The study area falls under the Survey of India Topo Sheet No. 84 E/7 and coordinates of the study area is (GPS)-23^0 25'19.3"N to $23^0$33'6.4"N latitudes and $93^0$20'05.0"E to 93^0 22'53.3" E longitudes.

1.2 PHYSIOGRAPHY

The Mizo Hills have ranges running from the north to south which taper from the middle of the state, towards the north, the west and the south. The average height of the hills in the west is 1,000 m, gradually rising to 1,300 m in the east. Some places have high ranges, going upto 2,500m.

The state is interspersed with innumerable river, streams and brooks. The important rivers in the northern part of the state are the Tlawng (Dhaleshwari), the Tuirial (Sonai) and the Tuivawl, which flow northwards and fall in the Barak river in Cachar district in Assam. In the southern part of the state, the Chhimtuipui (Kolodyne) is an important river having four tributaries –the Mat, the Tuichang, the

Tyao and the Tuipui. The Kolodyne enters Mizoram from Burma and flows first westward and then southward in Mizoram and reenters Burma.

Mizoram has several mountain peaks. The highest peak in Mizoram is Phawngpui (Blue Mountain) which has a height of 2,157m. It is situated in the south-eastern part of the state.

There are some small plains in the state scattered over the general hilly terrain.The largest plains in Mizoram is the Champhai Plains, situated near the Burma border, 150 km to the east of Aizawl. The Champhai Plains are 10 km long at its widest and 5 km across.

Mizoram terrain is very immature due to recent tectonism, because of that the topographic features show prominent reliefs. The major geographic features observed in the area are both structural and topographic 'heights', 'depressions'. 'flats' and 'slopes' sculptured on the topographic surface in a linear fashion. The physiography of the state shows north-south trending steep, mostly anticlinal, longitudinal parallel to sub-parallel hill ranges and synclinal narrow valleys with series of parallel hammocks on topographic highs. In general, the western limbs of the anticlines are steeper then the eastern limbs. In many cases faulting has produced steep fault scarps.

1.3 CLIMATE:

The physiographic location of Mizoram indicates the climate of the area. Although the tropic of Cancer passes through the middle of the State, it enjoys a moderate climate. During winter, the temperature varies from 11℃ to 21℃ and in the summer, it varies between 20℃ to 29℃. As the area comes under the direct influence of monsoon, Mizoram has an annual rainfall of 254 cm. Even so, due to global

warming, the temperature of the region often crossed 35℃ in summer and reached as low as 4℃ in winter.

1.4 FLORA AND FAUNA

Mizoram has great natural beauty and is rich in fauna and flora. The flora of Mizoram consists of brilliant green plantations full of different plant species throughout the year. The state has a dense bamboo forest and multiplicities of orchids reside in the state. The forest houses some of the rare varieties of Orchids that are found in this region. Apart from this it also has banana, bushes, ferns, fruits and grasses. Its tropical location, which provides favorable climatic condition like moderate temperature, sufficient rainfall, and the nature of soil and elevation facilitated to an abundant growth of vegetation. The vast and dense tropical forest gives rise to an impressive variety of flora and fauna. According to the forest report of India 2021, Mizoram has a vast area of forest covering as much as 84.53 percentages of the total areas.

The forest of Mizoram is inhibited by variety of fauna .A range of wild animals like tiger, clouded leopard, elephant, gaur, barking deer, sambar deer, wild boar, hillock gibbon, rhesus macaque, leaf monkey, common languor, etc, inhibit the forest of Mizoram. It also deals with nearly 1468 species belonging to 891 genre no fewer than 295 families, of which insects alone form 37 percent with 520 species. The next abundant group is the birds with nearly 370 species and sub-species distributed throughout the state. In spite of that, the forest cover in Mizoram has been greatly decreased due to devastation and deforestation for the purpose of infrastructure. Consequently, wildlife, game birds and fishes of all kinds and the rich

vegetation of various varieties had sadly depleted and exhausted the state. With that Mizos lost a great number of their source of food.

1.5 OBJECTIVES

The objectives of the present study are therefore, to study the ichnofossils from the Barail Group of rocks of Champhai District with the view to:

1) demarcation of lithic units and building of statifigraphic sequence.
2) systematic description of ichnofossils.
3) correlation of Barail succession of study area with coeval successions in other areas of Northeast India.
4) palaeoenvironmental signification of the ichnofossil assemblages.

1.6 METHODOLOGY

The research methodology employed in the study area has been broadly classified into following three categories:-

1.6.1 Literature survey: At the outset a survey of pertinent literatures has been undertaken in order to gather available information about the local as well as regional geology, especially the palaeontology of the region and adjoining areas with the help of available literature. For this purpose various published papers has been downloaded.

1.6.2 Field investigation: The field investigation included the following steps:

i) Collection of field data along the studied sections

ii) Preparation of lithologs.

iii) Field photographs of those ichnofossils with the host rocks which could not be collected were taken.

iv) Collection of trace fossils along with the enclosing rocks.

v) Marking of fossil yielding horizons in litho-logs.

vi) Field checks of data obtained through laboratory investigations.

1.6.3 Laboratory investigation: This include the following steps:

i) Cleaning of the collected trace fossils.

ii) Photograph of the specimens for preparation of plates.

iii) Plotting of position of trace fossils in litho-logs.

iv) Identification and systematic description of both the collected and photographed trace fossils was carried out with the help of available published work

v) Geographical distribution of the present collection was worked out, i.e. occurrence of the genus or species in other Oligocene exposures in Northeast India.

vi) Ichnofacies and ethological grouping of the described trace fossils was accomplished.

vii) Depostional environment of the studied rock successions of Barail Group was worked out on the basis of such ichnofacies and ethological groupings.

viii) Finally, correlation of the studied sections with the Oligocene successions from other parts of North East India where ichnological studies have been performed by other workers has been attempted.

1.7 STRUCTURE OF THE THESIS

The thesis is divided into the following Chapters:

1. **Chapter I- Introduction**:

   This chapter gives an outline introduction of the physical features, physiography, climate, flora and fauna of Mizoram, it also contains objective and methodolgy of the study and the entire structure of the thesis.

2. **Chapter II-Review of Literature**:

   This chapter contains review of existing literature from northern India, southern India, western India and Northeast India.

3. **Chapter III-Geological setting of the area:**

   Chapter three of the thesis covers general geology of Mizoram and Geology of the study area along with description of lithocolumn of different sections of the study area.

4. **Chapter IV-Systematic description:**

   The fourth chapter covers the details on systematical description of trace frossils collected from the study area and their ethological diversity along with analysis of the identified tracefossils.

5. **Chapter V- Depositional environment**:

   The fifth chapter dicusses the depositional environment of the study area on the basis of the recovered trace fossils.

6. **Chapter VI-Correlation**:

   Chapter six is divided into two, local correlation and correlation of the studied sections with Oligocene successions of Northeast India on the basis of depositional environment.

7. **Chapter VII-Summary and conclusions:**

This chapter summarizes the findings of the thesis.

CHAPTER-2

REVIEW OF LITERATURE

Ichnological researches in India started in the early seventies and subsequently there was a considerable progress. Many workers have put up important works in various features of the ichnological studies. Most of these studies focus on Precambrian-Cambrian and Palaeozoic-Mesozoic stratographic intervals. A little research work have been taken up in North India by Agrawal and Singh (1983). Sudan *et al*. (2002). While in the North-Western parts of India these works have been carried out by Rajnath (1942), Chiplonkar and Badve (1970), Kumar et al. (1975), Tandon and Bhatia (1978), Biswas (1981), Kumar *et al*. (1982), Shringarpure (1984, 1986), Patel and Shringarpure (1990, 1992), Srivastava and Kumar (1992), Borkar and Kulkarni (1992, 2006), Sanganwar and Kundal (1998), Kundal and Sanganwar (1998, 2000), Kundal and Dharashivkar (2006), Kundal and Mude (2008), Desai *et al*. (2008), Patel *et al*. (2008), Desai and Patel (2008) and Patel and Desai (2009). Desai (2012), Mude (2012), Patel (2012, 2014), Joseph *et al*. (2012) and Ahmad and Kumar (2014). In some parts of South-India these work have been taken up by Chiplonkar and Ghare (1979), Malarkodi *et al*. (2009) and in Kerala state by Mude *et al*. (2012). In North-Eastern India region, apart from Mizoram, the trace fossils study has been carried out by Reddy *et al.* (1992) in cores of Kopili, Barail and Tipam sediments of Upper Assam shelf; Bandopadhyay *et al*. (2009) worked on the Namunagarh grit of Eocene age in South Andaman island and suggested that the island is a submarine fan deposit where sedimentation occurred in deep marine environment mainly by turbidity currents. A detailed ichnological analysis, for the first time, has been performed on Upper Eocene-Lower Oligocene Transition of

Manipur, Indo-Myanmar Ranges by Singh *et al.* (2008). The Cenozoic sediments from the Disang and Barail groups of the area contain a relatively abundant and moderately diverse trace fossil assemblage that has been characterized at the ichnogenus and ichnospecies level. A total of eight ichnospecies, which belong to *Skolithos* and/or *Cruziana* ichnofacies have been described and suggested that the probable depositional environment was shallow-marine environment, with occasional high-energy conditions. The Oligocene-Miocene sediments of Bhuban and Boka Bil Formations in Manipur Wastern Hill have been studied by Singh *et al*. (2010). These formations are represented by eight lithogenus consist of fifteen ichnospecies belongs to *Skolithos*, *Cruziana* and *Skolithos/Cruziana* ichnofacies. Khaidem *et al*. (2015) studied trace fossils from Laisong flysch sediments, Manipur, India. The Oligocene Barail sediments in and around Jotsoma , Kohima in Nagaland have been studied by Kichu *et al*. (2018) and Rajkumar *et al*. (2019) worked out from Upper Disang Formation & Lower Barail Formation (Late Eocene to Early Oligocene) of Nagaland. Mizoram is well known for its mega-biota content. However, its rich and diverse assemblage of ichnofossils is not yet fully explored. Recently, Ichnological researches in Mizoram have gained momentum. Important contribution in this field are made by Mehrotra *et al.* (2001, 2002), Tiwari *et al*.(2011, 2013), Rajkumar *et al.* (2012), Lokho and Singh (2013), and Rajkonwar *et al.* (2013, 2014a, 2014b and 2015).

2.1 Northern India:

Few trace fossil studies has been done in northern India. In the state of Uttar Pradesh, trace fossils of the fluvial Middle Siwalik Successions have been described by Agrawal and Singh (1983). Sudan *et al*. (2002) described it from Murree Group

(Late Eocene-early Miocene) of Jammu and Kashmir. They considered that ichnofossils, mainly corresponding to dwelling forms and are facies-related, allowing for differentiation of four ichnofacies. These ichnofacies were used to interpret the environmental conditions during late Palaeogene related to several settings in coastal environments (Sudan *et al.,* 2002).

2.2 Southern India:

A little research work has been taken up in some parts of south-India by Chiplonkar and Ghare (1979), Malarkodi *et al*. (2009) and in Kerala state by Mude *et al.*, 2012.

The first report of trace fossils from the Cenozoic successions of the Kerala from the Ambalapuzha Formation (Mio-Pliocene) has been reported by Mude *et al.,* 2012. They observed only *Skolitho linearis* and *Planolites beverlyensis* which respectively belong to *Skolithos* and *Cruziana* ichnofacies, allowing interpretation of deposition in shallow water, near-shore marine environment with moderate to high energy conditions. (Mude *et al.,* 2012)

2.3 Western India:

Ichnological researches in western India are comparatively large and are mainly in the state of Gujarat. Early ichnological research in Gujarat was conducted in 1990 by Patel, and Patel and Shringarpure. Patel (1990), in his unpublished Ph.D Thesis, he studied trace fossils in carbonate rocks of western Kutch-Gujarat state, recognizing in hard yellowish limestones of the Vinjhanian state (early to middle Burdigalian; early Miocene) trace fossils including *Skolithos, Arenicolites, Planolites, Palaeophycus, Macanopsis* and *Manocraterion*. A close examination of these rocks made it possible to identify boring activities, including those by bivalves

(*Lithophaga* borings), barnacles (*Lithotrya* borings) and by polychaete worms (microboring), giving rise to interpretation of the typical *Glossigungites* ichnofacies developed in firm but unlithified substates, most likely intertidal to subtidal (Patel & Shringarpure, 1998). A brief description of ichnogenera registered in Aquitanian, Burdigalian and Helvetian rocks, their abundance and ethological were made by Patel and Shringarpure (1990). Ichnological data were used to interpret the depositional environments and parameters involved, such as energy and sedimentation rate (Patel and Shringarpure. 1990). Again, in 1 992, they recorded the presence of *Limulicubichnus* from early Miocene rocks in Western Kutch (Patel and Shringarpure, 1992). They differentiated two species, analysed the behavior pattern of the tracemaker, and interpreted the associated environmental conditions (Patel and Shringarpure, 1992). Kundal *et al* (2005) studied ichnofossils from the late Eocene to early Miocene of the Cambay Basin and from the Babaguru Formation (early Miocene) six ichnospecies were identified like *Keckia annulata, Ophiomorpha nodosa, Palaeophycus tubularis, Planolites beverlyensis, Planolites montanus, Thalassinoides paradoxicus*. Presence of *skolithos* and *Cruziana* ichnofacies is interpreted as indicating littoral to shallow sublittoral zones (Kundal *et al*., 2005). Trace fossils from Neogene to Quaternary successions were reported by Kundal and Dharshivkar (2006), in the Dwarka-Okha area, they recognized a rich and diversified ichnofossil assemblage consisting of seventeen ichnospecies, some of them discovered for the first time in the studied area. Stratigraphic distribution of ichnotaxa is presented, as well as morphological, ethological and ichnofacies classifications. This ichnoassemblage associated with *Skolithos-Cruziana* mixed ichnofacies, littoral to shallow sublittoral sandy shore environment and very high

energy conditions (Kundal and Dharashivkar, 2006). From Dwarka Formation (Miocene), Porbandar area, eight ichnospecies were differentiated, six of them, such as, *Granularia* isp., *Ophiomorpha irregulaire, O.nodosa, Palaeophycus heberti, P.tubularis,* and *Planolites beverlyensis,* occurring in the Dwarka Formation (Miocene). Four ichnospecies were interpreted as fodinichnia and two as domichnia. These ichnospecies belong to *Skolithos* and *Cruziana* ichnofacies, indicating that the Dwarka formation was deposited in shallow water marine conditions (Kundal and Mude, 2008). Mude (2012a, 2012b) hightlighted the palaeoenvironmental significance of ichnofossils from Miocene successions of different formations of the Cambay Basin. From the Babaguru Formation (early Miocene), the author presents four ichnofossils, the predominance of vertical structures is associated with deposition in a nearshore/shoreface marine environment having moderate to high energy conditions, and low diversity is interpreted as a paucity of nutrients (Mude, 2012a). At the Kand Formation (late Miocene), five ichnospecies were documented, including domichnia and fodinichnia behaviours, with a dominance of horizontal traces (Mude, 2012b). The trace fossils are associated with softgrounds, in shallow water marine environment, with a moderate to low energy conditions, and nutrient availability (Mude, 2012b)

2.4 Northeastern India:

Ichnological study in northestern India was first conducted by Reddy *et al.* (1992) from Assam State, the authors described several ichnospecies like *Planolites* isp., *Thalassinoides* isp., *Skolithos verticalis* and with ? *Muensteria* isp., occurring in the Tipam succession of Mio-Pliocene age. This ichnoassemblage, along with that of trace fossils from the Kopili and Barail Groups (Palaeocene to Oligocene) served to

differentiate ichnofacies and to interpret palaeoenvironment conditions of the Upper Assam Shelf. Ichnological studies has been carried out by Singh *et al.* (2008) on the Upper Eocene-Lower Oligocene Transition of the Manipur, Indo-Myanmar Ranges. Eight ichnospecies have been identified. This ichnoassemblage associated with *Skolithos* and /or *Cruziana* ichnofacies, shallow marine environment, with occasional high energy condition. Subsequently, Singh *et al.* 2010 done ichnological research in the Miocene succession in the Bhuban and Boka Bil, comprising Oligocene-Miocene sediments of Bhuban and Boka Bil Formations in Manipur Western Hill. They described and integrated facies and ichnofossils to interpret palaeoenvironmental and palaeoecological conditions associated with both the formations. Fifteen ichnospecies were identified representing a mixture of domichnia and fodinichnia behaviours, pertaining to a variety of ichnofacies like *Skolithos, Cruziana, Skolithos/Cruziana* and *Cruziana/ Zoophycus* ichnofacies. Trace fossils distribution pattern and sedimentary features implies fluctuation of sea level, varying energy level and nutrient availability in subtidal to lower intertidal environment of shallow marine conditions (Singh *et al*., 2010). Khaidem *et al*. (2015) studies ichnofossils from Laisong flysch sediments of Manipur. They described 33 ichnospecies, belonging to *Teredolite* ichnofacies, *Skolithos* ichnofacies, *Cruziana* ichnofacies, mixed *skolithos-Cruziana* ichnofacies, *zoophycos* ichnofacies and *Nereitis* ichnofacies. The vertical distribution of diverse ichnospecies at different level of succession is interpreted as indicating fluctuation in the basin depth that is shallowing and deepening (Khaidem *et al.,* 2015). Kichu *et al* (2018) described six ichnospecies from Oligocene Barail sediments in and around Jotsoma, Kohima, Nagaland, belonging to *Skolithos or Cruziana* ichnofacies. On the analysis of

lithofacies conducted by them and distribution pattern of the ichnofossils, they suggested the Barail sediments were deposited under frequently fluctuating sea, having moderate to strong energy levels, within shoreface environment and rich in nutrient content (Kichu *et al.,* 2018). Rajkumar *et al* (2019) described 14 ichnospecies belonging to *Skolithos* ichnofacies, *Cruziana* ichnofacies, *Nereites* ichnofacies from Upper Disang Formation and Lower Barail Formation of Nagaland. Presence of ichnofacies and sand sperules is interpreted as indicating fluctuation in the deep bathymetry, proximal to distal hyperpycnal delta-fed turbidite system and shoreline as one of the depositional environment (Rajkumar *et al.*, 2019).

In Mizoram, Mehrotra *et al.* (2001) studies trace fossils, for the first time, from the Bhuban Formation of the Surma Group of early-middle Miocene age. The authors reported *Teredolites clavatus* from the Upper Bhuban Unit of Bhuban Formation, Ramrikawn area about 10 km west of Aizawl city, Mizoram and interpreted as a warm water shallow marine transgressive phase of deposition for a part of Upper Bhuban sequence younger to the one exposed at Ropaiabawk, Aizawl. This ichnospecies was found in association with other shallow marine taxa mainly *tellinid* bivalves and fishes. Afterwords, Mehroatra *et al*. (2002) also described ichnogenus *Palaeophycus* from the Barail Group succession exposed at about 8.7 km from Champhai toward Aizawl road. This was considered the first record of *Palaeophycus* from the Tertiary succession of North-East India. The presence of *Palaeophycus* ichnospecies is interpreted as representing passive sedimentation. The first detailed ichnological study was carried out on the Bhuban Formation of Surma Group in Aizawl district of Mizoram by Tiwari *et al*. (2011). The study was carried out at two localities, i.e., Bawngkawn and Ropaiabawk where sandstone-shale

sequence is well exposed. Altogether 20 ichnospecies belonging to 14 ichnogenera have been identified, which were further categorised into *Skolithos* and *Cruziana* ichnofacies. Presence of *Skolithos* ichnofacies indicates sandy shifting substrate and high energy conditions in foreshore zone while the *Cruziana* ichnofacies indicate unconsolidated, poorly sorted soft substrate and low energy condition in the shore/offshore zone. One of the most significant works on ichnological study in Mizoram is taken up by Rajkonwar *et al.* (2013) at Bawngkawn-Durtlang road, Middle Bhuban of Mizoram, a total of 30 ichnospecies of 19 ichnogenera have been described. The behavioural nature and distribution pattern of the ichnofossils as well as sedimentological features is interpreted as indicating the Middle Bhuban succession was deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine environment. Subsequently, Rajkonwar *et al.* (2014) reported trace fossils from Middle Bhuban Unit, Mizoram. In his published literature, he documented 23 ichnotaxa, including vertical burrows, horizontal simple burrows and trails, horizontal branched burrows and bilobate structures. The authors further mentioned that eight ichnospecies were previously described and the remaining 16 are being described for the first time. Occurrence of *Skolithos*, *Cruziana* and at places *Skolithos*-*Cruziana* ichnofacies is interpreted as suggesting the rocks of Middle Bhuban unit were deposited under high energy conditions and sandy shifting substrate in foreshore zone and unconsolidated, poorly sorted, soft substrate and low energy condition in the shoreface to offshore zone, respectively. Later, ichnological study has been put up by Rajkonwar *et al*. (2015) from Bhuban succession of Surma Group Zuangtui section of Aizawl district of Mizoram. The author described a total of 17 ichnospecies, these are *Cochlichnus*

anguineus, Diplopodichnus biformis, Funalichnus bhubani, Gordia marina, Palaeophycus striatus, P. tubularis, Planolites beverleyensis, Planolites isp., *Psilonichnus upsilon, Psilonichnus* isp., *Rhizocorallium* isp. Type A, *Rhizocorallium* isp. Type B, *Skolithos* isp., *Teredolites clavatus, T. longissimus, Thalassinoides horizontalis* and *T. suevicus*. This ichnoassemblage associate with *Skolithos, Cruziana* and *Teredolites* ichnofacies and at places the mixed *Skolithos-Cruziana* ichnofacies.

Table 2.1: Published literature on Oligocene ichnological research in North East India.

Location **North East**	**Referance**	**State**	**Stratigraphic Horizon**	**Ichnotaxa**
1	Singh *et al*. (2008)	Manipur	Upper Eocene -Lower Oligocene,	*Arenicolite* isp. *Helminthopsis tenuis, Ophiomorpha nodosa Phycodes palmatum Planolites montanus Rhizocorallium jenense Thalassinoides paradoxicus Skolithos linearis.*
2	Singh *et al*. (2010)	Manipur	Oligocene-Miocene sediments.	*Arcorichnus ancorichnus Arthrophucus* isp., *Fucusopsis angulatus*

				Gyrochorte comosa *Helminthoida* isp., *Lockeia siliquaria* *Ophiomorpha nodosa* *Palaeophycus alternatus* *Palaeophycus tubularis* *Planolites beverlyensis* *Phycodes* isp., *Psilonichnus upsilon* *Rutichnus irregularis* *Thalassinoides* isp.
3	Khaidem *et al.*(2015)	Manipur	Laisong flysch sediments	*Acanthorhaphe* isp. *Ancorichnus ancoruhnus* *Bergaueria hemishperica* *Chondrites targionii* *Circulichnus* isp., *Desmograpton* *Furculosus* isp. *Gordia marinina* *Gyrochorte comosa* *Gyrophyllites,* *Halopoa imbricata* *Helminthopsis tenuis*

				Helminthoidichnus isp. *Helminthorhaphe* isp. *Megagrapton irregulare* *Nereites mussouri* *Ophiomorpha nodosa* *Paleodictyon* isp. *Palaeophycus* isp. *Parahaenzchelinia* isp. *Phycodes palmatum* *Protovirgylaria rugosa* *Rhizocorallium jenense,* *Scolicia plana* *Skolithos linearis* *Spongeliomorpha* isp. *Taphrahelminthopsis auricularis* *Teichichnus* isp. *Teredolites longissiminus* *Thalassinoides* isp. *zoophycus* isp.
4	Kichu *et al.* (2018)	Nagaland	Oligocene, Barail sediments	*Chondrites* isp. *Gyrochorte comosa* *Ophiomorpha nodosa*

				Skolithos linearis *Planolites* isp. *Thalassinoides horizontalis*
5	Rajkumar *et a*l.(2019)	Nagaland	Upper Disang Formation and lower Barail Formation.	*Bergaueria* *Gyrochorte comosa* *Ophiomorpha nodosa* *Skolithos linearis* *Thalassinoides paradoxicus* *Curvolithus vertebralis* *Treptichnus pedum* *Taenidium diesingi* *Palaeophycus tubularis* *Chondrites targionii* *Paleomeandron elegans*

CHAPTER-3

GEOLOGICAL SETTING

3.1 GENERAL GEOLOGY OF MIZORAM

In north-eastern part of India, Cenezoic rocks are well exposed, constituting one of the largest sedimentary basins, covering about 70% area of north east India and have nearly 13 km thick sedimentary succession, which is called Surma basin. Geologically, Mizoram is a part of Neogene Surma basin. It has an area of about 21,081 sq.km, situated between 21^0 58' to 24^0 29' North latitude and 92^0 29 to 93^0 22 East longitude. In Mizoram, the main lithostratigraphic groups found were the Barail group and the Surma group, Tipam group are also present. Of the two main lithost ratigraphic group, the Barail group is of Oligocene age and has a total thickness about 3,000 m. It is further subdivided into the lowermost Laisong formation, the middle Jenam formation and the uppermost Rengi formation. The Surma group is of Miocene age and attains a thickness about 5,000 m, it is subdivided into Boka Bil and Bhuban formations. The Bhuban formation is further subdivided into Lower, Middle and Upper Bhuban units. The surma group overlies the Barail group clearly defined unconformity. The complete sedimentary column of the formation is a repetitive succession of arenaceous and argillaceous rocks. Sandstone, siltstone, Shale, mudstone and their admixtures in dissimilar proportions and few pockets of shell limestone, calcareous sandstone and intraformational conglomerate are the main lithologies exposed in Mizoram (Tiwari and Kachhara, 2003). The stratigraphic succession with the lithological characteristics of each unit worked out by Karunakaran (1974) and Ganju (1975) is given in table 3.1

Table 3.1: Stratigraphic succession of Mizoram (Modified after Karunakaran, 1974 and Ganju, 1975 modified by Tiwar and Kachhara, 2003)

Age	*Group*	*Formation*	*Unit*	*Generalized Lithology*
Recent	Alluvium			Silt, clay and gravel
----------Unconformity----------				
Early Pliocene to Late Miocene	Tipam (+900 m)			Fraible sandstone with occasional clay bands
----------Conformable and transitional contact----------				
Miocene to Upper Oligocene	SURMA (+5950m)	BHUBAN (5000m)	Bokabil (+950 m)	Shale, siltstone and sandstone
			----------Conformable and transitional contact----------	
			Upper Bhuban	Arenaceous predominating with sandstone, shale and siltstone
			-------Conformable and transitional contact-------	
			Middle Bhuban	Argillaceous predominating with shale, siltstone-shale alternations ans sandstone
			-------Conformable and transitional contact-------	
			Lower Bhuban	Arenaceous predominating with sandstone and silty-shale
----------Unconformity obliterated by faults----------				
Oligocene	Barail (+3000 m)			Shale, siltstone and sandstone
----------Lower contact not seen----------				

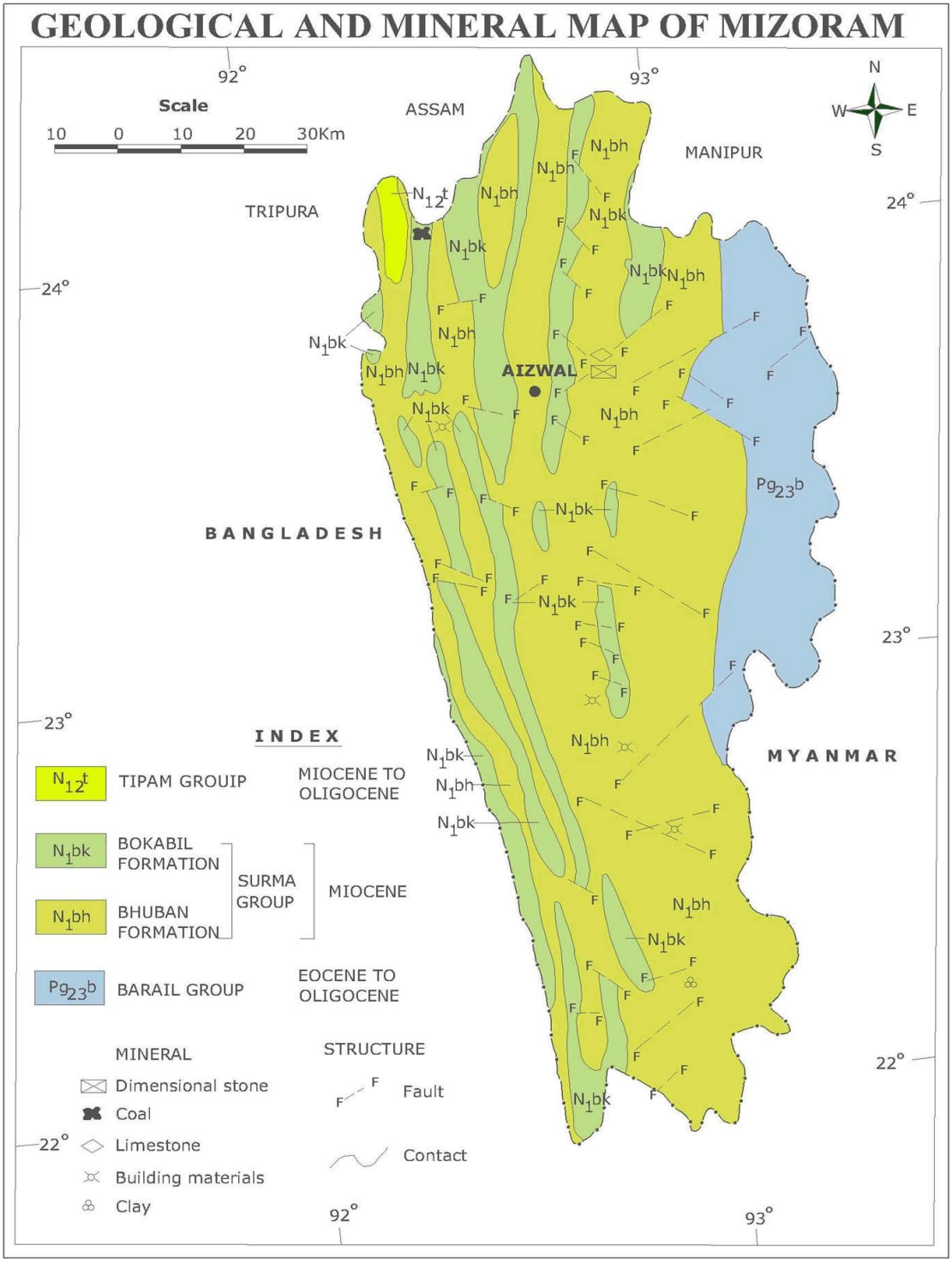


Figure 3.1: Geological map of Mizoram (after Behra *et al*. 2011)

3.2 GEOLOGY OF THE STUDY AREA

The Barail rock exoposed in Mualkawi-Ruantlang, Zote-Ngur and Ngur-Vapar sections comprises a fossiliferous succession of alternating sandstone, siltstone, silty-shale, shale and their admixture in varied proportion. The study area begins from the southern part of Champhai town from Mualkawi-Ruantlang section and in the northern part from Zote-Ngur and Ngur–Vapar sections. Geologically, this succession belongs to Barail sediments which are the only paleogene succession found in Mizoram and are of Oligocene age. The presence of Barail succession in Mizoram is controversial. Nandy (1972, 1982) of the Geological Survey of India have shown the occurrence of Barail sediments in the eastern part of the State around Champhai. Ganju (1975), Ganguly (1975), Ram and Venkataraman (1984) of Oil and Natural Gas Corporation of India, on the other hand, belief that the Barails do not occur in Mizoram and the rocks around Champhai should be included in the Surma Group only. Sandstone rocks found in the study area are very fine to fine grained and are of brown to grey in colour. Shales are light and dark grey to brown in colour. The study area falls under survey of India Topo Sheet No. 84 E/7. The location map of the studied area is showing at fig 3.2

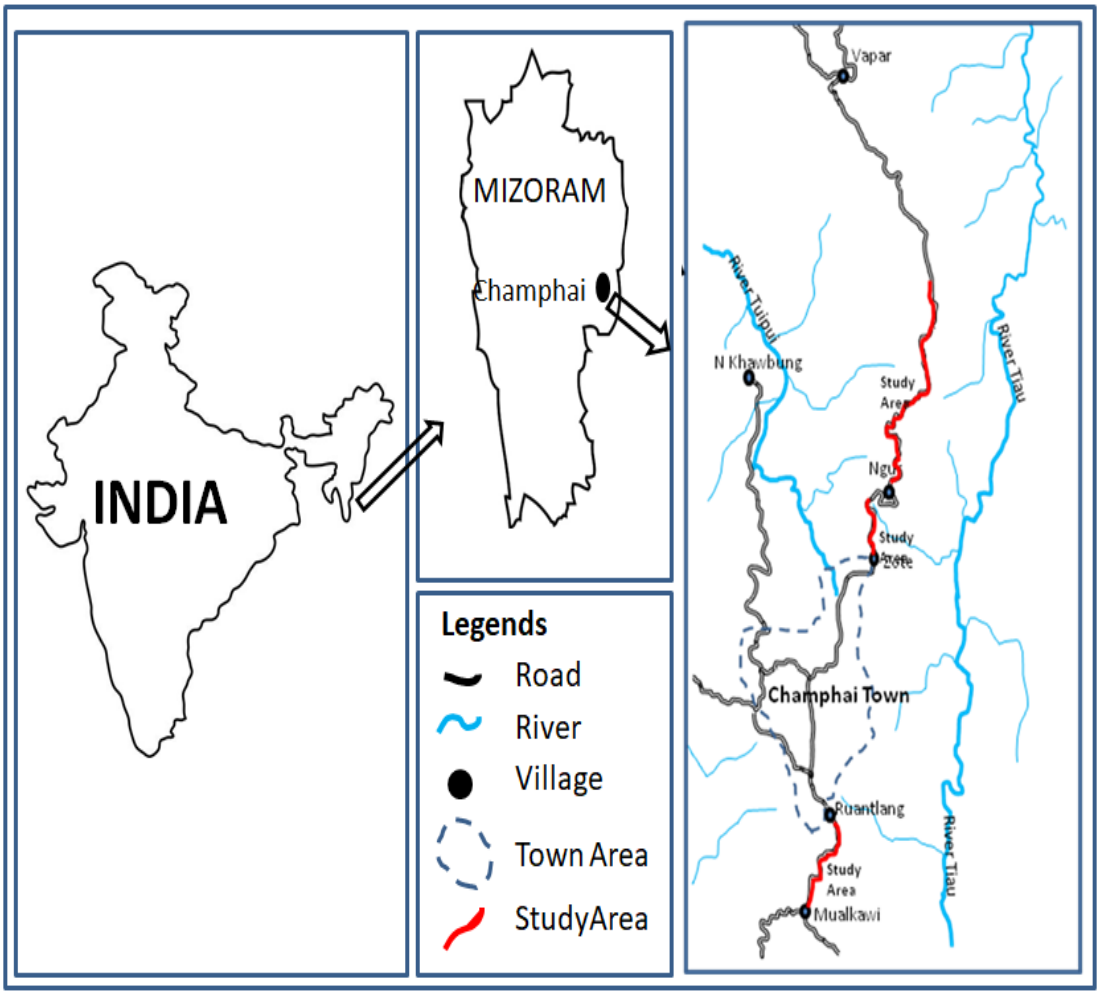


Figure 3.2: Location map of study area (modified after Malsawma, J., 2021).

3.2.1 Description of lithocolumns:

The rock successions belonging to Barail Group are well exposed in Mualkawi-Ruantlang, Zote-Ngur and Ngur–Vapar sections. These sections consist of rich and diverse assemblage of ichnofossil. Thus, they have been selected for ichnological study. To construct litho-column, describe sedimentological details and to work out distribution pattern of trace fossils, numerous field works has been carried out along these sections. Description of litho-columns along these sections is given below:

3.2.1.1 Mualkawi-Ruantlang section:

This section is located in the southern part of Champhai. About 480 m thick successions is well exposed, which comprises very fine to fine grained, brown/ buff coloured sandstone, light to dark grey and brown coloured shale, siltstone and silty-shale and their admixtures in different proportion. A total of 87 beds have been delineated in this section. The lowermost bed is bedded brown sandstone with thin shale parting, it attains thickness about 4m thick. Sedimentary structures encounter within this bed are cross bedding, lenticular, mud clast and current ripple structures. Bed no.2 is an alternation of sandstone and shale bed, it has total thickness about 18.5m. Within this bed ichnofossil like *Planolite beverlyensis* is observed. Bed no.3 is 2.5m thick succession of brown coloured block sandstone bed. It consist of numerous ichnofossils like *Avetoichnus luisae, Funalichnus bhubani, Glaciinium liebegastensis, Gordia carichkensis, Gyrochorte comosa, Ophiomorpha annulata, Macanopsis paguei* and *Macanopsis* isp., This bed is overlain by 1m thick succession of shale bed. Bed no.5 is brown coloured block sandstone bed which is about 3 m thick and embedded ichnospecies like *Archaeonassa* isp., *Avetoichnus*

luisae, Chondrites intricatus, Chondrites recurvus, Cylindrichnus isp.*, Lockeia siliquaria, Planolite montanus, Protovirgularia dichotomus, circulichnus* isp.*,* and *Thalassinoides suevicus.* Which is again overalain by 2m thick shale bed. The next bed is 7m thick succession of an alternation of sandstone and shale bed which is characterized by *Skolithos linearis, S.verticalis, Teichichnus spiralis and Thalassinoides horizontalis.* Followed by thinly bedded sandstone which is again overlain by 2.5m silty-shale bed. Overlying grey coloured silty-sand is 2m thick. An 11m thick grey coloured splintery shale is in bed no.11, classic dykes is observed in this bed which is overlain by 9m thick sandstone- shale alternation bed. Continuing 3m thick silty-shale bed which is followed by 4m thick shale bed. Ball and pillow structure is observed within brown coloured block sandstone bed which is about 1m thick. A 6m thick bedded sandstone is overlain by 3.5 m thick block sandstone bed consisting of ichnofossils like *Arenicolite* isp.*, Gastrochaenolite ornatus., Teichichnus spiralis* and *Thalassinoides horizontalis.* 7m thick block sandstone bed is overlain by 1 m thick silty-shale bed, it consist of *Cochlichnus anguineus.* Silty-shale bed is overlain by 3m thick sandstone- shale alternation bed, sand dominating the bed, followed by 5.5 m thick brown coloured block sandstone bed, this bed is highly bioturbated, yielding ichnospecies like *Funalichnus bhubani, Gastrochaenolite ornatus., Laevicyclus mongraensis, Macanopsis* isp.*, Ohpiomorpha irregulairre, O.nodosa, Palaeophycus annulatus, P.tubularis, Thalassinoides suevicus.* Bed no.25-28 are sandstone, shale and sandstone-shale alternation respectively, they are coarsening in an upward direction. Bed no 29 is silty-shale bed and is characterized by an ichnospecies like *Gastrochaenolite ornatus, Macanopsis* isp. and *Thalassinoides suevicus.* Bed no. 30-39 are also coarsening in an upward

direction, tidal bundles and tidal rythmites are observed between these bed. Among these bed, bed no.35 comprises ichnospecies like *Planolite beverlyensis* and bed no.38 comprises ichnospecies like *Palaeophycus tubularis, Thalassinoides horizontalis*. The overlying shale bed is about 18 m thick, containing ichnospecies of ichnospecies Type A. Next bed is 9m thick block sandstone bed that is overlain by 7m thick sandstone- shale alternation bed, at the bottom of the bed sand is dominanting and the bed contains ichnospecies of *Skolithos linearis* and *Thalassinoides horzontalis.* This bed is overlain by 2m thick bed of silty-shale containing *Skolithos verticalis*. Overlying block sandstone bed is about 1m thick succession. This is followed by 1m thick sandstone-shale alternation bed, having tidal rythmite. Bed no.46 is grey coloured silty-shale bed comprising ichnospecies like *Skolithos linearis* and *S.verticalis*. Next bed is shale bed, which is about 10 m thick and is followed by 3m thick bedded sandstone bed having fault at the top. A 23m thick of silty-shale bed occurs on the top of bedded sandstone bed, embedded ichnospecies like *Skolithos linearis*, *S.verticalis* and *Psilonichnus tubiformis*. Followed by 3m thick sandstone bed comprising burrows of *Ophiomorpha annulata.* Next one is 1m thick block sandstone bed, followed by 2m thick bedded sandstone and again followed by 2m thick block sandstone bed. This bed is overlain by 5m thick bedded sandstone yielding trace fossils of *Psilonichnus upsilon* and *Planolites beverlyensis*. Overlying 1.5m thick block sandstone bed contains ichnospecies of *Asterosoma* isp., *Psilonichnus tubiformis*, *P.*isp. and *Rosselia* isp., This bed is overlain by bedded sandstone bed consisting of *Scolicia stronzzii* and *Skolithos verticalis*. Bed no.57-60 are an alternation of block and bedded sandstone bed respectively. Within bed no. 59, Ball and pillow structure is observed. Continued by

8m thick sandstone-shale alternation bed, which is overlain by 1m thick block sandstone bed, followed by 6m thick shale-sandstone alternation bed. Next bed is 1m thick block sandstone bed, which is overlain by 2m thick shale-sandstone alternation bed. Followed by 21m thick splintery shale, coarsening upward containing ichnospecies like *Palaeophycus striatus, Skolithos verticalis* and *Thalassinoides horizontalis*. Bed no.66 is an alternation of sandstone and shale, which is characterized by *Thalassinoides horizontalis* and heterolithic structure. Overlying shale bed is 3m thick, followed by 3m sandstone-shale alternation, next is 1m thinly bedded sandstone with shale parting. Bed no 70 is 3m thick grey coloured shale bed consisting of *Skolithos linearis*. Next is 1m thick shale-sandstone alternation, overlain by 8m thick shale bed with thin sand bed, followed by 1m grey coloured silty-shale bed. Next bed is 9m thick siltstone, grey in coloured, overlain by 12m thick sandstone-shale alternation. Bed no.76 is grey coloured shale, about 24m thick, consisting *Thalassinoides horizontalis*. This bed is overlain by 17m thick bedded sandstone, having tidal rythmite and herterolithic structure. Sandstone bed is overlain by 7m silty-shale, followed by 1m thick bedded sandstone, 12 m thick silty-shale bed continued the bed, which is grey in coloured. 1m thick bedded sandstone followed the bed, continued by 9m thick sandstone-shale alternation. A 24 m thick silty-shale bed followed, containing ichnofossils like *Katbergia carltonichnus, Palaeophycus striatus, Psilonichnus upsilon* and *Thalassinoides horizontalis.* Next bed is 0.5m thick block sandstone, continuing an alternation of shale and sandstone bed, about 36m thick, characterized by *Planolites beverlyensis* and *Skolithos verticalis*. The top most exposed bed of Mualkawi-Ruantlang section comprises of 6m thick bedded

sandstone, which is characterized by the present of ichnospecies *Pholues bifurcates* and *Planolites beverlyensis*.

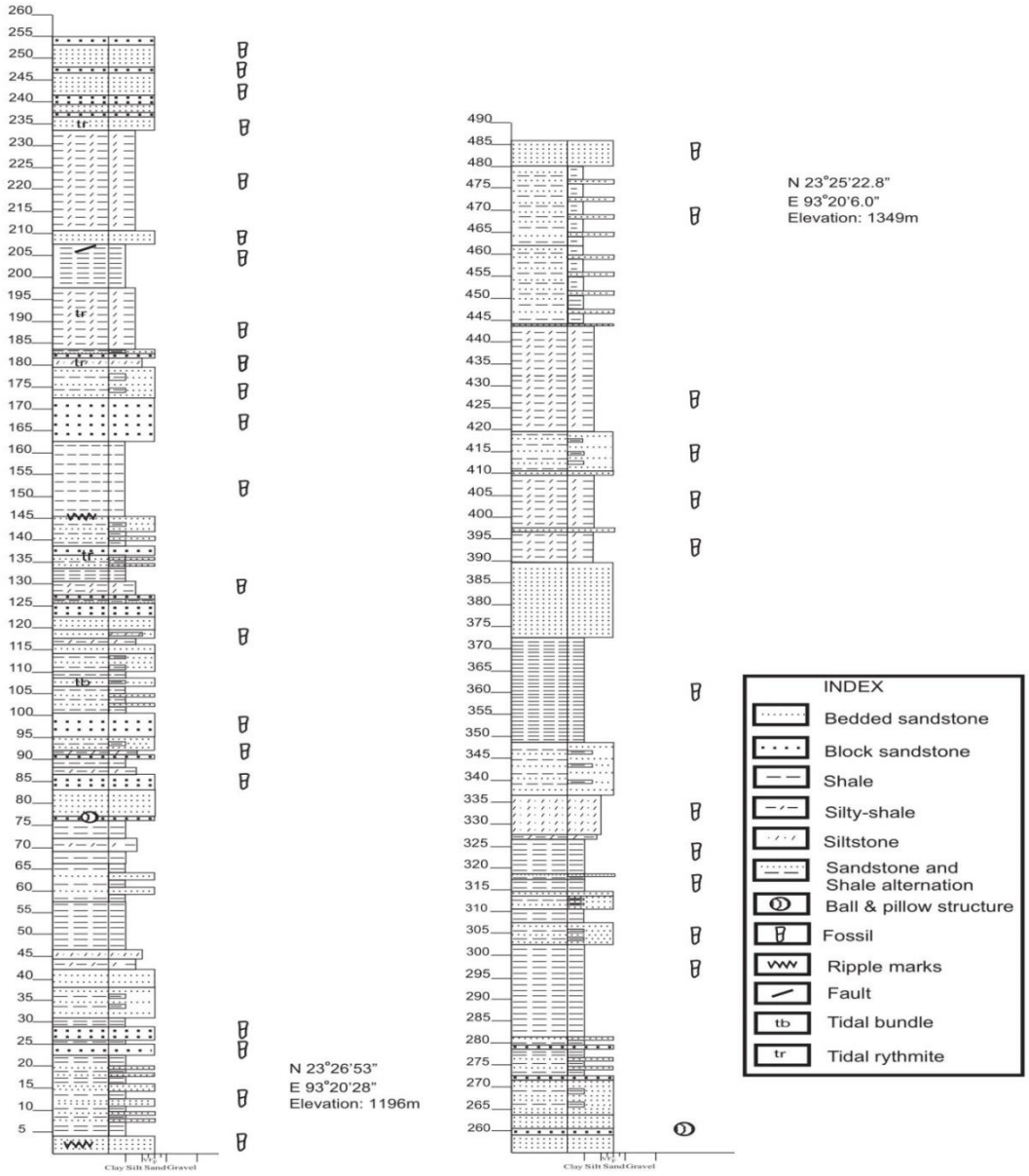


Figure 3.3: Lithocolumn of the Barail Succession in Mualkawi - Ruantlang area, Champhai.

3.2.1.2 Zote-Ngur section:

Rocks of Barail group are studied in Zote-Ngur section, Champhai. It is located in the northern part of Champhai (latitude $23^{o}30'10.9"$ N to $23^{0}30'18.5"$ N and longitude $93^{0}21'36.5"$ E to $93^{0}21'35.0"$E). The measured thickness of the rock succession yielding trace fossils and exposed along this section is approximately about 119m (Fig. 3.4). Ten litho-units have been delineated, which comprises sandstone, siltstone, shale, silty-shale and sandstone-shale alternations. The lowermost bed comprises of grey to brown coloured silty-shale. The bed is about 15m thick and is characterized by heterolithic structure and ichnospeices like *Ophiomorpha nodosa, Rosselia* isp., *Teichichnus spiralis and Thalassinoides horizontalis.* Overall, the bed is coarsening in an upward direction. The bed is overlain by 20m thick bed of brown coloured sandstone, bottom part is block sandstone while at the top the bed is in bedded with thin shale partings. Sedimentary structure encounter in this bed are current & wave ripples and load cast. This bed is rich in trace fossils and has yielded ichnospecies like *Helminthopsis abeli, H.hieroglyphica, Laevicyclus mongraensis, Palaeophycus heberti* and *Skolithos verticalis*. The overlying bed is shale-sandstone alternation, which is about 6m thick with wavy structure, comprising ichnospecies like *Gastrochaeonolite ornatus*. This bed is overlain by 9m thick block sandstone but at the top it is in bedded form. The floor of the bed is very smooth, it seems to indicate that at the time of its formation/deposition, force/current of water seems to be very strong, the bed is characterized by wave ripples and tidal bundle. Elongate ripples are observe at the middle of the bed and wave ripples and biofurcates are observe at the top. *Monomorphichnus* isp. is recovered from this bed. Bed no.5 is 12m thick shale bed

with speroidal structures like ball and pillow structures, contains ichnospecies like *Psilonichnus tubiformis*, A 8m thick grey coloured silty-shale bed overlain shale bed, comprising ichnospecies of *Arenicolite* isp*., Psilonichnus tubiformis Psilonichnus* isp. and *Thalassinoides paradoxicus*, Overlying sandstone-shale alternation is 34m thick, shale dominating the bottom of the bed while sand is dominated at the top of the bed. *Gyrolithes lorcaensis, Laevicyclus mongraensis, Lanicodichnus isp., Lockeia siliquaria, Skolithos linearis and S.verticalis* are the ichnofossils found in this bed. This bed is overlain by 3m thick block sandstone and is without any biogenic activity. Followed by 3m thick silty-shale bed, consisting ichnospecies like *Helminthopsis tenuis* and *Teichichnus rectus*. About 9m thick sandstone bed is observed at the top of the section which embedded ichnospecies like *Treptichnus pedum*.

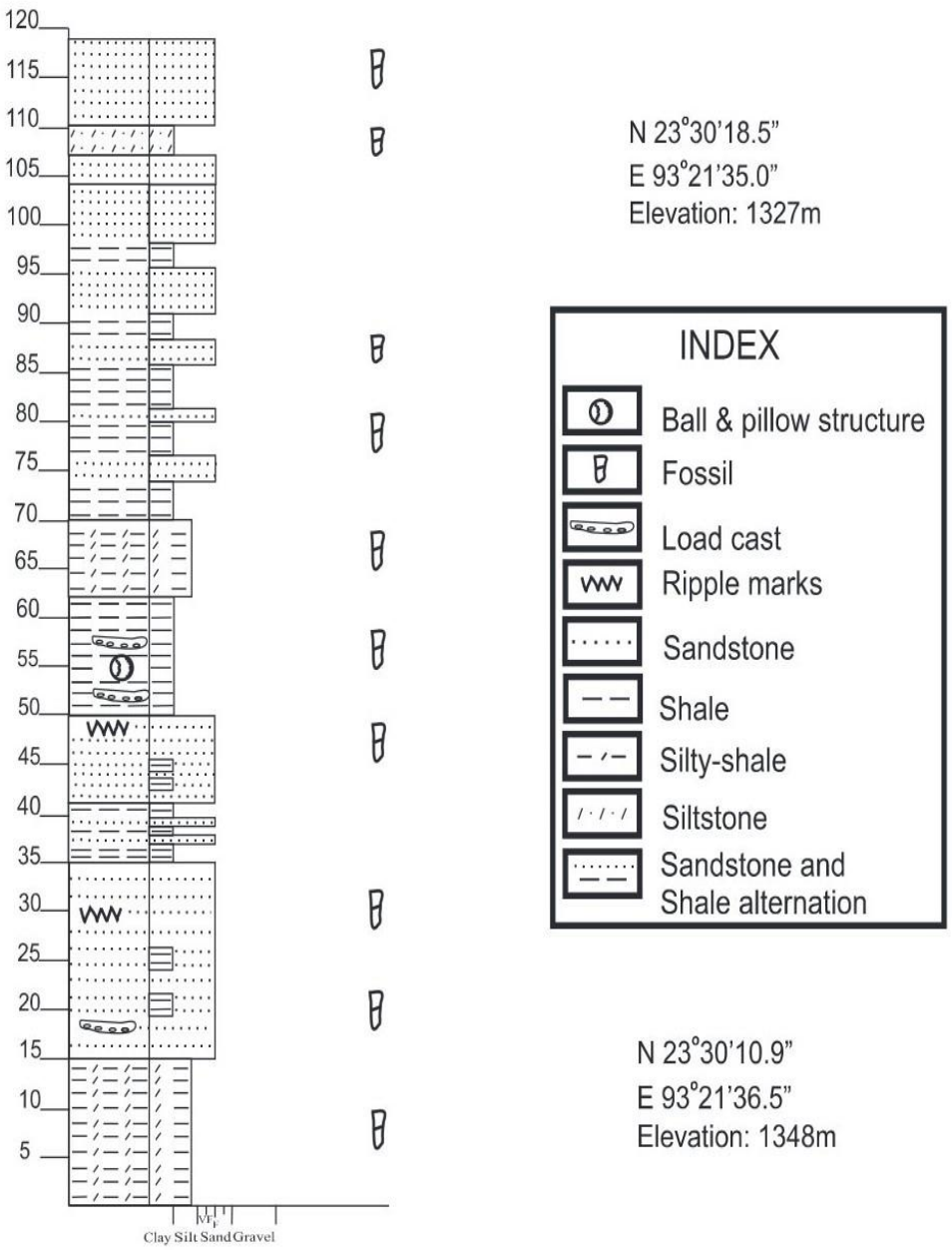


Figure 3.4: Lithocolumn of the Barail Succession in Zote - Ngur area, Champhai

3.2.1.3 Ngur -Vapar section:

This section is situated in the northern part of Champhai, between $23^0$32'30.3" N to $23^0$33'06.4" N latitude and $93^0$23'00.9"E to $93^0$22'53.3"E Longitude. About 387 m thick succession belonging to Barail Group is well exposed in this section, which comprises sandstone, shale, silty-shale and their admixtures. A total of nineteen beds have been delineated in this section. The lower most bed comprises of grey coloured, splintery shale. The bed is about 25m thick and is without any biogenic activity. This bed is overlain by 10m thick silty-shale. This bed has yielded ichnospecies of *Planolite beverlyensis.* Next bed is splintery shale, followed by 32m thick intercalation of shale with 10-35cm thick sandstone bed, yielding ichnospecies like *Skolithos verticalis* and *Thalassinoides horizontalis*. Next bed is 12.5m thick shale bed, comprising ichnospecies like *Lockeia siliquaria and Planolite beverlyensis*. A 18m thick alternation of sandstone and shale bed overlies the shale bed, the bed is dominated by Sand, consisting of ichnospecies like *Archaeonassa fossulata, Ophiomorpha annulata, Palaeophycus striatus, Rusophycus carbonarius* and *Thalassinoides suevicus*. Overlying grey coloured shale is about 5m thick, contains ichnospecies of *Phycodes curvipalmatum* and *Skolithos verticalis,* followed by 19.5m thick succession of intercalation of shale and sandstone beds, this bed is highly bioturbated, yielding ichnospecies of *Arenicolite tenuis, Cochlichnus anguineus, Didymaulichnus lyelli, Gyrolith mexicanus, Laevicyclus mongraensis, Palaeophycus annulatus, Planolite montanus, Psilonichnus upsilon, P.*isp., *Rusophycus versan* and *Thalassinoides horizontalis*. A 25m thick of bedded sandstone occurs on top of shale-sandstone alternation and is followed by 5m thick shale bed. This shale bed is overlain by 13m silty-shale bed, followed by 15m grey

coloured splintery shale, continuing alternation of shale and sandstone bed which is about 20.5m thick. Next bed is brown coloured sandstone bed, attaining thickness about 5m thick, followed by 23m thick intercalation of brown coloured sandstone and grey coloured shale bed. A 18m thick splintery shale bed occurs on top of sandstone and shale alternation, followed by 84m thickly bedded gray coloured sandstone bed, comprising sedimentary structure of cross lamination and heterolithic structures, with less biogenic activity, yielding *Skolithos verticalis* and *Fulanichnus bhubani* . 4m thick shale bed having *Rosselia* isp. is overlain by the top most exposed sandstone bed of Ngur-Vapar section, which is characterized by ichnospecies of *Rusophycus versans*.

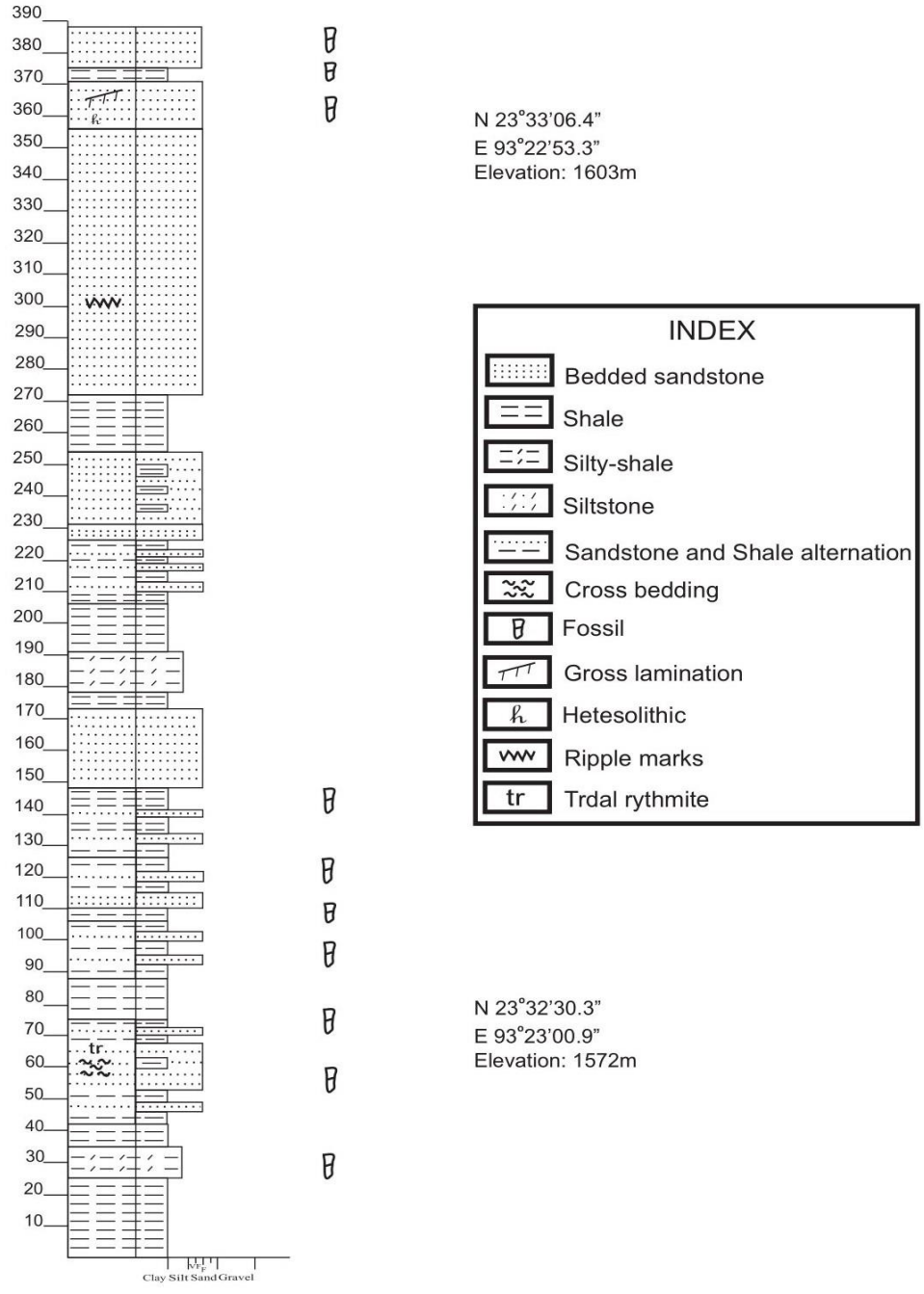


Figure 3.5: Lithocolumn of the Barail Succession in Ngur - Vapar area, Champhai.

CHAPTER-4

SYSTEMATIC DESCRIPTION OF ICHNOFOSSILS

4.1 GENERAL REMARKS:

Total ichnospecies described and illustrated in this thesis include *Archaeonassa fossulata, Archaeonassa ichnospecies, Arenicolite tenuis, Arenicolites* isp., *Asterosoma ichnospecies, Avetoichnus lusae, Chondrites intricatus, Chondrites recurvus, Circulonichnus* isp., *Cochlichnus* isp., *Cruziana* isp., *Cylindrichnus* isp., *Didymaulichnus lyelli, Funalichnus bhubani, Gastrochaenolites ornatus, Glaciinium liebegastensis, Gordia carickensis, Gyrochorte comosa, Gyrolithes lorcaensis, Gyrolithes mexicanus, Helminthopsis abeli, Helminthopsis hieroglyphica, Helminthopsis tenuis, Katbergia carltonichnus, Laevicyclus mongraensis, Lanicodichna medulata, Lockeia siliquaria, Macanopsis pagueyi, Macanopsis* isp., *Monomorphichnus* isp., *Ophiomorpha annulata, Ophiomorpha irregulaire, Ophiomorpha nodosa, Palaeophycus annulatus, Palaeophycus heberti, Palaeophycus sulcatus, Palaeophycus striatus, Palaeophycus tubularis, Pholeus bifurcates, Phycodes curvipalmatum, Planolites beverlyensis, Planolites montanus, Protovirgularia dichotoma, Psilonichnus upsilon, Psilonichnus tubiformis, Psilonichnus* isp., *Rosselia* isp., *Rusophycus carbonarius, Rusophycus versan, Scolicia stronzzii, Skolithos linearis, Skolithos verticalis. Taenidium barretti, Teichichnus recturs, Teichichnus spiralis, Thalassinoides horizontalis, Thalassinoides paradoxicus, Thalassinoides suevicus and Treptichnus pedum.*

In the present study, ichnogenera and ichnospecies are named according to I.C.Z.N. Rules, using the binomial system of nomenclature and described alphabetically.

4. 2 SYSTEMATIC DESCRIPTION:

1. Ichnogenus: *Archaeonassa* Fenton and Fenton (1937)

Ichnogenus *Archaeonassa* are trace fossils with an upper surface that is either bilobed or consists of prominent marginal raised ridged flanking a central area. The nature of the base of the trace generally is not known. Khaidem *et al*. (2015) mentioned that *Archaeonassa* is interpreted chiefly as the work of gastropods in proximity of the sediment/water interface; may also have been produced by echinoids, and represent the exogenic expression of either surface or shallow subsurface location.

Ichnospecies: *Archaeonassa fossulata* Fenton and Fenton (1937)

(Plate I, fig. A)

Material: Specimen no: Ng/ A/6 and field photographed of sandstone with burrows.

Occurrence: Fine grained, brown coloured sandstone bed (bed no 6), Barail group, Ngur-Vapar section, Champhai district, Mizoram.

Description: Horizontal burrow, concave axial grooves locally flanked by marginal positive ridges, full relief, burrow course is curved, irregularly winding, rarely meandering. Axial groove is 3 to 4 mm wide and the trail width is 9 to 12 mm. Simple (transversely ornamented) exhibiting variable ornament definition.

Remarks: Buatois and Mangano (2002); Jensen (2003); Jensen *et al*., (2006) considered that the ichnogenus *Archaeonassa* has been extensively used for describing simple trails displaying a median groove flanked by levees. Fenton and Fenton (1937) suggested gastropods as a trace maker for *Archaeonassa*. Buckman (1994) also inferred that echinoids and trilobites as probable trace makers. Ediacaran

and lower Paleozoic *Archaeonassa* might have been created by "mollusc type" animals (Jensen, 2003)

Distribution: It has been described by Hofmann *et al.* from the Middle Cambrian of Jordan in 2012.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

Ichnospecies: *Archaeonassa* isp.

(Plate I: fig B)

Materials: Field photographed of grey coloured sandstone with semi-relief burrow.

Occurrence: Grey colour sandstone bed (bed no. 6) in Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Horizontal burrow, straight, unbranched, constituted by two symmetrical lobes separated by central furrow, preserved as positive epirelief. Width of the structure is 3mm and length is 40mm. It is co-occured with *Protovirgularia dichotoma*

Remarks: *Archaeonassa* is a poorly known ichnonogenus which is a member of the *Scolicia* group. The ichnotaxonomic status of *Archaeonassa* is still debated (Yochelson and Fedonkin 1997); usually interpreted as a pascichnia produced by arthropods and mollusks (Mangano *et al.* 2005). *Archaeonassa* has been reported from floodplain deposits (Buatois and Mangano 2002). The ichnogenus is interpreted chiefly as the work of gastropods in proximity of the sediment/water interface; may also have been produced by echinoids, and represent the exogenic expression of either surface or shallow subsurface locomotion. Poor preservation and incomplete specimen does not warrant specific level identification.

Distribution: Khaidem *et al*. (2015) reported *Archaeonassa* from the flysch sediments of Laisong area of Manipur, India. Also by Singh *et al*. (2015) from the lower part of the Banded Siltstone Member of the Sankholi Formation (Tal Group) exposed at Ganog locality, Nigali Dhar syncline (Sirmur district) Himachal Pradesh. It was the first record of this ichnotaxon from the Cambrian succession of Indian Himalayas. This ichnospecies has been described from Bhuban Unit of Bhuban Formation, Surma Group, Aizawl, Mizoram by Rajkonwal *et al*. (2014).

This ichnospecies is being reported for the first time from Barail Group of Mizoram.

2. Ichnogenus: *Arenicolites* Salter (1857)

According to Savrda (2007) and MacEachern *et al*. (2007), Ichnogenus *Arenicolites* is generally vertical to subvertical dwelling structure made by suspension-feeding, worms like organisms. *Arenicolites* is characterized as a dwelling trace of typical shallow marine realm (Bromley, 1996) with several deep water instances (Bromley and Asgaard, 1979). In general, this tracefossil point towards high energy intertidal to subtidal condition of deposition (Fursich, 1974). Fursich (1974a) mentioned that this ichnogenus differs essentially from *Diplocraterion* in the absence of spreiten. Bromley (1996) noted that similar structures are produced in modern environments by deposit feeders, including polychaetes and holothurians of shallow marine higher energy environments (Gérard & Bromley 2008). However, it has also been reported from deep and marginal marine and lacustrine settings (Bromley & Asgaard 1979; Guillette *et al*. 2003; Hofmann 2008). *Arenicolites* is stratigraphically widely distributed through the entire Phanerozoic.

Ichnospecies: *Arenicolite tenuis* Kulkarni, Borkar and Petare (2008)

(Plate I: fig C)

Material: Field photographed of shale with full relief burrow.

Occurrence: Shale bed (Bed no. 8) from Ngur-Vapar section Champhai District, Mizoram.

Description: Vertical burrow, cylindrical, slender, u-shaped with no spreiten. Burrow limbs are closely spaced and are nearly parallel to each other, depth of the burrow is 8 cm; arm width is 0.3-0.5 cm and diameter between the limbs is about 0.5 cm. Burrow filled is more massive than the host rock.

Remark: Being slender, U-shape, parallel limbs with circular cross section of the present specimen, it has been placed under *Arenicolite tenuis*.

Distribution: *Arenicolites tenuis* has been reported by Kulkarni *et al.* (2008) from the Fort Member (Jurassic) of the Jaisalmer Foramtion, marine Mesozoic sequence of the Marwar region of Rajasthan, India. It has been recorded by Rajkonwar *et al* (2013) from Bhuban Formation, Aizawl, Mizoram.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

Ichnospecies: *Arenicolite* ichnospecies

(Plate I: fig D & E)

Material: Field photographed of brown coloured sandstone with full relief burrow and grey coloured siltstone bed with full relief burrow.

Occurrence: Brown coloured sandstone (Bed no.18) of Mualkawi-Ruantlang section and grey coloured siltstone bed (Bed no.6) from Zote-Ngur section Champhai District, Mizoram.

Description: Endichnial, vertical to subvertical, cylindrical, u-shaped with no spreiten. Burrow filled are identical to the host rock, their limbs are widely space and are not parallel to each other. Diameter of the tube vary from 1.8-3 cm. The present burrow are widening upward.

Remark: On the basis of U-shaped which is in vertical to subvertical structure, present specimen is assigned to ichnogenus *Arenicolite* but identification upto species level is not possible due the lack of poor preservation and incomplete specimen.

Distribution: Singh *et al.* (2008) reported this ichnospecies from Upper Eocene-Lower Oligocene Transition of Manipur. Paranjape *et al*. (2013) described it from the Bada Bagh Member of Jaisalmer Formation, Rajasthan. It has been recorded by Tiwari *et al* (2011) and Rajkonwar *et al* (2014) from Bhuban Formation, Aizawl, Mizoram.

This ichnospecies is being reported for the first time from Barail Group of Mizoram.

3. Ichnogenus: *Asterosoma* Von Otto (1854)

Hantzchel, 1975 considers that the original diagnosis of *Asterosoma* von Otto (1854) was mostly based on the star-like arrangement of bulbs, typical for *A.radiciforme*. Subsequently, Schlirf (2000) mentioned that the ichnogeneric diagnosis was expanded to include the dichotomous to fan-like pattern of branching bulbs typical for *A.ludwigae*. The radial pushing exerted internally by the tracemaker produces both the concentric lamination and the external longitudinal furrows and striae-interpreted as microfaults-commonly preserved in the German type material.

Ichnospecies: *Asterosoma* isp.

(Plate I; fig F)

Material: Field photographed of grey coloured sandstone with burrow.

Occurrence: Sandstone bed (Bed no. 55), Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Large, horizontal bulbs with a star like arrangement radiating from a central point. Bulbs egg shaped, 1 cm long and 0.3-0.8 cm wide, overall observed is about 4 cm across in diameter, right side of the burrow is broken. Exhibit bulbous tubes radiating out from a central axis, like the spokes of a wagon wheel, preserved on bottom of thin bedded sandstone beds as convex hyporelief

Remarks: *Asterosoma* is distinguished from the ichnogenus *Phycodes* Richter by its bulbous shaped burrow terminations which radiate from a single axial tube, against the dense bundles of thin cylindrical tubes which are generated distally and independently in *Phycodes* (Hantzchel, 1975; Seilacher, 2000). The tubular nature of borrows and their active, concentric backfill, point to a vermiform producer for *Asterosoma* (Chamberlain, 1971). The possible producers for *Asterosoma* is assumed as Crustacean decapods by the presence of striae on its surface (Altevogt 1968, Hantzchel 1975, Schlirf 2000 and Neto de Carvalho and Pessoa e Costa Rodrigues 2001)

Distribution: *Asterosoma* isp.has been documented by Hofmann *et al* in 2012 from the Middle Cambrian of Jordan.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

4. Ichnogenus: *Avetoichnus* Uchman & Rattazzi (2011)

Avetoichnus is younger than *Planolites* and older than *Chondrites* rises as a fact (Anistoroae, 2014). Martinsson's terminology, 1970 assumed that the specimens of *Avetoichnus* are endichnia type trace fossils.

Ichnospecies: *Avetoichnus luisae* Uchman & Rattazzi (2011)

(Plate I; Fig G & H)

Material: Field photographed of brown and grey coloured sandstone with burrow.

Occurrence: Brown coloured sandstone (Bed no.3) and grey coloured sandstone (Bed no.5) in Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Endichnial, horizontal, simple, straight or slightly curved, appears as one and two rows of oval or circular dots (1.0-2.0 mm in diameter) alternatively arranged along a central horizontal axis. A tightly-spaced spiral was found to be up to 13- 16mm long and 3-6 mm wide. The number of whorls in the helical spiral is 5-6, 1-2mm apart from each other.

Remarks: This is assigned to *Avetoichnus luisae* descriped and figured by Rodriguez & Uchman (2012). The structure is interpreted as a non-graphoglyptid agrichnion generated probably by polychaetes, and less probably by enteropneusts.

Distribution: *Avetoichnus luisae* has been described from Uppermost Palaeocene and lowermost Eocene sediments of the Iberian Peninsula, Northern Spain by Rodriguez & Uchman (2012)

This ichnospecies is being reported for the first time from Barail Group of Northeast Inida.

5. Ichnogenus: *Chondrites* von Sternberg (1833)

The ichnogenus *Chondrites* is a feeding trace of unknown trace makers. According to Seilacher (1990), the trace-maker of *Chondrites* may be able to live under anaerobic conditions. Kotake (1991 a, b) considered that this ichnotaxon is produced by surface ingestors, packing their faecal pellets inside burrows. The ichnoform *Chondrites* is considered as an indicator of poor oxygenation conditions (Bromley 1996; Uchman *et al.* 2008) and polychaete worms are considered as the most likely producers of *Chondrites* (Bromley *et al.* 1984; Gingras *et al*. 2011).

Ichnospecies: *Chondrites intricatus* Brongniart (1823)

(Plate II; Fig A)

Material: Field photographed of sandstone bed with burrow.

Occurrence: It occurred sandstone bed (Bed no.5) in Mualkawi section, Champhai District, Mizroam.

Description: A system of tree-like branching, flattened tunnels with a width of 0.3-0.8 mm. Branches form sharp angles. The entire trace fossil is about 10 cm wide. The branches are filled with lighter material than the host rock.

Remarks: *Chondrites intricatus* differs from *Ch.targionii* by its more winding and wider branches (e.g., Uchman *et al.*, 2012). Various organisms are considered as the producers of *Chondrites* but considered worms to be the most likely producers (Fu, 1991)

Distribution: Patel *et al.* 2009 described Chondrites intricatus from Jhura Dome, Mainland Kachchh of Western India.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

Ichnospecies: *Chondrites recurvus* Brongniart (1823)

(Plate II; Fig B)

Material: Field photographed of sandstone with burrow

Occurrence: It occurred on sandstone bed (Bed no.5) in Mualkawi section, Champhai District, Mizroam

Description: Horizontal, radial, branched tunnels, specimen show two faintly main tunnels curving away and branching mainly to the outside. The second-order branches arise from the convex side of first order branch. Short, the second order branches are slightly winding, up to 10 mm long. All tunnels are about 1.5 mm wide. The traces are preserved in concave epirelief. Traces are preserved at the bedding plane.

Remarks: Present specimen shows peculiar curved branches following the main stem, due to this it has been placed under *Chondrites recurvus* Brongniart (1823).

Distribution: Bhattacharya and Banerjee recovered *Chondrites recurvus* from Eastern Peninsualar India in 2014. Chamberlain 1977 described it from Nevada.

This ichnospecies is being reported for the first time from Barail Group of North East India.

6. Ichnogenus: *CIrculichnus* Vialov (1971)

Circulichnus is a puzzling, ring-like trace fossil preserved on bedding planes. *Circulichnus* is considered as a fodinichnian produced by annelids, or an unspecialized grazing trail (Buatois *et al*. 1998a, 1998b, 2006; Mangano *et al.*, 1997)

Ichnospecies: *Circulichnus* isp. Vialov (1971)

(Plate II; Fig C)

Material: Field photographed of sandstone with burrow.

Occurance: It occurred on sandstone bed (Bed no.5) in Mualkawi section, Champhai District, Mizroam

Description: Horizontal, cylindrical burrow, which shows a course along a regular circular or ellipse, cylinder of the ring is more or less of uniform width. Outer diameter is 5 mm and burrow is about 1 mm thick.

Remarks: Present specimen is considerably close to the type specimen described by Vialov 1971. Closely resemblance with *C.montanus* described by Buatois and Mangano 1993 from Carboniferous lacustrine deposits of Argentina in shape and size. *C.montanus* is fodinichnia probably produced by vermiform animals. They are regarded as marginal marine, eurybenthic ichnotaxon (Fillion and Pickerill, 1984)

Distribution: Khaidem *et al.* (2015) reported this ichnospecies from Laisong flysch sediments of Manipur.

This ichnospecies is being reported for the first time from Barail Group of Mizoram.

7. Ichnogenus: *Cochlichnus* Hitchcock (1858)

Cochlichnus occurs as thin meandering grooves on the upper parting surfaces or hypichnial meandering ridges on the lower parting surfaces, which display first-order sinuous meanders. *Cochlichnus* has been discussed by several authors, particularly the Palaeozoic examples (Fillion and Pickerill, 1990; Walter and Hofmann, 2001). Only surface traces have been included in *Cochlichnus* by Rinsberg (1994). The subsurface forms have been distinguished by the latter author as a new

ichnogenus *Cymatulus*. Different organisms are regarded as producers of non-marine *Cochlichnus*. Hitchcock (1858) suggested annelids as producers; however, recent traces of this morphology are produced mainly by insect larvae (Toula, 1908). The chironomid dipterous insects, including Chironomus motilator (Andersson, 1897) were also suspected to produce this kind of trace. Other authors regarded *Cochlichnus* as nematode trails (Moussa, 1970; Metz, 1998). Walter and Hofmann (2001) underlined occurrence of *Cochlichnus* in extreme environments and what is certainly true for proglacial lakes.

Ichnospecies: *Cochlichnus anguineus* Hitchcock (1858)

(Plate II; Fig D & E)

Material: Field photographed of grey coloured sandstone with burrow and Specimen no: Ng/B/14

Occurrence: Grey coloured sandstone (Bed no.21) in Mualkawi-Ruantlang section and Specimen no: Ng/B/14 (Bed no.8) in Ngur-Vapar section, Champhai District, Mizoram.

Description: Horizontal, smooth, sinusoidal, unlined and unbranched feeding trails, preserved as hyporelief and filled material is identical to the surrounding sediments. Regular meanders look like sine curves and without any ornamentation. The length of the trail is about 4-5 cm and diameter is 1-2 mm. One of the specimens is associated with *Didymaulichnus lyelli.*

Remarks: Present specimen shows regular sinuoisity in structures which is identical to *C.anguineus* Hichcock (1858). It is very confusing to differentiate the hitherto known species of *Cochlichnus* namely *C.anguineus* Hitchcock (1858), *C.Kochi* Ludwig (1869) and *C.Serpens* Webby (1970) and these can at best be regarded as

conspecific. *Cochlichnus* are the crawling traces and probably are the feeding structures of small worms or warm like animals (Eager *et al.*, 1985). According to Hakes (1976), *Coachlichnus* has been reported in sediments of supposedly low salinity palaeoenvironment.

Distribution: Patel *et al.* (2012) documented this ichnospecies from the Jurassic rocks of Ganta Bet, Eastern kachchh of Western India. Joseph *et al.* (2012) described *Cochlichnus anguineus* from the Kaladongar Fomation, Patcham Island of Kachchh. It was also reported from surma succession of Mizoram by Tiwari *et al.* (2011) and Chinmoy *et al* (2014, 2015)

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

8. Ichnogenus: *Cruziana* d'Orbigny (1842)

Ichnospecies: *Cruziana* isp.

(Plate II; Fig. F)

Materail: Specimen No: Ng/B/8 with burrow.

Occurrence: Sandstone bed (Bed no. 8) in Ngur-Vapar section, Champhai District, Mizoram

Description: Horizontal, straight, bilobate, preserved as convex hypirelief and lobes are covered by faintly transverse straitations.Width of the lobes is about 8 mm and are separated by up to 1 mm. It is co-occurs with *Rusophycus carbonarius*.

Remarks: The present specimen shows resemblance with the ichnogenus *Cruziana* in the pattern and nature of claw markings. Although the striations are not clearly visible, the specimen is assigned to *Cruziana* and identification upto ichnospecies level can not be possible due to lack of good material and less in number.

Distribution: Parcha (1998) documented *Cruziana ichnospecies* from the Zanskar Region, Ladakh Himalaya, India.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

9. Ichnogenus: *Cylindrichnus* Howard (1966)

Ichnospecies: *Cylindrichnus* isp.

(Plate II; Fig G)

Material: Field photographed of sandstone bed with burrow

Occurrence: Sandstone bed (Bed no.5) of Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Vertical, semicircular in cross section having central core, diameter of the traces ranges from 25-30 mm, diameter of central sand filled burrow is 3mm.

Remarks: Haentzschel (1975) mentioned that *Cylindrichnus* is a permanent domichnial burrow and filter feeding organisms. Burrows are vertical, semicircular in cross section having central core, exterior wall of the burrows has crudely preserved concentric layers. *Cylindrichnus* is interpreted morphologically as shaft and ethologically as domichnia. More material with well preserved burrows is needed to described upto specific level. Therefore, the present specimen is assign to *Cylindrichnus* isp.

Distribution: Badve (1987) documented *Cylindrichnus* from the Nimar Sandstone Formation exposed at Yalam, Madhya Pradesh. Kundal and Sanganwar (1998) described it from the Nimar Sandstone Formation exposed at Hardaspur, M.P. Mude *et al.* (2012) also reported this ichnospecies from Mesozoic Jaisalmer Basin, Rajasthan.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

10. Ichnogenus: *Didymaulichnus* Young (1972)

According to Young (1972); Fillion and Pickerill (1990), the ichnogenus *Didymaulichnus* is morphologically horizontal, straight or gently curved, moderately deep, smooth trail, which is bisected longitudinally by a narrow furrow, it is preserved as hyporelief. Young (1972) noted that *Didymaulichnus* Young, 1972 is morphologically similar to *Cruziana* d'Orbigny, 1842, but differs in the absence of ridges (moulds of scratch marks), perpendicular or oblique to the axis. *Didymaulichnus* is interpreted as a locomotion trail of gastropods (Hakes, 1976) or trilobites (Crimes, 1970)

Ichnospecies: *Didymaulichnus lyelli* Rouault (1850)

(Plate II; Fig. H)

Material: Specimen no: Ng/B/2 and field photographed of sandstone with burrow

Occurrence: Alteration of sandstone and shale bed (Bed no.8) in Ngur-Vapar section, Champhai District, Mizoram

Description: Horizontal, gently curved, smooth, bilobate trails, horizontal to the bedding plane and preserved as convex hyporelief. The lobes are separated centrally by a very narrow median furrow. The traces are about 7 cm in length and 6mm wide.

Remarks: Present specimen show resemblance with ichnospecies *Didymaulichnus lyelli* Rouault (1850). Therefore it is assigned to ichnospecies *Didymaulichnus lyelli*. Hantzchel (1975); Hakes (1976) mentioned that *Didymaulichnus* is generally described as the crawling trails and the probably tracemaker are of molluscan origin.

Distribution: Sudan *et al*. (2000) described it from the Pin section of Spiti Valley. Himachal Pradesh. Patel *et al.* (2012) also documented it from the Jurassic rocks of Gangta bet of Western India. Joseph *et al*. (2012) reported *Didymaulichnus lyelli* from the kaladongar Formation, Patcham Isaland of kachchh. It has also been described by Chinmoy *et al.* (2013) from Surma succession of Mizoram.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

11. Ichnogenus: *Funalichnus* Pokorny (2008)

The ichnogenus *Funalichnus* is subvertical to vertical, straight, simple burrows, avoid in cross-section, smooth, ornamented by closely spaced, swollen ribs oriented obliquely to the axis. The lower termination is tapered to one side and smooth. Fill is structureless, homogenous and finer than the surrounding rock. Ethologically, they are dwelling burrows, but the ethological interpretation is unclear, the complex form of which may have been related to the requirement to be closely embedded in the substrate. The traces were created by unknown invertebrates, possibly annelids, in the sea floor, representing the Skolithos ichnofacies (Tiwari *et al.* 2013)

Ichnospecies: *Funalichnus bhubani* Tiwari (2013)

(Plate II; Fig I, J & Plate VI; Fig J)

Material: Field photographed of brown coloured sandstone with burrow

Occurrence: Sandstone bed (bed no. 3) Mualkawi-Ruantlang section and bedded sandstone bed (bed nio.18) Ngur-Vapar section, Champhai District, Mizoram

Description: Vertical- to steeply inclined, straight to gently curved, long, unbranched, unlined burrow and circular to sub-circular in cross-section. Observed

length of the burrow is 7.5-18 cm whereas diameter of the burrow varies from 1-3 cm. burrow fill is identical to the host sediments. The burrow consists of a number of small cylindrical segments imparting a twisted rod like structure to the burrow. The interspaces between the cylindrical bodies form curved depressions. The individual segments are smooth, slightly higher as compared to the interspaces and the interspaces are usually parallel to the bedding plane and are inclined to right or left sides.

Remarks: Present specimen closely similar with the ichnospecies *Funalichnus bhubani* described by Tiwari *et al.* (2013) and *Rajkonwar el al*. (2015). According to authors, the type ichnospecies of Pokorny (2008) differs from *Funalichnus bhubani* on the basis of their morphology features and dimensions. The vertical nature and cylindrical segmented form of *Funalichnus bhubani* indicates that the animal excavated the surrounding compact sediments to this body length and pushed the sediments periodically downward to maintain its position Tiwari *et al.* (2013)

Distribution: *Funalichnus bhubani* has been reported by Tiwari *et al* (2013) from Surma succession of Mizoram.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

12. Ichnogenus: *Gastrochaenolites* Leymerie (1842)

According to Bromley (1994) *Gastrochaenolites* are generally shallow water trace fossils and usually appearing in waters only a few metres deep (Bromley, 1994).Typically associated with the actions of endolithic bivalves, but similar borings are also excavated by recent coralliophilid gastropods and some siphunculan worms (Bromley, 2004).

Ichnospeceis: *Gastrochaenolite ornatus*, Kelly and Bromley (1984)

(Plate III; Fig. A & B)

Material: Field photograph of sandstone and siltstone with full rerief burrow.

Occurrence: Sandstone bed (Bed no. 18) in Mualkawi-Ruantlang section and sandstone and shale alternation bed (Bed no.3) in Zote-Ngur section, Champhai District, Mizoram.

Description: Vertical to steeply inclined, burrow filled massive fine sandstone. Diameter of the burrow is about 40-50 mm and maximum observed length is about 130 mm.

Remarks: Present sprcimen resemblance well with *gastrochaenolites ornatus* described by singh *et al*. 2012. So, it has been placed under *Gastrochaenolites ornatus* Kelly and Bromley, 1984.The concentric grooves were formed by the serrated anterior portion of the shell rotating within the boring and grinding away the base of the boring, thus enlarging it.

Distribution: It has been previously reported by Rajkumar *et al*. (2012) from Middle Bhuban, Surma Group of Mizoram.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

13. Ichnogenus: *Glaciichnium* Walter (1985)

Ichnospecies: Glaciichnium liebegastensis, Walter (1985)

(Plate III; Fig. C)

Material: Field photographed of sandstone with full relief burrow.

Occurrence: Sandstone bed (Bed no.3) In Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Horizontal, slightly winding, specimen show a central ridge, which is about 1 mm wide, and straight bars. The trace fossil is 5 mm wide over the entire length. Four bars are visible, the bars are oblique on the sides. The oblique bars are concordantly inclined to the main course of the trace fossil at the angle up to 60^0 and form V-like pattern.

Remarks: *Glaciichnium liebegastensis* is interpreted as a trackway of an isopod crustacean (Gibbard and Stuart, 1974), which is a typical animal of glacial lakes feeding on algae and plant detritus. It is able to survive temporary freezing (Gibbard and Dreimanis, 1978).

Distribution: This ichnospecies has been reported by Uchman *et al*. (2009) from Lacustrine sediments in eastern Lithuania.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

14. Icnogenus: *Gordia* Emmons (1844)

Gordia is a facies-crossing form known from marine and non-marine setting (Pickerill *et al*., 1984). It occurs commonly in lacustrine deposits (Pickerill, 1987; Acenolaza and Buatois, 1991). In the terrestrial environment, Boy (1976) and Rolfe (1980) considered that loop-like trails are produced by the millipede Julus, and are caused by a dragging body in wet mud and Ahlbrandt *et al*. (1978) mentioned that it is produced by crane fly larvae. According to Abel (1935), looped trails are also left by pulmonate gastropods. In fresh waters, Gibbard and Dreimanis (1978) considered that similar traces can be interpreted as locomotion trails (repichnia) or feeding traces (fodinichnia), produced by insect larvae or gastropods (Gibbard and stuart, 1974; Merta, 1980)

Ichnospecies: *Gordia carickensis* Smith (1909)

(Plate III; Fig.D)

Material: Field photographed of Brown sandstone with full relief burrow.

Occurrence: Brown sandstone bed (Bed no.3) in Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Horizontal, very thin, winding, about 0.2mm wide, and consists of densely looped ridges.

Remarks: *Gordia carickensis* is so far described as *Mermia carickensis* (Smith, 1909). *Mermia* is distinguished from *Gordia* by its less worm like appearance and its tendency to intensive looping (Walker, 1985). It is very close resembles *G.marina* but the latter displays less dense looping and a magnitude larger size. *G.carcikensis* is known so far from the Devonian and Carboniferous.

Distribution: Uchman *et al.* described *Gordia carickensis* from late Pleistocene varved lacustrine sediments in eastern Lithuania in 2009.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

14. Ichnogenus: *Gyrochorte* Heer (1865)

Ichnospecies: *Gyrochorte comosa* Heer (1865)

(Plate III; Fig. E)

Material: Field photographed of brown coloured sandstone with full relief burrow.

Occurrence: Brown coloured sandstone bed (Bed no.3) In Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Horizontal, preserved as epirelief plated ridges with biserially arranged, separated by median furrow. Burrow 2 mm wide and up to 1mm in height obove

bedding planes, entire burrow length is unknown. Interpenetration of the burrow can be poorly observed.

Remarks: *Gyrochorte* is commonly interpreted as trace of animal passing through the sediment in inclined position, selecting sediment for food over the entire length of its body. The sediment was transported backward along the body by a polychaeate-like worm and moved into a higher level. According to Weiss (1941) they are commonly interpreted as traces of animal like polychaete worm, passing through the sediment in inclined position, selecting sediment for food over the entire length of its body.

Distribution: The ichnogenus *Gyrochorte* has been reported from India by Ghare and Kulkarni (1986) and Patel *et al*. (2008). Rajkumar *et al.* (2012) documented *Gyrochorte comosa* from Middle Bhuban, Surma Group, Mizoram.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

15. Ichnogenus: *Gyrolithes* Saporta (1884)

Centimetric-scale, vertical to inclined corkscrew-shaped burrows in the fossil record are generally assigned to the ichnogenus *Gyrolithes.* It is believed to be produced by decapods crustaceans as deduced from its common interconnection with *Opiomorpha* and *Thallassinoides* or by the presence of scratch marks in the burrow inner wall (Gernant, 1972; Bromley and Frey, 1974; Mayoral and Muniz, 1993; Grimm and Follmi, 1994). *Gyrolithes* represents a permanent dwelling burrow produced chiefly in marginal-marine settings, as originally suggested by Gernant (1972). Considering that a deep infaunal habitat protects the organism against rapid and extreme salinity variations in brackish-water settings (Sanders *et al.*, 1965;

Knox, 1986; Pemberton and Wightman, 1992), the vertical helical morphology represents a specialized burrowing architecture to seek refuge from extreme salinity fluctuations in brackish-water environments (Beynon and Pemberton, 1992; Buatois *et al*., 2005).

Ichnospecies: *Gyrolithes Lorcaensis* Uchman (2013)

(Plate III; Fig.F)

Material: Field photographed of grey colour shale with a full relief burrow.

Occurrence: Grey coloured shale (bed no.7) Zote-Ngur section, Champhai District, Mizoram.

Description: Vertical, Corkscrew-shaped spiral burrows and composed of few, irregularly curved coils. Tunnel cross-section is circular or oval. Burrow width is 0.4 mm, radius of the whorls is 0.5 mm and length is 5 cm. burrow are unbranched, unlined. Specimen is preserved as endichnia. Six whorls is visible.

Remarks: Burrow width and radius of whorls assigned the present specimen to ichnospecies *G.lorcaensis*. Uchman. A *et al.* (2013) suggested Crustacean is the tracemaker of *G.lorcaensis*.

Distribution: Uchman and Hanken described *Gyrolithes lorcaensis* in 2013 from the Miocene of SE Spain. Joseph *et al*. (2012) also reported this type of ichnospecies from Kaladongar Formation of Kachchh.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

Ichnospecies: *Gyrolithes Mexicanus* Manfield (1930)

(Plate III; Fig. G)

Material: Field photographed of brown coloured shale with a full relief burrow.

Occurrence: Brown coloured shale and sandstone alternation bed (bed no.8) Ngur-Vapar section, Champhai District, Mizoram.

Description: Corkscrew-shaped spiral burrows oriented perpendicular to bedding and composed of few, irregularly curved coils. Tunnel cross-section is sub-circular. Radius of the whorls is 1.2 cm, burrow width is 1 cm and length is 18 cm. burrow are unbranched, unlined. Specimen is preserved as endichnia and are passively filled by well sorted, fine-grained sandstone. 14 whorls is visible.

Remarks: *Gyrolithes* is a vertically oriented burrow that shows a tightly spiraling form in vertical section; the breadth of the sprial is consistent throughout the length of the burrow. In some instances, *Gyrolithes* is spiraling offshoot of *Thallasinoides* and can extend for several meters into a sedimentary sequence. *Gyrolithes* is interpreted as a dwelling structure that may have had some feeding combined; and arthropod tracemaker is probable. Hantzschel (1975) suggested decapode crustaceans are the probable trace maker for *Gyrolithes* burrow.

Distribution: Joseph *et al.* (2012) described this ichnospecies from Kaladongar Formation of Kachchh.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

16. Ichnogenus: *Helmintopsis* Heer (1877).

According to Fillion & Pickerill (1990) *Helminthopsis* is an unbranched, irregularly winding or meandering, horizontal burrow or trail that does not touch or

cross itself. Only one order of meandering may be present. Burrow fill is massive. *Helminthopsis* is common in deep-marine deposits, but is also in shallow-marine and non-marine environments (Buatois *et al*. 1998); thus, this ichnogenus can be considered as a 'facies-crossing" occurring in a variety of ichnofacies (Kim *et al.* 2002). Only some species of *Helminthopsis* have been considered valid; *H.abeli* and *H.hieroglyphica* were accepted in both re-evaluation (Han & Pickerill 1995; Wetzel & Bromley 1996), while *H.granulata* is only considered valid by Han & Pickerill (1995). These ichnospecies are essentially differentiated on the analysis of their course and their diameter. From those, H.abeli shows horseshoe-like turns, and the most characteristic feature of *H.hieroglyphica* is the presence of straight element with often windy curves giving a box-shaped fold appearance (Wetzel & Bromley 1996). *H.granulata* is characterized by an external ornament of warts and ridges (Blissett & Pickerill 2004).

Ichnospecies: *Helminthopsis abeli* Ksiaziewicz (1977)

(Plate III; Fig.H)

Material: Field photographed of sandstone bed with full relief burrow.

Occurrence: Sandstone bed (Bed.3) in Zote-Ngur section, Champhai District, Mizoram.

Description: Horizontal, hypichnial, smooth, unbranched, semicircular ridges, 1mm wide, preserved in semi-relief. It forms deep, winding and irregular meanders. Horse shoe like turn, Burrow diameter is constant throughout, typically alternating between winding straight course. Maximum observed length of the burrow is 40 mm and diameter is 3 mm. Burrow fill is massive.

Remark: Present specimen is closely resemblance with *Helminthopsis abeli* (Rodriguez-Tovar, F.J. *et al.* 2009). *Helminthopsis* is interpreted ethologically as pascichnial grazing trails, produced by deposit feeders (Buatois *et al.* 1998). Various tracemakers can be considered; Polychaete annelids in brackish to fully marine environments, different types of arthropods, nematodes and insect larvae in freshwater settings and larvae of Diptera in modern ponds.

Distribution: Tiwari *et al*. (2011) documented this ichnospecies from Middle Bhuban unit, Bhuban Formation, Surma Group, Mizoram.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

Ichnospecies: *Helminthopsis hieroglyphica* Wetzel and Bromley (1996)

(Plate III; Fig.I)

Material: Field photographed of sandstone bed with semi- relief burrow.

Occurrence: Sandstone be (Bed no.2) in Zote-Ngur section, Champhai District, Mizoram.

Description: Horizontal, hypichnial, smooth, semicircular ridges, 1mm wide, preserved in semi-relief. It forms deep, winding and box shape. The length of the burrow is about 2.5 cm long

Remarks: According to Pickerill (1981), Crimes and Anderson (1985) and Han and Pickerill (1995) the ichnogenus *Helminthopsis* is similar to other simple grazing traces, such as *Gordia* and *Helminthoidichnites*. It is distinguished from *Helminthoidichnuites* by its tendency to meander and from *Gordia* by its lack of self-overcrossing.

Distribution: Blissett and Pickerill described *Helminthopsis hieroglyphica* from the Cenozoic white limestone group, Jamaica of west Indies in 2004.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

Ichnospecies: *Helminthopsis tenuis* Ksiazkiewicz (1968)

(Plate III; Fig.J)

Material: Field photographed of sandstone bed with full relief burrow.

Occurrence: Siltstone bed (Bed no.10) in Zote-Ngur section, Champhai District, Mizoram.

Description: Horizontal, irregular meandering convex, hypichnial, unlined, smooth ridges, which are about 10 mm wide and upto 160 mm long. They are filled with mudstone with some proportions of fine silts, similar to the host rock.

Remarks: *Helminthopsis tenuis* Ksiazkiewicz 1968 presents irregular, high amplitude windings but only with U-turns, without horseshoe-like turns (Wetzel & Bromley 1996).

Distribution: Rajkonwar *et al.* (2008) reported this ichnospecies from Upper Eocene-Lower Oligocene Transition of Manipur and it also previously reported by Khaidem *et al.* (2015) from Laisong Flysch sediments, Manipui. Rajkumar *et al.* (2012) described it from Middle Bhuban, Surma Group, Mizoram.

This ichnospecies is being reported for the first time from Barail Group of Mizoram.

17. Ichnogenus: *Katbergia* Gastaldo and Rolerson (2008)

Grow (1981) mentioned that *Katbergia* consist of several morphologies like depressions, U-shaped, and networks, but the most common is an angular pit

consisting of a simple tunnel that ends in a terminal chamber (Lawrence, 2001). Crustacea; Smith and Botha (2005) assumed that potential tracemakers of *Katbergia* include spiders (Chelicerata), beetles (Uniramia), and crabs and shrimps.

Ichnospecies: *Katbergia carltonichnus* Gastaldo and Rolerson (2008)

(Plate IV; Fig A)

Material: Field photographed of silty-shale with full relief burrow.

Occurrence: Silty-shale bed (Bed no.83) in Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Long, cylindrical, unlined, non-branching burrow with terminal chamber. Inclined at angles of approximately 50 degrees. Burrows penetrates 14 cm in downward direction, maximum burrow diameter of 1.8 cm is observed at terminal chamber and gradually decreasing upward thereafter. Burrow fill is similar to host sediments.

Remarks: Present specimen shows terminal chamber, therefore, assingned to *Katbergia carltonichnus.*

Distribution: Castaldo and Rolerson reported *Katbergia carltonichnus* from the late Permian and Early Triassic of the Karoo Basin of South Africa in 2008.

This ichnospecies is being reported for the first time from Barail Group of Northeast India.

18. Ichnogenus: *Laevicyclus* Quenstedt (1879)

According to Verma (1971) the ichnogenus *Laevicyclus* is vertical to slightly inclined burrows consisting of scraping circles surrounding a central vertical shaft, perpendicular to the bedding planes, two distinct circles visible in transverse section. They are morphologically shaft and ethologically domichnia. They are regarded as

the feeding burrow of trace fossil comparable with recent annelid *Scolecolepis* (Seilacher, 1953).

Ichnospecies: *Laevicyclus mongraensis* Verma (1971)

(Plate IV: Fig B-D)

Material: M/2, Z/B/5 and Ng/B/1 with field photographed.

Occurrence: Sandstone bed (Bed no.23) in Mualkawi-Ruantlang, Zote-Ngur and Ngur-Vapar sections respectively, Champhai District, Mizoram.

Description: Vertical, endichnial, full relief, cylindrical body consists of central shaft surrounded by scraping circle and perpendicular to the bedding plane. The diameter of the central shaft is about 4-5mm and 6-10mm of scraping circle and depth of the burrow is between 70-150 mm. The outer ring sediments are coarser than the inner shaft which reflect the distinct relief and fill as well. The diameter of the burrow is constant throughout and infill material is different from the surrounding.

Remarks: Diameter of central shaft and scraping circles show close resemblance with *Laevicyclus mongraensis* Verma (1971). It is considered to be a circular trace of the suspension feeding animals (Uchman 1998). They are morphologically shaft and ethologically domichnia.

Distribution: Chiplonkar and Badve 1970) originally described it from Bagh bed, Gujarat. Verma (1971) described it from Nimar Sandstone at Mongra, Amba Dongar area, Gujarat. Subsequently, Badve and Ghare (1980) and Sanganwar (1998) from other exposures of Bagh. Sanganwar and Kundal (1998) describe this ichnospecies from Nimar sandstone Formation, Bagh Group of Madhya Pradesh. Kundal and Dharshivkar (2006) aso reported *L.mongraensis* from Neogene and Quarternary

deposits of Dwarka-Okha area of Jamnagar district, Gujarat. Patel *et al*. (2008) also described it from the Jurassic of the Habo dome, Gujarat. *Laevicyclus mongraensis* also reported from the Jurassic rocks of Ganga Bet of eastern Kachchh by Patel *et al.* (2012). Joseph *et al*. (2012) described this ichnospecies from Kaladongar Formation of Kachchh. Kundal *et al*. (1998, 2006), Mude (2012) documented from the Babaguru Formation, Gujarat It has been reported by Tiwari *et al.* (2011), Rajkonwar *et al.* (2013, 2014) from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast.

19. Ichnogenera: *Lanicoidichna* Chamberlain (1971)

Lanicodichnus is distinguished from the polychaete tubes and *skolithos*, which are generally unbranch burrows. It is interpreted as dwelling burrow of suspension feeding polychaetes which generally lives in the subtidal environments.

Ichnospecies: *Lanicoidichna medulata* Chamberlain (1971)

(Plate IV; Fig. E)

Material: specimen no: Z/1

Occurrence: Fine to medium grained sandstone and alternation bed (Bed no.7) Zote section, Champhai District

Description: U-shaped vertical burrow with a secondary gallery branching at the base of the main U form burrow and running parallel to it yielding a W-shaped structure; linked at the base by a horizontal burrow. Each tube of the burrow shows uniform diameter of 1.5 cm and penetrate upto 12 cm. The whole system of burrow is 6 cm. The burrow field material is darker than the host sediments and consists of fine grained particles.

Remarks: *Lanicoidichna* is considered as the permanent shelters of vagile or hemisessile animals procuring food outside sediment. It also resembles occasionally to the W-shaped tubes of the recent *polychaete Lanice* (Seilacher, 1953).

Distribution: *Lanicoidichna* isp. has been reported by Malarkodi *et al.* (2009) from the Palaeocene sediments of Pondicherry area. Rajkonwar *et al*. (2013) reported this ichnospecies from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

20. Ichnogenus: *Lockeia* James (1879)

Ichnospecies: *Lockeia siliquaria* James (1879)

(Plate IV; Fig.F-H)

Material: Field photographed coloured sandstone with full relief burrow.

Occurrence: Sandstone bed (Bed no.5) in Mualkawi-Ruantlang section, sandstone and shale alternation bed (Bed no.7) in Zote-Ngur section and grey coloured sandstone and shale alternation bed (Bed no.8) in Ngur-Vapar section, Champhai District, Mizoram.

Description: Horizontal, bilaterally symmetrical, elongated, almond shaped, 0.3-1 cm wide and 0.6-2 cm in length and preserved as isolated or row like arrangement of convex hypichnial mounds.

Remarks: Isolated *Lockeia* is commonly interpreted as a bivalve resting trace most probably produced by a wedge-like foot (Seilacher, 1994). However, small crustaceans may have also produced such traces (Bromley & Asgaard, 1979; Pollard, 1981).

Distribution: Various workers from India like Kundal *et al*. (1998, 2006), Mude (2012) documented from the Babaguru Formation, Gujarat. Rankonwar *et al.* (2013) reported it from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

21. Ichnogenus: *Macanopsis* MacSotay (1967)

Ethologically, *Macanopsis* can be interpreted as a domichnion. Its only known ichnospecies are *M.pagueyi* and *M.astreptum.*

Ichnospecies: *Macanopsis pagueyi* Macsotay (1967)

(Plate IV: Fig.I)

Material: Field photographed of sandstone bed with full relief burrow.

Occurrence: Sandstone bed (Bed no.3) in Mualkawi–Ruantlang section, Champhai District, Mizoram.

Description: Vertical to slightly incline to bedding plane, J-shaped burrows terminating in basal chamber, straight, unbranched, cylindrical, and circular in outline and fill identical with the matrix. Burrow bent before enlarging to hemispherical form at the end. The maximum observed length is 12 cm and diameter is about 1.3 cm.

Remarks: The present specimen is virtually similar, both morphologically and preservationally to *Macanopsis pagueyi.*

Distribution: Patel (2014) recorded this ichnospecies from Miocene sequence of the Western Kachchh, india.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Macanopsis* isp.

(Plate IV: Fig.J)

Material: Field photographed of sandstone bed with full relief burrow.

Occurrence: Sandstone bed (Bed no. 23) in Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Vertical, straight, cylindrical, unbranched tube. Circular in outline, slightly bent before it passes downward into hemispherical knot. The maximum observed length is about 8 cm with 1.2 cm diameter and hemispherical diameter is about 2.4 cm. Sediment filling the burrows is the same grain size as the surrounding rock.

Remarks: On the basis of its morphology the present specimen is assigned to the ichnogenus *Macanopsis.*

Distribution: Patel (2014) recorded this ichnospecies from Miocene sequence of the Western Kachchh, India.

This ichnospecies is being reported for the first time from Barail Succession of Northeast India.

22. Ichnogenus: *Monomorphichnus* Crimes (1970a)

Ichnospecies: *Monomorphichnus* isp.

(Plante V; Fig A)

Material: Field photographed of sandstone bed with full relief burrow.

Occurrence: Sandstone bed (Bed no.4) in Zote-Ngur section, Champhai District, Mizoram.

Description: Horizontal, a set of isolated, slightly curved, sigmoidal ridges, repeated laterally. The ridges vary in length from 0.8-34mm. the width of each ridge varies

from 0.5mm- 0.8mm. Ridges are parted from one another by 0.4-.7mm. in some specimens the tracks form a series of sigmoidal grooves.

Remark: The present specimens differ from the species of *Monomorphichnus* described by Bhargava *et al*. 1982 from the Spiti Valley of Himachal Pradesh and from *Monomorphichnus bilineatus* Crimes, (1970a) in the pattern, shape and size of the ridges. The specimens equally differ with the species of *Monomorphichnus monolinearis* described by Shah and Sudan (1983) from Kashmir and from Zanskar by Shah *et al* (1998) in the pattern, shape and size of the ridges. It is similar with the species of *monomorphichnus* isp. type A described by Parcha and Singh from Ladakh Himalaya, India in 2010.

Distribution: Parcha and Singh described it in 2010 from Ladakh Himalaya, India. Rajkonwar *et al.* (2013) reported *Monomorphichnus bilinearis* from Surma Group, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Norhteast India.

23. Ichnogenera: *Ophiomorpha* Lundgren (1891)

Vertical to horizontal shaft and tunnel, simple to complex burrow systems, distinctly lined with agglutinated pelletoidal sediments. Burrow lining more or less smooth interiorly; densely to sparsely mammalated or nodosa exteriorly. Individual pellets or pelletal masses may be discoidal, ovoid, mastoid, bilobate, or irregular in shape, (Frey *et al.* 1978). They are interpreted morphologically as shaft and ethologically as domichnia. *Ophiomorpha* is interpreted as the work of calliannasid shrimp or similar burrowing decapods in marine-influence environments (Welmer and Hoyt, 1964; Frey *et al*., 1978, 1984; Goldring *et al*., 2007). *Opiomorpha* does not

normally occur in mud-dominated environments, nor is it in freshwater-dominated systems, with very few exceptions (Loope and Dingus, 1999), it represent marine or marine-influenced environments.

Ichnospecies: *Ophiomorpha annulata* Ksiazkiewiez (1977)

(Plate V; Fig. B & C)

Material: Field photographed of sandstone bed with full relief burrow.

Occurrence: Sandstone bed (Bed no.3) in Mualkawi-Ruantlang section and shale bed (Bed no.6) in Ngur-Vapar section, Champhai District, Mizoram.

Description: Horizontal, tubular structure with or without a wall, ornamented with pellets. 1.5-2 cm in diameter, traced for a distance up to 10 cm, preserved in full relief in sandstone beds.

Remarks: This ichnospecies was described also under *Granularia* Pomel or *Sabularia simplex* Książkiewicz, 1977 but it was included in *Ophiomorpha* Lundgren, 1891 on the basis of morphological features, foremost the granulated wall, even if it is occasionally preserved (Uchman, 1995; Tunis & Uchman, 1996a, b).

Distribution: Rajkonwar *et al*. (2014) described it from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northesat India.

Ichnospecies: *Ophiomorpha irregulaire* Frey, Howard and Pryor (1978)

(Plate V; Fig. D)

Material: Field photographed of sandstone with semi-relief burrow.

Occurrence: Sandstone bed (Bed no.23) in Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Vertical burrow, lined and packed with the different sized pellets which are irregularly distributed over burrow tubes. Observed depth of the burrow is 14 cm long and diameter 3 cm. The burrow fill and the host rock are composed of different material.

Remarks: The present burrow is assigned to be *Ophiomorpha irregulaire* due to its wall structure, which is consisting of irregular pellets of variable size. Ekdale, 1992; Uchman and Gazdzicki, 2006 considered that the trace maker of *Ophiomorpha* is complex and may be a variable combination of deposit and /or suspension feeding behaviours. Frey *et al.*, 1978 also considered to be a dwelling structure of the suspension feeding crustaceans and ranges from Permian to Recent. It occurs predominantly in shallow water near shore deposits (Frey *et al*., 1978; Patel and Desai, 2001, 2009)

Distribution: *Opiomorpha irregulaire* is reported from Neogene and Quaternary deposits of Dwarka-Okha area of Gujarat by Kundal and Dharashivkar (2006). Kundal and Mude (2008) reported it from the Neogene-Quaternary sediments of Portbandar area, Gujarat, Mude (2011) from the Chaya Formation, Porbandar Group of southwest coast of India. it has also been documented from the Jurassic rocks Ganga Bet, Kachchh by Patel *et al.* (2012) and Rajkonwar *et al.* (2013) described it from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Ophiomorpha nodosa* Lundgren (1891)

(Plate V; Fig. E & F)

Material: Specimen no: M/2 and field photographed of shale bed with full relief burrow.

Occurrence: Brown sandstone bed (Bed no.23) in Mualkawi-Ruantlang section and in shale bed (Bed no.1) in Zote-Ngur section, Champhai District, Mizoram.

Description: Vertical, endichnial, straight cylindrical burrow with wall, 15-30 mm in diameter, the walls of the burrows consist of regularly distributed discoidal pellets, diameter of the pellets ranges from 2-5mm. The burrow fill is same as the host rock but pellet lined structures consist of darker material than the host sediment. This ichnospecies is very common in fine grained sandstone facies.

Remarks: The morphological characters of the present burrows are identical to *O.nodosa* Lundgren (1981). Frey *et al.* (1978); Howard and Frey (1984); Uchman (2001) mentioned that different ichnospecies of *Ophiomorpha* are differentiated on the basis of variations in burrow configuration, shape and distribution of the pellets.

Distribution: From India *O.nodosa* has been reported by Chiplonkar and Ghare (1975) from Bagh Group, Dhar district, Madhya Pradesh and Kundal and Sanganwar (2000) from Nimar Sandstone Formation at Baria, Dhar district, Madhya Pradesh. Kundal and Dharashivkar (2006) also reported it from Neogene and Quarternary deposits of Dwarka-Okha area of Gujarat, Kundal and Mude (2008) described *O.nodosa* from the Neogene-Quaternary sediments of Porbandar area, Gujarat and Mude (2011) Chaya Formation, Porbandar Group of southwest coast of India. Patel *et al.* (2008) described *O.nodosa* from Jurassic of Kachchh, Gujarat and Mude (2011) from Chaya Formation, Porbandar Group of southwest coast of India.

Subsiquently, Joseph *et al*. (2012) reported this ichnospecies from the Kaladongar Formation of Patcham Island, Kachchh. From North-East India Rajkonwar *et al*. (2008), Singh *et al.* (2010) and Kheidem *et al*. (2015) reported this ichnospecies from the Bhuban Formation of various parts of Manipur. Kichu *et al*. (2018) reported it from Barail sediment, Nagaland and also by Rajkumar *et al*. (2019) from Upper Disang Formation and Lower Barail Formation of Nagaland. And from Mizoram, Rajkonwar *et al.* (2013, 2014) documented it from Bhuban Formation.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

24. Ichnogenus: *Palaeophycus* Hall (1847)

Pemberton and Frey (1982); Fillion and Pickerill (1984), (1990); Keightley and Pickerill (1995) explained *Palaeophycus* as predominantly horizontal, straight, slightly curved or undulating, ornamented or smooth, essentially cylindrical, branched or unbranched, lined burrow. Bifurcations are irregular and without swelling. Filling typically massive, similar to the host rock. *Palaeophycus* Hall, 1847 is morphologically very similar to *Planolites* Nicholson, 1873. Remarks on the differences between these ichnogenera are provided by Pemberton and Frey (1982), Fillion and Pickerill (1990) and Keighley and Pickerill (1995). According to Pemberton & Frey (1982) and Fillion & Pickerill (1984) *Palaeophycus* represents a eurybathic domichnion of a predaceous, deposit-feeding or suspension-feeding organism (probably polychaete annelids). The ichnotaxon is quite common in, but not restricted to shallow marine sand-dominated environments and stratigraphically known from Ediacaran to Recent (Häntzschel 1975; Gérard & Bromley 2008).

Ichnospecies: *Palaeophycus annulatus* Badve (1987)

(Plate V; Fig. G & H)

Material: Field photographed of brown sandstone with semi- relief burrow and specimen no: Ng/ A/12

Occurrence: Brown coloured sandstone (Bed no. 23) in Mualkawi-Ruantlang section and alternation of sandstone and shale bed (Bed no. 8) in Ngur-Vapar section, Champhai District, Mizoram.

Description: Horizontal, thinly lined burrow encircled by thin ring like structures or distinctly placed annulations arranged serially on the burrow. The observed length of the burrow is 100 mm long and diameter of the burrow ranges from 10-130 mm. the burrow fill is similar to the surrounding materials.

Remarks: On the basis of the presence of regular annulations the present specimen is identical to the *Palaeophycus annulatus*. Pemberton & Frey (1982); Fillion and Pickerill (1990) mentioned that *P.annulatus* is different from *P.alternatus* in lacking the longitudinal striations. According to Pemberton and Frey (1982), *Palaeophycus* is a eury-benthic facies-crossing form produced probably by polychaetes or annelids.

Distribution: Joseph *et al*. (2012) described this ichnospecies from the Kaladongar Formation of Patcham Island, Kachchh. Rajkonwar *et al*. (2013) also described it from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Palaeophycus heberti* Saporta (1872)

(Plate V; Fig. I)

Material: Field photographeded of brown coloured sandstone with burrow

Occurrence: Brown coloured sandstone bed (Bed no.2); Zote- Ngur section, Champhai District, Mizoram.

Description: Smooth, thickly lined, unornamented, gently curved, endichnial burrows. Length of the burrow is 160 mm in broken specimen whereas diameter is constant in a given specimen and is of 12 mm. Burrow fill is structureless and identical to the host rock. Thick wall of the burrow can be seen on the present specimen.

Remarks: Present specimen show resemblance with the *Palaeophycus heberti* in the pattern of its thickly lined, horizontal and unbranched. It is distinguished from other species of *Palaeophycus* by its thick wall lining (Pemberton and Frey 1982). Saporta (1872); Saporta and Marion (1883) mentioned that *Paleophycus heberti* were assigned initially to the ichnogenus *Siphonites*, although their affinity with Palaeophycus was noted subsequently.

Distribution: *Palaeophycus heberti* has been reported from Neogene and Quaternary deposits of Dwarka-Okha area of Gujarat by Kundal and Dharashivkar (2006). Mude *et al.* (2012) documented it from Mesozoic Jaisalmer basin of Rajasthan and from the Chaya Formation of Porbandar area of Gujarat. Kundal and Mude (2008) recovered it from the Neogene-Quarternary sediments of Porbandar area and from the Jurassic rocks of Gangta Bet of Kachchh by Patel *et al.* (2012). Tiwari *et al*. (2011) and Rajkonwar *et al.* (2013) documented this ichnospecies fromb Surma Group, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Palaeophycus striatus* Hall (1852)

(Plate V; Fig. J and Plate VI; Fig A)

Material: Field photograph of silty-shale with full relief burrow and specimen no. Ng/A/10.

Occurrence: Silty-shale bed (Bed no.83) in Mualkawi- Ruantlang section and shale bed (Bed no.6), Champhai District, Mizoram.

Description: Endichnial, horizontal, straight to gently sinuous, lined burrow. Often the burrow enlarges at some distance and shows variation in diameter. The observed length of the burrow is 220 mm and diameter is 18–20 mm. Nature of the burrow fill is similar to that of the host rock.

Remarks: The studied specimen can be assigned to *Palaeophycus striatus* on the basis of having striations.

Distribution: Kundal and Sanganwar (2000) documented *P.striatus* from the Nimar Sandstone Formation, Bagh Group of Madhya Pradesh. Josehp *et al*. (2012) recovered this ichnospecies from the Kaladongar Formation of Patcham Island, Kachchh. Rajkumar *et al.* (2012); Rajkonwar *et al.* (2013, 2014, 2015) described it from Middle Bhuban, Surma Group, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Palaeophycus sulcatus* Miller and Dye (1878)

(Plate VI; Fig. B)

Material: Field photographed of siltstone with semi-relief burrow.

Occurrence: Siltstone bed (Bed no.5) in Zote-Ngur section, Champhai District, Mizoram.

Description: Endichnial, horizontal, straight, lined burrow. Burrow shows dissimilarity in diameter. The observed length of the burrow is 50 mm and diameter is 10-13 mm. Burrow fill is identical to the host sediment.

Remarks: Crimes and McCall (1995) mentioned that *Palaeophycus sulcatus* differs from *P.striatus* by anastomising rather than longitudinal striations and from *P.alternatus* in having consistent rather than alternating striations.

Distribution: Tiwari *et al.* (2011) described it from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Palaeophycus tubularis* Hall (1852)

(Plate VI; Fig. C)

Material: Field photographed of sandstone with full relief burrow.

Occurrence: Sandstone bed (Bed no. 23) in Mualkawi-Ruantlang section, Champhai District, Mizoram.

Description: Endichnial, full relief, long, horizontal to the bedding plane, smooth body wall, straight and cylindrical in outline, unbranched, unornamented and lined burrow. Length of the burrow is 7 cm and diameter is 0.8 cm; burrow is compressed, appears as elliptical in cross section and filled with the same sediment as the host rock.

Remarks: Present specimen is classified as *P. tubularis* on account of the horizontal smooth, straight, long and unbranched burrows with distinct lining. The distinction between *Palaeophycus, Planolites* and *Macaronichnus* is partially controversial (Pemberton and Frey 1982; Fillion 1989; Fillion and Pickerill 1990). *Palaeophycus* is a eurybenthic facies-crossing form produced probably by polychaetes or annelids

(Pemberton and Frey 1982). The structure is interpreted as the result of dwelling activity of the animal

Distribution: Badve (1987) and Kundal and Sangawar (1998) reported this species from the Bagh Group of Madhya Pradesh. Kundal and Mude (2008) described this ichnospecies from the Neogene-Quaternary sediments of Porbandar area of Gujarat. Joseph *et al.* (2012) reported this ichnospecies from the Kaladongar Formation of Patcham Island, Kachchh. *P.tubularis* is also known to occur in the Miocene sediments of Dwarka-Okha area (Kundal and Dharashivkar, 2006), Middle Jurassic of Kachchh (Patel *et al.* 2008), Mesozoic Jaisalmer basin of Rajasthan (Mude *et al.* 2012) and Nagaur group, western India (Ahmad and kumar, 2014). From North Eastern India, it has also been documented by Singh *et al*. 2010 from Surma Group of Manipur and by Rajkumar *et al.* (2019) from Disang formation of Nagaland.

This ichnospecies is being reported for the first time from Barail succession of Mizoram.

25. Ichnogenus: *Pholeus* Fiege (1944)

Ichnospecies: *Pholeus bifurcatus* Knaust (2002)

(Plate VI; Fig. D)

Material: Field photographed of buff sandstone with relief burrow**.**

Occurrence: Sandstone bed (Bed no.87) in Mualkawi-Ruantlang section, Barail Group, Champhai District, Mizoram.

Description: Endichnial, full relief, thinly lined three dimensional branched burrow systems. It consists of a vertical shaft which bifurcates at lower end into three inclined shafts. The diameter of burrow is constant and being of 20 mm. The burrow swells at junctions.

Remarks: *Pholeus bifurcatus* is a large size burrow that bifurcates at the lower end. On these counts, this ichnospecies can be differentiated from the *Pholeus abomasoformis* (Knaust 2002). The burrow producers were most probably decapod crustaceans.

Distribution: Tiwari *et al.* (2011) recorded *Pholeus bifurcatus* from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

26. Ichnogenus: *Phycodes* Richter (1850)

Accoding to Osgood (1970); Fillion & Pickerill (1990); Han & Pickerill (1994), *Phycodes* is a horizontally bundle burrow preserved outwardly as convex hyporeliefs. The overall pattern is reniform, fasciculate, flabellate, broom-like, ungulate, linear, falcate or circular. Most forms consist of a single or a few main branches showing a spreite-like structure that give rise distally to numerous free branches. In other forms the spreiten are lacking and branching tends to be second or more random. Individual branches are terete and finely annulate or smooth. Seilacher (2000); Mangano *et al.* (2005) noted that, *Phycodes* is commonly present at the base of centimeter-thick siltstone or silty sandstone beds within shales.

Ichnospecies: *Phycodes curvipalmatum* Hall (1852)

(Plate VI; Fig. E)

Material: Specimen no: Ng/B/5

Occurrence: Grey Shale bed (Bed no.7) in Ngur-Vapar section, Champhai District, Mizoram.

Description: Horizontal, hypichnial structures, consisting of three branches originate from nearly the same point or a thick, slightly curved single stem. Oval-cross sections of the branches, with burrow diameters of 6-11mm in the horizontal and the main tube is 6-12 mm in diameter. Burrows filled with very fine-grained and while the host rock is a mudstone with fine silts.

Remarks: According to Han & Pickerill (1994) *phycodes* reflects a variety of behavioral activities by the tracemaker, but two basic interpretations are: (i) a fodichnion produced by an organism that systematically mining a nutrient-rich layer along a silt-mud surface (Seilacher 1955), ir (ii) a structure performed by an organism that burrowed outwards from a single point and then withdrew to a 'home-case'only to re-burrow outwards again in part the previously excavated tunnel (Marintsch & Finks 1982; Singh *et al*. 2008) .

The trace is mainly related with shallow water environments, being characteristic trace fossil of the Cruziana ichnofacies. It is also less frequently found in deep-marine and non-marine conditions (Han & Pickerill 1994). *Pycodes palmatus* (Hall 1852) can be distinguished from similar but smaller *P.curvipalmatum* (Pollard 1981).

Distribution: A morphologically similar but bigger *Phycodes palmatus* has been described from Eocene-Oligocene transition of Manipur and Laisong flysch sediments of Manipur respectively by Singh *et al*. (2008) and Khaidem *et al*. (2015). Rajkonwar *et al.* (2013) reported *Phycodes curvipalmatum* from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

27. Ichnogenus: *Planolites* Nicholson (1873)

According to Pemberton and Frey (1982); Stanley and Pickerill (1998), the ichnogenus *Planolites* is horizontal burrow, unlined, rarely branched, straight or tortuous, smooth surface, irregular or annulated, circular or elliptical in cross-section, of variable dimensions and configuration; homogeneous, structureless in fillings of burrows, differing in lithology from host rock. The major difference between *Palaeophycus* Hall, 1847 and *Planolites* Nicholson is the distinct lining of the former. Planolites is produced by worm like a deposit feeders in all facies (Pemberton and Frey, 1982; Fillion and Pickerill, 1984). Morphologically, *Planolite* is tunnel and ethologically fodichnia. It is an eurybathic extremely facie-crossing form (Pemberton & Frey, 1982; Keighley & Pickerill, 1995). *Planolites* is known from the Precambrian to the Recent (Hantzschel, 1975).

Ichnospecies: *Planolites beverleyensis* Billings (1862)

(Plate VI; Fig. F & G)

Material: Specimen no: M/10 and Ng/A/9

Occurrence: Silty-shale bed (Bed no. 35) in Mualkawi-Ruantlang section and shale bed (Bed no.5) in Ngur-Vapar section, Barail Group, Champhai, Mizoram.

Description: Simple, horizontal, long, circular to elliptical in cross section, smooth-walled, unlined, straight to curved, unbranched burrow and oriented more or less parallel to bedding plane and preserved as epichnial ridges. Burrow occurs as a single isolated specimen. The maximum observed length is 300 mm and diameter is about 30 mm. The other figured specimen (Plate 6g) is undulated and showing somewhat larger dimension. The burrow fill is different to the the host sediments.

Remarks: The observed burrows are long and usually lack in burrow lining. *Planolites beverleyensis* differs from *Planolites montanus* in its curved to arcuate courses and more penetrative nature (Pemberton and Frey, 1982). *Planolites* is interpreted as feeding traces produced by deposit feeders such as worms from Littoral environment (Pemberton and Frey, 1982).

Distribution: Kundal *et al*. (2005) documented it from the Babaguru Formation at Bhilod village, Broach district, Gujarat. Patel *et al*. (2008) from the Jurassic rocks of Habo Dome, Kachchh; Mude *et al.* (2012) from Mesozoic Jaisalmer basin of Rajasthan; Malarkodi *et al.* (2009) from the Kaladongar Formation of Kachchh. Borkar and Kulkarni (1992) and Kundal and Sanganwar (1998, 2000) recorded *Planolites beverlyensis* (Billings) from the Wadhawan Formation of Gujarat and Bagh Group of Madhya Pradesh, respectively. In Northeast India *P.beverlyensis* has been described by Singh *et al*. (2010) from Western Hill of Manipur. Tiwari *et al*. (2011), Rajkumar *et al.* (2012) and Rajkonwar *et al.* (2013, 2015) from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

Ichnospecies: *Planolites montanus* Richter 1850

(Plate VI; Fig. H & I)

Material: Field photographed of brown coloured sandstone and specimen no: Ng/ B/ 11

Occurrence: Sandstone bed (Bed no.5) in Mualkawi-Ruantlang section and sandstone and shale alternation bed (Bed no.7) in Ngur- Vapar section, Champhai district, Mizoram.

Description: Hypichnial, smooth, visible as short ridges on bedding surfaces, straight to slightly curved, plunging in the bed under different angle. The diameter of the burrows ranges from 5-11 mm and observed length is 5mm- 30 mm.

Remarks: The studied form are small size and tortuous in nature. So, they are placed under *Planolites montanus*. Pemberton & Frey (1982) suggested that *Planolites montanus* is distinguished from other ichnospecies of *Planolites* by its tortuous course with horizontal and inclined segments, penetrative nature, and lack of ornamentation. *Planolites montanus* differs from *P.beverleyensis* by its smaller size and contorted morphology (Pemberton and Frey, 1982).

Distribution: Hofmann described it in 2012 from the middle Cambrian of Jordan. Singh *et al.* (2008) reported *Planolite montanus* from Upper Eocene-Lower Oligcene of Manipur.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

28. Ichnogenus: *Protovirgularia* M'coy (1850)

The ichnogenus *Protovirgularia* consist of delicate, inclined to horizontal, chevronate structures, mostly symmetrical in relation to a median axis. Identification of *Protovirgularia* at sandstone sole beds (hypichnion) is quite straightforward. Endichnial, exichnial and epichnial preservation in heterolithic facies, however, provides a wide variety of forms that depart from the archetypal Protovirgularia and challenges ichnotaxonomic classification. Most specimens show sharp, closely spaced chevrons and occur along sandstone/mudstone interfaces of the proximal prodelta and distal delta-front deposits. *Protovirgularia* reflect how tracemakers experienced significant friction while advancing through the sediment, which

resulted in relatively smaller increments of movement. In contrast, variants of *Protovirgularia* formed in muddier beds, such as in prodeltaic facies, show irregular, poorly defined and unevenly spaced chevrons, and locally asymmetric with reapect to the axia, refecting softer, water-rich, and plastic substrates. These occurrences of *Protovirgularia* in tide influenced, marginal-marine deposits suggests that protobranchs were tolerant of fluctuations in salinity, sedimentation rates, turbidity, and oxygen depletion, displaying opportunistic strategies in stressed nearshore environments (Carmona *et al*. 2010).

Ichnospecies: *Protovirgularia dichotoma* M'coy (1850)

(Plate VII; Fig. A)

Material: Field photographed of grey coloured sandstone with burrow.

Occurrence: Grey coloured sandstone bed (Bed no. 5) in Mualkawi section, Barail Group, Champhai District, Mizoram.

Description: Horizontal, gently curved, burrow consists of bi-serially arranged, paired, ribs arranged in chevron with median keel-like furrow. Observed length of the burrows is 75 mm long and 10 mm wide. Preserved as full relief and positive epirelief.

Remarks: Patel *et al.*, 2012 mentioned that the wedge-shaped appendages on either side of the median groove differentiate this genus from *Gyrochorte*. It is generally considered to be produced by bivalves (Seilacher and Seilacher, 1994; Ekdale and Bromley, 2001)

Distribution: Joseph *et al.* (2012) documented *Protovirgularia dichotoma* from the mixed siliciclastic-carbonate sediments, Kaladongar Formation of Kachchh and Patel *et al.* (2012) from the Jurassic rocks of Gangta Bet of Kachchh area. The ichnogenus

Protovirgularia rugosa has been described by Khaidem *et al*. (2015) from the flysch sediments of Laisong area, Manipur.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

29. Ichnogenus: *Psilonichnus* Fursich (1981)

According to Fursich (1981), the ichnogenus *Psilonichnus* was characterized as a simple, vertical, cylindrical burrow with a Y shaped upper part, short side branches and four ichnospecies have been described: *P.tubiformis* (Fursich, 1981), *P.upsilon* (Frey *et al.*, 1984), *P.quietis* (Myint, 2001), and *P.lutimuratus* (Nesbitt and Campbell, 2002). *Psilonichnus* is now known to occur within *Skolithos* ichnofacies, *Glossifungites* ichnofacies and *Psilonichnus* ichnofacies. The first order ichnogenus level characters were used to differentiate this ichnogenus from other decapods crustacean ichnogenus such as *Thalassinoides*, *Ophiomorpha* and *Spongliomorpha* (Nesbitt and Campbell, 2006).

Ichnospecies: *Psilonichnus tubiformis* Fursich (1981)

(Plate VII; Fig C & D)

Material: Field photographed of silty-shale and grey coloured silty-shale with full relief burrow.

Occurrence: Silty-shale bed (Bed no.49) in Mualkawi- Ruantlang section and grey coloured shale bed (Bed no.5) in Zote-Ngur section, Barail Group, Champhai District, Mizoram.

Description: Vertical, I–J shaped, cylindrical burrows with short horizontal to slightly inclided side branches. The depth of the burrow is between 100-140 mm, diameter is about 20 mm and short size branche ranges from 10-15 mm in diameter.

Remarks: On account of it shaped and short side branches, the present specimen is assigned to ichnospecies *Psilonichnus tubiformis*. According to Fursich (1981), *Psilonichnus tubiformis* corresponds to Y-J and I-shpaed burrows, with irregular vertical to inclined main shafts and common bulnous swellings. They are predominantly vertical, unlined cylindrical burrows with ovate cross section, short horizontal or oblique side branches, upper part frequently Y-shaped

Distribution: de Carvalho (2016) recorded *P.tubiformis* from Praia do Salgado, Western Portugal.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Psilonichnus Upsilon* Frey *et al.* (1984)

(Plate VII; Fig. E & F)

Material: Field photographed of grey coloured silty-shale and grey coloured shale with a full relief burrow.

Occurrence: it occurs on grey colour silty shale bed (Bed no.83) in Mualkawi-Ruantlang section, grey coloured shale bed (Bed no. 7) in Ngur section, Barail group, Champhai District, Mizoram.

Description: The burrow exhibit steeply inclined Y shaped structures, grading downward with shafts. One of the branches is short and smaller in diameter than the other. Diameter of the burrow varies from 10-15 mm, angle of bifurcation is between 45-65 degree and maximum observed depth is about 140 mm.

Remarks: The present burrow shows identical morphological characters with *Psilonichnus upsilon* described by Frey *et al*. (1984), and hence it has been placed under *P.upsilon*. The trace maker of *P.upsilon* is considered as the extant ghost crab

Ocypode quadrata (Fabricus) and as elucidated by polyester cast of J-shaped burrows from the lower backshore, Sapelo Island, Georgia (Frey and Pemberton (1987).

Distribution: Kundal and Dharshivkar, (2006) documented Psilonuchnus upsilon from Dwarka-Okha area of Gujarat. Singh *et al.* (2010) reported this ichnospecies from the Bhuban and Bokabil Formation of Western Hill, Manipur. Lokha and Singh, (2013), Rajkonwar *et al*. (2013, 2015) described *P.upsilon* from the Bhuban Formation, Surma Group of Aizawl, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

Ichnospecies: *Psilonichnus* isp.

(Plate VIII; Fig. A-C)

Material: Field photographed of sandstone, silty-shale and sandstone with full relief burrows,

Occurrence: Sandstone bed (Bed no.49) in Mualkawi-Ruantlang section, Siltstone bed (Bed no.6) in Zote-Ngur section and sandstone and shale alternation bed (Bed no.8) in Ngur-Vapar section, Barail Group, Champhai District, Mizoram.

Description: Vertical to slightly incline to the bedding plane, J- shaped burrows, unbranched, depth of the burrow ranges from 30 mm- 80 mm and diameter is between 8 mm to 25 mm.

Remarks: Present specimen shows resemblance with ichnogenus *Psilonichnus* on the basis of J-shaped burrow. Thus, it has been placed under *Psolonichnus* isp.

Distribution: Rajkonwar *et al.* (2015) reported this ichnospecies from Bhuban Formation, Mizoram.

30. Ichnogenus: *Rosselia* Dahmer (1937)

Ichnospecies: *Rosselia* isp.

(Plate VIII; Fig. D &-F)

Material: Field photographed of sandstone, shale with burrow.

Occurrence: Sandstone bed (Bed no.55) in Mualkawi-Ruantlang section, shale bed (Bed no.1) in Zote – Ngur section and shale bed (Bed no.19) in Ngur-Vapar section, Barail Group, Mizoram

Description: Vertical to slightly inclined burrows with concentric infill, downward tapering, straight or curved burrow with a funnel-shaped, consisting either of a small central burrow surrounded by spreitelike helicoids swirls. Maximum observed depth of the burrow is 160 mm and diameter of the burrow is varied.

Remarks: Chamberlain (1971); Hantzschel (1975); Frey and Howard (1985); Desjardins *et al.* (2010) compared *Rosselia* with the ichnogenera *Asterosoma* and *Cylindrichnus*. *Rosselia* has a similar concentric sand-mud infill to that of *Cylindrichnus* concentricus (Frey and Howard, 1985). The latter, however, does not display the funnel shaped morphology of *Rosselia*. In contrast to *Rosselia*, *Asterosoma* is a branched structure, commonly arranged in flower-shaped patterns with multiple inclined to horizontal components. *Rosselia* ichnospecies represents a dwelling structure of detritus feeding organisms and terebellid polychaetes have been suggested as trace makers.

Distribution: This ichnospecies has been described from the Nimar Sandstone of Bagh Beds, Madhya Pradesh by Kundal and Sanganwar (1998).

This ichnospecies is being reported for the first time from the Barail successions of Northeast India.

31. Ichnogenus*: Rusophycus* Hall (1852)

Rusophycus is a trace fossil associated to *Cruziana*, it is the resting trace while *cruziana* is produced when the organism moved. Small to medium bilobate structures, lobes are parallel or sometimes merged near the posterior. The sculpture of *Rusophycus* may reveal the approximate number of legs that the tracemaker had, although striations (scratchmarks) from a single leg may overlap or be repeated. Can be interpreted as shallow marine settings, but also reported in fluvial and shallow lacustrine soft-ground media. *Rusophycus* is known from Cambrian-ordovician deep-marine flysch deposits. *Trilobites* (Precambrian-recent), starfish, bilateral arthropods and vertebrates, or other non-sessile benthic dweller (Permian-recent) are the possibly tracemaker. Larger specimens could be made by vertebrates.

Ichnospecies: *Rusophycus carbonarius* Dawson (1864)

(Plate VIII; Fig. H)

Material: Field photographed of buff colour block sandstone with burrows.

Occurrence: Brown coloured Sandstone and shale alternation bed (Bed no. 6), Barail sediment, Ngur section, Champhai, Mizoram.

Description: Structure is short, small, bilobate resembling a coffee bean, 0.5-1.3 cm long and 0.4-1 cm across and consisting of two parallel lobes separated by median furrow.The individual lobe is 0.2-0.6 cm wide. The two similar lobes are separated by a distinct furrow. The furrow is 0.1-0.2 cm wide. Lobes are parallel, rarely oblique, but some specimens display an anterior subtriangular gap and 0.2-0.5cm in height from the bedding surface. Lobes are covered by fine transverse striae that extend almost to the margin and preserved as convex hyporelief. This trace fossil co-occurs with *Cruziana isp.* and *Planolites beverlyensis*

Remarks: Present form is closely resembles ichnospecies *R.carbonarius* reported from Nagaur group, western India (Ahmad and Kumar. 2014). *R.carobonarius* was possibly produced by small trilobite (Stachacz, 2012). *R.carbonarius* is believed to be a resting trace of tiny arthropod (Hofmann *et al*., 2012). *R.carbonarius* is distinguished from *R.eutendorfensis* by the presence of transverse striae (Schlirf *et al.*, 2001), from *R. stromnessi* by the absence of extended, smooth and lily-like ends (Trewin, 1976; Keighley and Pickerill, 1996), from *R. furcossus* in the arrow shape of the latter (Gand, 1994) and from *R.minutus* in its triangular shape (Debriette and Gand, 1990). This ichnogenus is present from the Cambrian to the recent.

Distribution: *Rusophycus carbonarius* has been documented by Schlirt from the southern part of the Germnic Basin in 2005. From the Middle Cambrian of Jordan, Hofmann described it in 2012. Ahmad and Kumar (2014) reported this ichnospecies from Nagaur Group, Western India.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Rusophycus versans* Schlirf & Uchman (2001)

(Plate VIII; Fig.G)

Material: Specimen no: Ng/B/3 and Field photographed of sandstone with burrows.

Occurrence: Alternation of sandstone and shale bed (Bed no.8) in Ngur-Vapar section, Barail Group, Champhai district, Mizoram.

Description: Cluster of variably oriented, small, short, bilobate, smooth, coffee-bean shaped, median groove is narrow and shallow, poorly ornamented, preserved as convex hyporelief. Length of the trace is 2.2 cm and width is about 1.8 cm

Remarks: Present specimen shows resemblance well with *Rusophycus versans* Schlirf & Uchman, 2001. Therfore, it has been placed under *Rusopycus versans. R.versan* probably have been produced by Trilobites. (Seilacher, 1955; Osgood, 1970)

Distribution: Schlirf documented *Rusophycus versans* from the southern part of the Germnic Basin in 2005.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

32. Ichnogenus: *Scolicia* De Quatrefages (1849)

The term *Scolicia* group was used by Hantzschel 1975. This group embraces bilobate and *trilobite* traces which have been related to Mesozoic and Cenozoic echinoid burrows (Smith and Crimes 1983). All members of the group are included in the ichnogenus *Scolicia* by Seilacher 1986

Ichnospecies: *Scolicia stronzzii* Savi & Meneghini (1850)

(Plate IX; Fig. D & E)

Material: Field photographed of sandstone with burrows.

Occurrence: It occurs on brown coloured sandstone bed (Bed no.56) in Mualkawi section, Barail Group, Champhai District, Mizoram.

Description: Hypichnial, smooth, bilobate ridge with median groove in fine-grained sandstone. The ridge is 10 mm-13 mm in width, and 3-5 mm in height. The median furrow is semi-circular in cross section.

Remarks: Present specimen is closely resemblance with *Scolicia stronzzi* described and photographed by Rodiguez *et al.* 2010. Thus, it has been assigned to *Scolicia stronzzii.* It was produced at shallow tiers and its Mesozoic-cenozoic producers

(spantangoid echinoids) can not be excluded. The Paleozoic forms are probably casts of washed out burrows of *Cruziana* and Curvolithus.

Distribution: *Scolicia stronzzii* has been reported by Tovar *et al*. in 2010 from Eocene turbiditic deposits, Gorrondatxe section of N.Spain.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

33. Ichnogenus: *Skolithos* Haldemann (1840)

Skolithos is widely found in near shore/ shallow water marine environment (Seilacher, 2007), but is also reported from the deep water (Alpert, 1974) and also in the flood plains (Curran and White, 1987). Straight tubes or pipes perpendicular to bedding plane, shafts parallel to each other, subcylindrical to cylindrical, unbranched. *Skolithos* is known from the Late Precambrian (Fedonkin, 1985) to the Pleistocene (Pemberton and Jones, 1988).

Ichnospecies: *Skolithos linearis* Haldemann (1840)

(Plate VIII: fig. I & J)

Material: Field photographed of silty- shale and shale with full relief burrow.

Occurrence: Silty-shale bed (Bed no.46) in Mualkawi-Ruantlang section and shale bed (Bed no.7) in Zote-Ngur section, Barail Group, Champhai District, Mizoram.

Description: Vertical or steeply inclined, isolated, unbranched, cylindrical, unlined, straight, structure-less fill and perpendicular to the bedding plane. The observed depth of the burrow is 80mm-140 mm and diameter varies from 15 mm-20 mm. Infill material is different than the surrounding sediment.

Remark: Morphologically, the present specimen is assigned to *Skolithos linearis* as described by Alpert (1974), Curran and Frey (1977) and Curran (1985). Besides it

resembles well with the earlier record of the species reported by Tiwari *et al*. (2011); Rajkonwar *et al*. (2013) and (2014) from the Bhuban Formation of Mizoram and from Cenozoic succession of Manipur by Singh *et al*. (2008).). They are mostly occurs in shallow-marine environments (Fillion and Pickerill 1990) but also rarely occurs in non-marine environments (Bromley and Asgaard 1979, Schlirf *et al.*2001).

Distribution: Nagendra *et al.* (2010) documented *Skolithos linearis* from Kulakkalnattam Sandstone of Garudamangalam Formation, Tamil Nadu. It has also been described from the Ambalapuzha Formation, Papanasam, Varkala cliff section by Mude *et al*. (2012). Joseph *et al.* (2012) recovered it from Kaladongar Formation of Patcham Island. *S.linearis* has been reported from flysch sediments of Manipur by Khaidem *et al.* (2015) and by Singh *et al*. (2008) from Upper Eocene-Lower Oligocene Transition of Manipur. Kichu *et al.* (2018) and Rajkumar *et al*. (2019) has been described this ichnospecies from Nagaland. From Miozam, it has been previously reported by Tiwari *et al.* (2011) and Rajkonwar *et al.* (2013, 2014) from Bhuban Formation.

This ichnospecies is being reported for the first time from Barail succession of Mizoram.

Ichnospecies: *Skolithos verticalis* Hall (1843)

(Plate IX: fig A-C)

Materials: Field Photographed of block sandstone with semi-relief burrow.

Occurrence: It occurs on sandstone bed (Bed no.56) in Mualkawi-Ruantlang section, shale bed (Bed no. 2), Zote-Ngur section and sandstone-sale alternation bed (Bed no. 8) in Ngur section, Champhai District, Mizoram.

Description: Vertical burrow, thick, stout, isolated, cylindrical, lined and perpendicular to the bedding plane and preserved in an isolated form. The diameter of the burrow ranges from 10 mm to 250 mm. The burrows filled sediments are structureless.

Remark: Seilacher (1967) mentioned that *Skolithos verticalis* can be differentiated from the *Skolithos linearis* by the filled material, latter is filled with muddy sediments. *Skolithos* verticalis has rough, annulated burrows walls. Fillion and Pickerill (1990); Alpert (1974) noted that It is widely recognized in the shallow water, intertidal deposits and is probably thought to be produced by annelids or phoronids (Alpert, 1974).

Distribution: *Skolithos verticalis* has been described by Patel *et al*. (2012) from the Jurassic rocks of Gangta Bet, Kachchh and Mude *et al.* (2012) from the Mesozoic Jaisalmer basin of Rajasthan. Malarkodi *et al*. (2009) reported it from the Palaeocene sediments of Pondecherry area while Reddy *et al*. (1992) recorded from the Tipam succession of Assam. Rajkumar *et al.* (2012) and Rajkonwar *et al.* (2013) documented this ichnospecies from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

34. Ichnogenus: *Taenidium* Heer (1877)

The ichnogenus *Taenidium* is variously oriented, unlined, straight, curved or sinuous, cylindrical trace fossil, containing a segmented fill, articulated by meniscus-shaped partings, usually considered to be produced by an animal progressing axially through the sediment and depositing alternating packets of differently constituted

sediment behind it, as it moves forward (Bromley *et al.*, 1999). Secondary branches may be present, but true branching is absent (Keighley and Pickerill, 1994).

Ichnospecies: *Taenidium barretti* Bradshaw, 1981

(Plate IX; Fig.F)

Material: Specimen no: Ng/A/5

Occurrence: Grey coloured shale bed (Bed no.5) in Ngur-Vapar section, Barail Group, Champhai District, Mizoram.

Description: Endichnial, horizontal, slightly winding, unbranched, unwalled, meniscate backfill burrow, menisci are commonly hemispherical, tightly packed. 0.3 cm wide and 2.5 cm long

Remarks: In the pattern, nature of back fill and the arcuate menisci, the present specimen can be assigned to ichnospecies *Taenidum barretti*. Squires & Advocate (1984) interpreted the meniscate burrows as traces of infaunal deposit-feeders, probably aquatic oligochaetes. T. barretti occurs in different nonmarine environments from the Lower Ordovician to the Pleistocene (Keighley & Pickerill 1994).

Distribution: *Taenidum barrette* has been described by Hofmann *et al* from the Middle Cambrian of Jordan in 2012.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

35. Ichnogenus: *Teichichnus* Seilacher (1955)

Teichichnus is long, straight, sinuous to zigzag shaped, unbranched or branched, wall-like spreite structures, formed by vertical displacement of horizontal or oblique, erect to undulose tubes lacking wall lining, resulting in single, gutter shaped or double gutter shaped spreite lamellae. Seilacher (1955) introduced

Teichichnus and described it as horizontal, dwelling-feeding structures, in the form of walls with parallel lellaminae, made by deposit-feeders, moving within the sediment.

Ichnospecies: *Teichichnus rectus*, Frey and Bromley (1985)

(Plate IX; Fig. I)

Material: Field photographed of grey coloured siltstone with burrow.

Occurrence: Grey coloured silty-shale bed (Bed no.8) in zote-Ngur section, Barail Group, Champhai District, Mizoram.

Description: Verticallty stacked with spreites. In cross section, the width of this trace fossil ranges from 1-1.4 cm and the length from 6-12 cm. Preserved as endichnial full relief within siltstone, horizontal burrows that shifted upwards perpendicular to the bedding plane (Seilacher 1955; Frey and Bromley 1985)

Remarks: Frey and Bromley (1985) classified *Teichichnus rectus* as long structures with spreite. This ichnospecies is generally interpreted as dwelling/ feeding burrows of a deposit feeder; the retrusive spreite probably represents as equilibrium response to slowly aggrading substrate (Pemberton, 1992). Probably producers of*Teichichnus* include annelids (Buatois *et al*., 2005; Farrow, 1966), arthropods (Buatois *et al.*, 2005) and crustaceans (Stanton and Dodd, 1984)

Distribution: Tiwari *et al.* (2012) described *Teichichnus rectus* from Bhuban, Surma Group, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

Ichnospecies: *Teichichnus spiralis* Mikulas, 1990

(Plate IX; Fig. G & H)

Material: Field photographed of sandstone with burrow and shale with burrow

Occurrence: It occurs on sandsand bed (Bed no.18) in Mualkawi-Ruantlang section and shale bed (Bed no.1) in Zote-Ngur section, Barail Group, Champhai District. Mizoram.

Description: Vertical coiled structure with three backfill lamellae, observed length of the specimen is 50- 80 mm and diameter is 10-14 mm.

Remarks: Present specimen is closely resemblance with *Teichichnus spiralis* Mikulas,1990 described by Lokha and Singh. Therefore, it has been placed under *Teichichnus spiralis.* It is a tunnel system made by crustaceans and characterized by the presence of tightly siparaled gutter- like backfill lamellae.

Distribution: Lokha and Singh described *Teichichnus spiralis* from the Miocene Bhuban Formation, Mizoram in 2013.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

36. Ichnogenus: *Thalassinoides* Ehrenberg (1944)

Morphologically, *Thalassinoides* is usually interpreted as tunnel and ethologically as a fodinichnial/domichnial structure, passively filled, but occasionally an agrichnial behavior has been interpreted for the tracemaker (Myrow 1995; Bromley 1996; Ekdale and Bromley 2003). *Thalassinoides* is a facies-crossing form most typical of shallow-marine environment and is produced mainly by crustaceans or other type of arthropods (Frey *et al.*, 1984; Bromley, 1996; Ekdale, 1992). The ichnogenus *Thalassinoides* is the most characteristic biogenic structure produced by

arthropods in the marine geological record (Seilacher, 1986). The burrows are characterized by an irregular width that can exceed 110 mm, and their length can reach more than 1 m. they ramify at acute angles, are Y-shaped, and frequently have expanded diameters in divergence areas (i.e., turning chambers). Transverse sections are elliptical, with the major axis parallel to the bedding planes due to diagenetic compaction. *Thalassinoides* is also reported from deep marine environment (Srivastava *et al.*, 2017). Frequently, related to oxygenated situations and soft but fairly cohesive sediments (Bromley and Frey 1974; Kern and Warme 1974; Ekdale *et al.* 1984; Bromley 1990). The recognized association between *Thalassinoides* and firm hardground substates has been commonly used in sequence stratigraphy, especially in relation with the *Glossifungites* ichnofacies (MacEachern *et al*. 1992; Pemberton and MacEachern 1995; Pemberton *et al.* 2001; Savrda *et al.* 2001).

Ichnospecies: *Thalassinoides horizontalis* Myrow (1995)

(Plate IX; Fig. J; Plate X; Fig. A & B)

Material: Field photographed of sandstone, shale with burrow

Occurance: It occurs on sandstone bed (Bed no.18) in Mualkawi-Ruantlang section, shale bed (Bed no.1) in Zote-Ngur section and sandstone and shale bed (Bed no.8) in Ngur-Vapar section of Champhai District, Mizoram.

Description: Smooth, unlined, three dimensional, horizontal burrow and parallel to the bedding plane. Tunnels are straight to curved, length varies from 50 to 280 mm and diameter from 10 to 260 mm.

Remarks: Present specimen is placed under *T. horizontalis* as it is in horizontal form and no vertical shaft. It resembles *T. bacae* but differs from it in lacking entirely of

vertical shafts. *T. horizontalis* is robust and often occurs on the ripple marked silty-sandstone.

Distribution: *T.horizontalis* has been documented from Jurassic rocks of Habo Dome, Mainland Kachchh by Patel *et al*. (2008) and from Gangta Bet of Eastern Kachchh by Patel *et al*. (2012). Malarkodi *et al.* (2009) recovered this ichnospecies from Palaeocene sediments of Pondicherry and Mude *et al.* (2012) from the Mesozoic Jaisalmere basin of Rajasthan. Joseph *et al*. (2012) reported it from the Kaladongar Formation of Patcham Island. Rajkonwar *et al.* (2013, 2015) documented *T.horizontalis* from Bhuban Formation, Surma Group, Mizoram. Subsequently, Kichu *et al*. (2018) described it from Barail sediment, Nagaland.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

Ichnospecies: *Thallasinoids paradoxicus* Rieth 1932

(Plate X; Fig. C)

Material: Field photographed of siltstone with full relief burrow.

Occurrence: Burrow occurs on alternation of sandstone and shale bed (Bed no.6) in Zote-Mualkawi section, Barail Group, Champhai District, Mizoram

Description: Endichnial, full relief, horizontal, three-dimensional structure irregular burrow system spread on the bedding plane. The burrow fill is different than the surrounding. Burrow diameter varies from 10-20 mm and observed length is about 400 mm. The burrow system comprises of inclined shaft connected to surface; bifurcation is T shaped and also show swelling at junction.

Remark: Present specimen resembles well with the specimen of *Thalassinoides paradoxicus* described by Rieth (1932). *T.paradoxicus* (Woodard) corresponds to

branching, boxwark burrows highly irregular in size and geometry (Kennedy, 1967; Bromley and Ekdale 1984; Frey and Howard, 1985). According to Howard and Frey (1984), *Thalassinoides paradoxicus* differs from *T.horizontalis*, on the basis of consisting vertical or inclined shaft and branch dichotomous.

Distribution: Kundal *et al* (2005) reported *Thalassinoides paradoxicus* from Babaguru Formation of Gujarat. Kundal and Dharashivkar (2006) documented it from Dwarka-Okha area, Patel *et al.* (2008) from the Habo Dome area of Kachchh, Mude *et al*. (2012) from the Kand Formation of Gujarat. It has been described by Sanganwar and Kundal (1997), Kundal and Sangarwar (1998, 2000) from the Nimar Sandstone Formation, Bagh Bed of Madhya Pradesh. Singh *et al*. (2008) reported it from upper Eocene-Lower Oligocene Transition of the Manipur, Indo-Myanmar Ranges and by Rajkumar *et al.* (2019) from Disang sediment, Nagaland. Tiwari *et al* (2011), Rajkumar *et al.* (2012) and Rajkonwar *et al*. (2013, 2014) documented this ichnospecies from Bhuban Formation, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

Ichnospecies: *Thalassinoides Suevicus* Rieth (1932)

(Plate X; Fig. D & E)

Material: Specimen no. Ng/A/4 and field photographed of sandstone with burrow.

Occurrence: The burrows occur on the bedding plane of sandstone (Bed no.23) in Mualkawi-Ruantlang section and sandstone-shale alternation bed (Bed no. 6) in Ngur-Vapar section, Barail Group, Champhai District, Mizoram.

Description: Horizontal, profusely branching burrows, unornamented, irregular burrows, passively filled and disposed horizontal to the bedding plane. Burrows on average have 2 cm in diameter and length reaches upto 16 cm.

Remarks: Burrow are abundantly branched and therefore assigned to *Thallasinoides suevicus* Rieth. Bromley and Ekdale (1984); Frey and Howard (1985, 1990) considered that *T.suevicus* is mostly horizontal structure that may contain enlargements at Y-shaped bifurcations.

Distribution: *Thalassinoides suevicus* has been described by Bandopadhyay *et al.* from Palaeogene Succession of Andaman and Nicobar Islands in 2009. Rajkumar *et al*. (2012) and Rajkonwar *et al.* (2103, 2015) also documented *T.suevicus* from Bhuban Formation, Surma Group, Mizoram.

This ichnospecies is being reported for the first time from Barail group of Northeast India.

37. **Ichnogenus**: *Treptichnus* Miller (1889)

Ichnospecies: *Treptichnus pedum* Seilacher, 1955

(Plate X; Fig. F)

Material: Specimen no: Z/7

Occurrence: Sandstone-shale alternation bed (Bed 7) in Zote-Ngur section, Barail Group, Champhai District, Mizoram.

Description: Horizontal, shallow, preserved as positive hyporelief in fine grained sandstone. Segments linked in a zigzag or irregular or other patterns near their ends. At places they show branching twig like structures. Width of the burrow is between 3-5 mm and length ranges between 10-14 mm.

Remarks: On the basis of its diagnostic characteristic of feather-stitch like arrangement of segments, the present specimen appears close to ichnogenus *Treptichnus* Miller, 1889. *T.pedum* is probably produced by the sediment-feeding animals (Hantzschel, 1975) and interpreted as fodichnion produced by vermiform animals (Buatois *et al*., 1998),

Distribution: Rajkumar *et al*. (2019) described it from Disang Formation, Nagaland.

This ichnospecies is being reported for the first time from Barail group of Mizoram.

38. Ichnospecies Type A

(Plate X; Fig.G)

Material: Field photographed of grey coloured sitly-shale with a full relief burrow.

Occurrence: Grey coloured shale bed (Bed no.40) in mualkawi section, Champhai District, Mizoram.

Description: Burrow disposed horizontal to the bedding plane, meandering and branched. The burrow fill is dissimilar from the host rock. The maximum observed length of the burrow is about 14 cm and the diameter ranges from 0.5-0.8 cm

Remark: The horizontal meandering pattern of the present burrow close with ichnogenus *Cochlichnus,* but its branching nature refuses the category. There is no previous record of burrow like ichnospecies type A from the other sedimentary successions of India. Specific identification has been deferred for the want of mote material.

4.3: ETHOLOGICAL DIVERSITY OF TRACE FOSSILS:

A total of 60 ichnospecies have been identified and described from the collection made and photographs taken from the three studied sections in the Barail succession of Mizoram. Ethologically, the ichnofossils assemblage is dominated by domichnia and fodinichnia, but repichnia, pascichnia, cubichnia and agrichnia groups are also present (Fig. 4.1)

Ethological Group	Farming (Agrichnia)	Resting (Cubichnia)	Dwelling (Domichnia)	Feeding (Fodinichnia)	Grazing (Pascichnia)	Crawling (Repichnia)
No. of Fossil	1	3	21	21	6	8

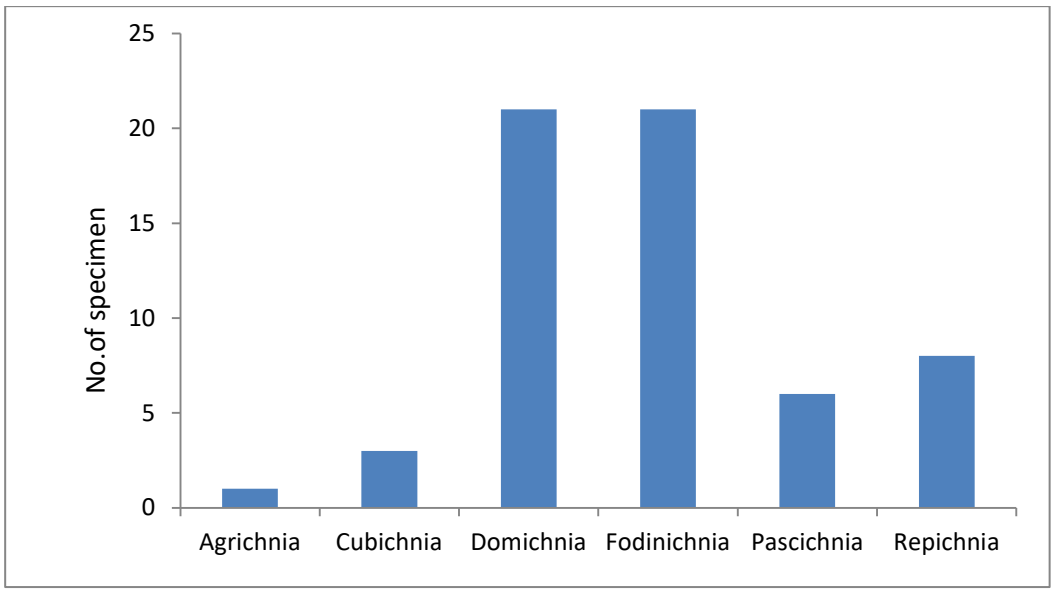


Figure 4.1: The diversity of agrichnia, cubichnia, domichnia, fodinichnia, pascichnia and repichnia

4.4: ANALYSIS OF TRACE FOSSILS:

A total of 60 ichnospecies belonging to 39 ichnogenera have been identified from the collection, photographed and described. Out of these ichnospecies one ichnospecies could not be identified up to generic level owing to poor preservation and less number of specimens. The remaining 59 ichnospecies were already described by previous workers.

Among these 60 ichnospecies, 15 ichnospecies are found in more than one sections. Six ichnospecies, namely, *Laevicyclus mongraensis, Lockeia siliquaria, Psilonichnus* isp., *Rosselia* isp., *Skolithos verticalis* and *Thalassinoides horizontalis* have been reported from all the three sections.

The following 59 ichnospecies are being reported for the first time from Oligocene succession of Mizoram:- *Archaeonassa fossulata, Archaeonassa* ichnospecies, *Arenicolites tenuis, Arenicolites* isp., *Asterosoma* ichnospecies, *Avetoichnus luisae, Chondrites intricatus, Chondrites recurvus, Circulonichnus* isp., *Cochlichnus anguineus, Cylindrichnus* isp., *Cruziana* isp., *Didymaulichnus lyelli, Funalichnus bhubani, Gastrochaenolites ornatus, Glaciichnium liebegastensis, Gordia carickensis, Gyrochorte comosa, Gyrolithes lorcaensis, Gyrolithes mexicanus, Helminthopsis abeli, Helminthopsis hieroglyphica, Helminthopsis tenuis, Katbergia carltonichnus, Laevicyclus mongraensis, Lanicodichna medulata, Lockeia siliquaria, Macanopsis pagueyi, Macanopsis* isp., *Monomorphichnus* isp., *Ophiomorpha annulata, Ophiomorpha irregulaire, Ophiomorpha nodosa, Palaeophycus annulatus, Palaeophycus heberti, Palaeophycus sulcatus, Palaeophycus striatus, Palaeophycus tubularis, Pholeus bifurcates, Phycodes curvipalmatum, Planolites beverlyensis, Planolites montanus, Protovirgularia*

dichotoma, Psilonichnus upsilon, Psilonichnus tubiformis, Psilonichnus isp.*, Rosselia* isp.*, Rusophycus carbonarius, Rusophycus versan, Scolicia stronzzii, Skolithos linearis, Skolithos verticalis. Taenidium barretti, Teichichnus recturs, Teichichnus spiralis, Thalassinoides horizontalis, Thalassinoides paradoxicus, Thalassinoides suevicus and Treptichnus pedum.*

The following 42 ichnospecies are being reported for the first time from the Oligocene succession of Northeast India:

Archaeonassa fossulata, Arenicolites tenuis, Asterosoma isp.*, Avetoichnus luisae, Chondrites intricatus, Ch.recurvus, Cochlichnus anguineus, Cruziana problematica, Cylindrichnus* isp.*, Didymaulichnus lyelli, Funalichnus bhubani, Gastrochaenolites ornatus, Glaciichnium liebegastensis, Gordia carickensis, Gyrochorte comosa, Gyrolithes lorcaensis, Gyrolithes mexicanus, Helminthopsis abeli, Helminthopsis hieroglyphica, Katbergia carltonichnus, Laevicyclus mongraensis, Lockeia siliquaria, Macanopsis paguei, Macanopsis ichnospecies, Monomorphichnus* isp.*, Ophiomorpha annulata, Ophiomorpha irregulairre, Palaeophycus annulatus, Palaeophycus heberti, Palaeophycus striatus, Palaeophycus sulcatus, Pholeus bifurcates, Psilonichnus tubiformis, Psilonichnus* isp.*, Rosselia* isp.*, Rusophycus carbonarius, Rusophycus versans, Scolicia stronzzii, Taenidium baratti, Teichichnus rectus, Teichichnus spiralis* and *Thalassinoides suevicus.*

Overall, above ichnospecies belong to *Trypanite, Skolithos, Cruziana* and Mixed *Skolithos-Cruziana* ichnofacies. Ethologically, the ichno-assemblage is dominated by fodinichnia and domichnia followed by repichnia, pascichnia,

cubichnia and agrichnia. The occurrence and relative frequency of the trace fossils from the study area shown in table 4.1.

Table 4.1: Occurrence and relative frequency of trace fossils in different localities. (A=Abundant, F= Frequent, R=Rare)

Trace Fossils	**Localities**		
	Mualkawi – Ruanntlang	**Zote – Ngur**	**Ngur – Vapar**
Archaeonassa fossulata			R
Archaeonassa ichnospecies	R		
Arenicolite tenuis			R
Arenicolite ichnospecies	F	F	
Asterosoma ichnospecies	R		
Avetoichnus luisae	R		
Chondrites intricatus	R		
Chondrites recurvus	R		
Circulichnus ichnospecies	F		
Cochlichnus anguineus	R		R
Cruziana isp.			R
Cylindrichnus ichnospecies	R		
Didymaulichnus lyelli			R
Funalichnus bhubani	F		R
Gastrochaenolites ornatus	R	R	
Glaciichnium liebegastensis	R		

Gordia carickensis	F		
Gyrochorte comosa	R		
Gyrolites lorcaensis		F	
Gyrolites mexcanus			R
Helminthopsis abeli		F	
Helminthopsis hieroglyphica		R	
Helminthopsis tenuis		F	
Katbergia carltonichnus	R		
Laevicyclus mongraensis	F	F	F
Lanicodichnas medulata		R	
Lockeia siliquaria	F	F	R
Macanopsis paquei	R		
Macanopsis ichnospecies	R		
Monomorphichnus isp.		R	
Ophiomorpha annulata	F		R
Ophiomorpha irregulaire	F		
Ophiomorpha nodosa	A	R	
Palaeophycus annulatus	F		F
Palaeophycus heberti		R	
Palaeophycus striatus	F		F
Palaeophycus sulcatus		F	
Palaeophycus tubularis	R		
Pholeus bifurcatus	R		

Phycodes curvipalmatum			R
Planolites beverlyensis	A	F	F
Planolites montanus	R	R	R
Protovirgularia dichcotoma	R		
Psilonichnus tubiformis	R	F	
Psilonichnus upsilon	F		R
Psilonichnus ichnospecies	A	F	R
Rosselia ichnospecies	R	R	R
Rusophycus carbonarius			A
Rusophycus versans			F
Scolicia stronzzii	R		
Skolithos linearis	A	A	
Skolithos verticalis	A	A	A
Taenidium barrette			R
Teichichnus spiralis	F	R	
Teichichnus rectus		R	
Thalasinoides horizontalis	F	F	A
Thalasinoides paradoxicus		F	
Thalasinoides suevicus	R		R
Treptichnus pedum		R	
Ichnospecies Type A	R		

CHAPTER-5

DEPOSITIONAL ENVIRONMENT

5.1 GENERAL REMARKS

Trace fossil, also called Ichnofossils, are fossilized equivalents of the structures produced in rocks or sediments by the life processes of an organisms. The study of trace fossil is called ichnology, it is concerning with understanding the disturbance of the sediments by living organisms. Trace fossils are important paleoecological and paleoenvironmental indicators as they are preserved in situ, or in the life position of the organism that made them. They record behavioural, ecological and sedimentological events which body fossils and other sedimentary structures cannot highlight directly (Seilacher, 1967; Pemberton *et al.*, 1990; Bromley, 1996). It also record important information for environmental interpretation in terms of water depth, salinity, energy level, oxygenation variation etc.

According to Patel *et al*. (2001) and Desai (2003), three zones were evolved with respect to biogenic structures and bioturbational index. Which are supratidal, intertidal and subtidal. Taylor and Goldring (1995) assumed that supratidal zone is rarely submerged and comprises low bioturbation index. Patel (2002) opined that intertidal zone is characterized by a variety of biogenic structures with 2 bioturbational index near the high water to 4 near the low water line. And Desai and Patel (2008) considered that subtidal zone is characterized by higher degree of bioturbation index (6), demolished physical sedimentary structures and feeding

dwelling structures. *Thalassinoides* association is a characteristic of subtidal environment.

Ichnofossils reflect the behavioural response of animals and these responses are controlled by energy conditions, substrate types, availability of food and they are more sensitive environmental indicators Crimes (1975). The author further mentioned that sandy shore is a very difficult environment and somewhat few benthic animals can fill this niche. The animal must be able to live through current and wave energy, desiccation, rapid fluctuations in temperature and salinity. Animals that can tolerate such extreme conditions often do show by excaping from the surface into permanent or semi-permanent burrows. Kundal and Dharashivkar (2006) mentioned that such reaction is reflected in ichnofossils which show dominance of vertical burrows, U-shaped burrows and burrows with pellets (Kundal and Dharashivkar, 2006)

5.2: DEPOSITIONAL ENVIRONMENT AND PALAEOECOLOGY

5.2.1: Mualkawi-Ruantlang section:

Barail rocks are studied in Mualkawi-Ruantlang section, Champhai (Fig 5.1) for their trace fossil content.

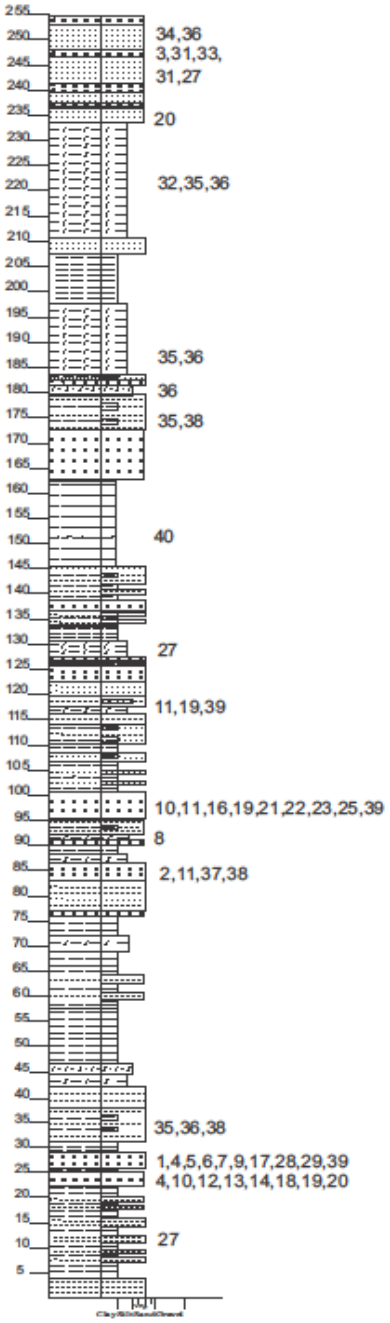
A 480 m thick succession exposed in this section comprises a succession of Sandstone, siltstone, shale, silty-shale and their admixtures belonging to Oligocene, Barail Group (Figure 5.1). They are highly bioturbated and hosts a variety of trace fossils. A total of 40 ichnospecies belonging to 29 ichnogenera have been recovered from this section. The ichnofossil assemblage recorded from this section shows a wide range of behavioral patterns. The assemblage is dominated by domichnia but fodinichnia, repichnia, pascichnia, cubichnia and agrichnia members are also present.

The domichnia signatures are reflected in ichnospecies like *Arenicolite* isp., *Cylindrichnus* isp., *Funalichnus bhubani, Gastrochaeonolite ornatus, Katbergia carltonichnus, Laevicyclus mongraensis, Macanopsis pagueyi, Macanopsis* isp., *Ophiomorpha annulata, O.irregulairre, O.nodosa, Psilonichnus upsilon, P.tubiformis, Psilonichnus* isp., *Skolithos linearis and S.verticalis while fodinichnia features are clearly evident in Asterosoma* isp., *Chondrites intricatus, C.recurvus, Cochlichnus anguineus, Palaeophycus annulatus, P.striatus, P.tubularis, Pholeus bifurcatus, Planolites beverlyensis, Planolites montanus, Teichichnus spiralis, Thalassinoides horizontalis, T.paradoxicus and T.suevicus.* A crawling trails like *Archaeonassa* isp., *Glaciichnium liebegasensis, Gyrochorte comosa, Protovirgularia dichotoma and Scolicia stronzzii, resting traces like Lockeia siliquaria and agrichnion behavior* are evidence in ichnospecies like *Avetoichnus luisae.* A few grazing traces like *Circulichnus* isp. and *Gordia carickensis* are also present. Presence of *Archaeonassa* indicates low energy conditions, shallow marine environment, break in sedimentation, characterizing prodelta environment (Hofmann *et al.* 2012) and also occurred in a variety of ichnofacies (Kim *et al*. 2002). *Arenicolites* point towards high energy, intertidal to subtidal zone (Fursich, 1974) of typical shallow marine environment (Bromley, 1996) with several deep water instances (Bromley and Asgaard, 1979) and characterized as a dwelling trace (Bromley, 1996). *Circulichnus* is considered as a fodinichnian produced by annelids, or an unspecialized grazing trail (Buatois *et al*. 1998a, 1998b, 2006; Mangano *et al.*, 1997). *Cochlichnus* is a crawling trace, probably the feeding structures of small worms or worm like animals (Eager *et al.* 1985) and reported in sediments of low salinity palaeoenvironment (Hakes, 1976). Occurrence of *Didymaulichnus lyelli,*

Planolites beverlyensis and *Gordia carickensis* represents superficial grazing structures of detritus feeders and deposit feeding activites of vermiform organisms. *Funalichnus bhubani* is suspension feeding organisms and are typical members of the *skolithos* ichnofacies (Tiwari *et al.,* 2013). *Gastrochaenolites ornatus* displays a preference for a very shallow marine environments and only a few meters of water may be inferred (Bromley, 1994). Presence of *Gyrochorte* also suggested well oxygenated, low rate of sedimentation, fluctuating energy condition and shallow marine environment with rich in surface food sources (Gilbert and Benner, 2002). *Laevicyclus mongraensis* is a cylindrical dwelling burrow having strong wall and is known to occur in shallow marine set-up (Uchman, 1998). *Lockeia siliquaria* is indicative of sudden changes in the colonization pattern of benthic community, occurring in the shallow marine, estuarine and fluvial environments (Fillion and Pickerill, 1990). *Palaeophycus* suggested well oxygenated, low rate of sedimentation, fluctuating energy condition and shallow marine environment with abundant subsurface food sources (Pemberton and Frey, 1982). Presence of *Planolites, Ophiomorpha, Thalassinoides*, *Gyrolithes* and *Chondrites* indicates a shallow marine environment with occasional deep water condition within shoreface setup (Kichu *et al*. 2018). Presence of *Portovirgularia dichotoma* suggest sudden drop of energy conditions and indicates subtidal region above the fair weather wave base for the deposition (Patel *et al.,* 2012). *Psilonichnus upsilon* suggest backshore marginal marine environment (Frey *et al.* 1984). *Rosselia* indicates very high sedimentation in storm dominated environment of lower shoreface (Pemberton *et al*. 2001). *Scolicia* is a eurybenthic trace fossil and has been reported in the strata of early cambrian (Crimes and Andersonm 1985) to Holocene age (Kitchell and Clark,

1979). *Skolithos* is known from the late Precambrian (Fedonkin, 1985) to the Pleistocene (Pemberton and Jones, 1988) and is widely reocognized in the shallow marine high energy environment, intertidal deposits (Seilacher, 1967) but is also reported from the deep waters (Alpert, 1974) and also in the flood plains (Curran and White, 1987). Both *Teichichnus* and *Thalassinoides* indicates well oxygenated muddy bottom with a low sedimentation rate.

The trace fossils assemblages belong to *Trypanite* ichnofacies, *Skolithos* ichnofacies, *Cruziana* ichnofacies and at places mixing of both *Skolithos/Cruziana* ichnofacies. *Trypanite* ichnofacies normally associated with non-depositional or erosional breaks (Martin, J.A., 2009) and represents a hardground community in an area such as reefs, beach rock or rocky coastline (Frey and Seilacher, 1980). *Skolithos* ichnofacies indicates sandy shifting (muddy) substrate and high energy environment in foreshore zone while the *Cruziana* ichnofacies indicates unconsolidated, fine grain sediment, poorly sorted and low energy condition in the shoreface/offshore zone. Overall these ichnofacies suggest that the Barail succession exposed in Mualkawi to Ruantlang section was deposited under fluctuating (medium/high to low) energy condition within foreshore to shoreface/offshore zones of shallow marine environment with occasional deep water condition.



1. *Archaeonassa isp.*
2. *Arenecolite isp.*
3. *Asterosoma isp.*
4. *Avetoichnus lusae*
5. *Chondrites intricatus*
6. *Chondrites recurvus*
7. *Circulichnus isp.*
8. *Cochlichnus anguineus*
9. *Cylindrichnus isp.*
10. *Funalichnus bhubani*
11. *Gastrochaenolites ornatus.*
12. *Glaciinium liebegastensis*
13. *Gyrochorte comosa*
14. *Gordia carickensis*
15. *Katbergia carltonichnus*
16. *Laevicyclus mongraensis*
17. *Lockeia siliquaria*
18. *Macanopsis paguei*
19. *Macanopsis isp.*
20. *Ophiomorpha annulata*
21. *Ophiomorpha irregulaire*
22. *Ophiomorpha nodosa*
23. *Palaeophycus annulatus*
24. *Palaeophycus striatus*
25. *Palaeophycus tubularis*
26. *Pholeus bifurcates*
27. *Planolites beverlyensis*
28. *Planolites montanus*
29. *Protovirgularia dichotomus*
30. *Psilonichnus upsilon*
31. *Psilonichnus tubiformis*
32. *Psilonichnus isp.*
33. *Rosselia isp.*
34. *Scolicia stronzzii*
35. *Skolithos linearis*
36. *Skolithos verticalis*
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- Block sandstone
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- Siltstone
- Sandstone and Shale alternation

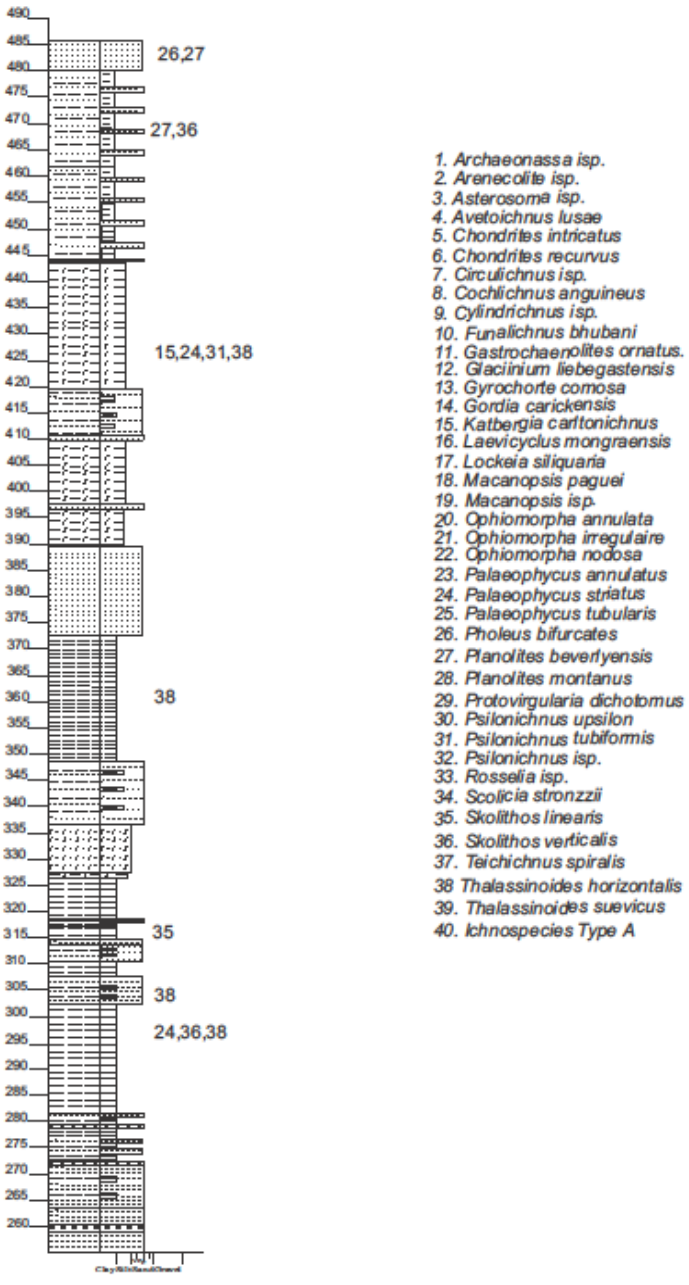


Figure 5.1: Lithocolumn of Barail Succession along Mualkawi-Ruantlang section, Champhai.

Table 5.1: Morphologcial, pre-post origin, ethological and facies classification of Mualkawi-Ruantlang section.

Name of Ichnospecies	**Morphological (Simpson, 1975)**	**Pre-Post origin (Tovar et al.,2010)**	**Ethological (Seilacher,1964)**	**Ichnofacies (Seilacher, 1964,1967)**
Archaenassa isp.	Tunnel	Post	Repichnia	*Cruziana*
Arenicholite isp.	Shaft	Pre	Domichnia	*Skolithos*
Asterosoma isp.	Tunnel	Post	Fodinichnia	*Cruziana*
Avetoichnus luisae	Tunnel	Post	Agrichnia	*Cruziana*
Chondrites intricatus	Tunnel	Post	Fodinichnia	*Cruziana*
Chondrites recurvus	Tunnel	Post	Fodinichnia	*Cruziana*
Circulichnus isp.	Tunnel	Post	Paschichnia	*Cruziana*
Cochlichnus anguinus	Tunnel	Post	Fodinichnia	*Cruziana*
Cylindrichnus isp.	Shaft	Pre	Domichnia	*Skolithos*
Funalichnus bhubani	Shaft	Pre	Domichnia	*Skolithos*
Gastochaenolites ornatus	Tunnel	Post	Domichnia	*Trypanite*
Glacichinium liebegastensis	Tunnel	Post	Repichnia	*Cruziana*
Gyrochorte comosa	Tunnel	Post	Repichnia	*Cruziana*
Gordia carickensis	Tunnel	Post	Paschichnia	*Cruziana*
Katbergia carltobichnus	Shaft	Pre	Domichnia	*Skolithos*
Laevicyclus mongraensis	Shaft	Pre	Domichnia	*Skolithos*

Lockeia siliquaria	Tunnel	Post	Cubichnia	*Cruziana*
Macanopsis pagueyi	Shaft	Pre	Domichnia	*Skolithos*
Macanopsis isp.	Shaft	Pre	Domichnia	*Skolithos*
Ophiomorpha irregulair	Shaft	Pre	Domichnia	*Skolithos*
Ophiomorhpha nodosa	Shaft	Pre	Domichnia	*Skolithos/Cruziana*
Ophiomorpha annulata	Shaft	Pre	Domichnia	*Skolithos/Cruziana*

Palaeophycus annulatus	Tunnel	Post	Fodinichnia	*Cruziana*
Palaeophycus striatus	Tunnel	Post	Fodinichnia	*Cruziana*
Palaeophucus tubularis	Tunnel	Post	Fodinichnia	*Cruziana*
Pholeus bifurcates	Tunnel	Pre	Fodinichnia	*Skolithos/Cruziana*
Planolite beverlyesis	Tunnel	Post	Fodinichnia	*Cruziana*
Planolite montanus	Tunnel	Post	Fodinichnia	*Cruziana*
Protovirgularia dichotoma	Tunnel	Post	Repichnia	*Cruziana*
Psilonichnus upsilon	Shaft	Pre	Domichnia	*Skolithos*
Psilonichnus tubiformis	Shaft	Pre	Domichnia	*Skolithos*
Psilonichnus isp.	Shaft	Pre	Domichnia	*Skolithos*
Rosselia isp.	Shaft	Pre	Domichnia	*Skolithos*
Scolitia stronzzii	Tunnel	Pre	Repichnia	*Cruziana*
Sklithos linearis	Shaft	Pre	Domichnia	*Skolithos*

Skolithos verticalis	Shaft	Pre	Domichnia	*Skolithos*
Teichichnus rectus	Tunnel	Post	Fodinichnia	*Cruziana*
T. horizontalis	Tunnel	Pre	Fodinichnia	*Skolithos/Cruziana*
Thalassinoides suevicus	Tunnel	Pre	Fodinichnia	*Skolithos/Cruziana*
Ichnospecies type A	Tunnel	Post	Fodinichnia	*Skolithos*

5.2.1.1: DIVERSITY OF TRACE FOSSILS FROM MUALKAWI-RUANTLANG SECTION:

A total of 40 ichnospecies belonging to 29 ichnogenera have been recovered from this section. A number in diversity classification of morphologcial, pre-post origin, ethological and ichnofacies of Mualkawi-Ruantlang section also present in Fig.5.2.

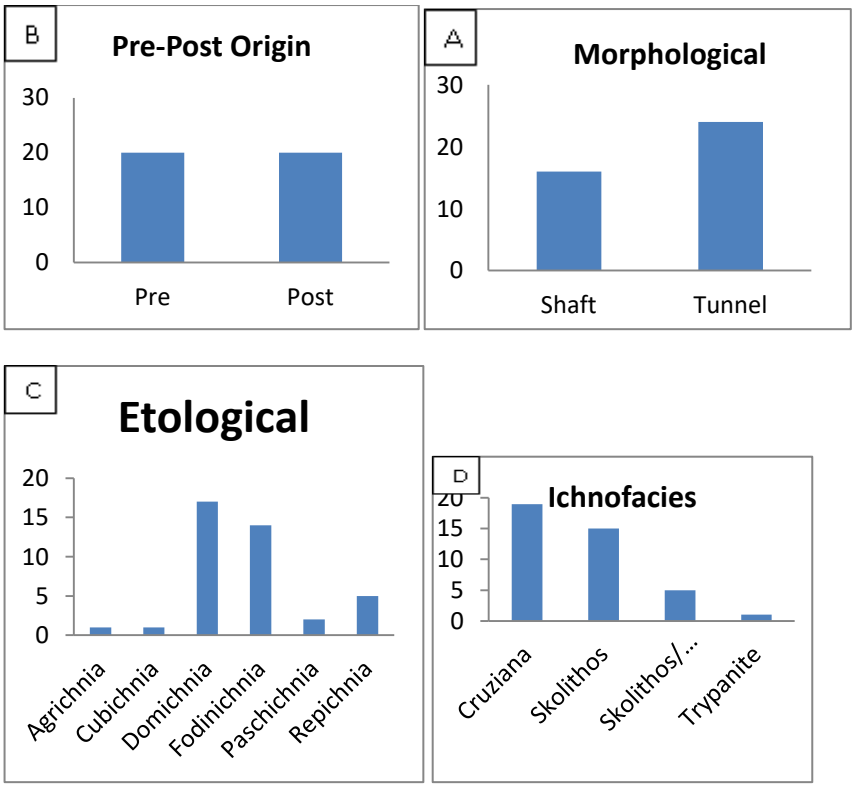


Figure 5.2: The classification of 40 ichnospecies in (A) Morphological (B) Pre and Post origin (C) Ethological and (D) Ichnofacies of Mualkawi-Ruantlang section.

5.2.2 Zote-Ngur Section:

The Barail succession of the Zote-Ngur road section, Champhai shows 119 m thick intercalated sequence of Sandstone, siltstone, silty-shale, shale and their admixtures in different proportions. Sedimentary facies encounter throughout the section show a general upward coarsening indicating upward shoaling facies succession (Singh *et al*., 2012). This succession has yielded a total of 23 ichnospecies belonging to 16 ichnogenera. The occurrence and overall distribution of the trace fossil assemblages found in Barail Group of Zote-Ngur section are shown in figure 5.3 and ethology in table 5.2.

Pemberton (2001) mentioned that the occurrence and distribution of trace fossils are controlled by various environmental parameters such as energy level, substrate, light, salinity, oxygen level and bathymetry. These parameters have controlled the distribution and activities of trace producers during the deposition of the Barail succession of this section. The ichnofossil assemblage recorded from this section shows a wide range of behavioural patterns but is dominated by dwelling burrows. *Gyroliths* represents a permanent dwelling burrow produced chiefly in marginal-marine settings as originally suggested by Gernant (1972). The grazing traces of *Helminthopsis* are most likly produced by deposit feeders and probably made by polychaetes/annelids in brackish to fully marine environments (Buatois*et al.* 1998). It is commonly trace fossil in deep-marine deposits but is also known from the shallow-marine and non-marine environment (Buatois *et al.,* 1998). Both *Ophiomorpha* and *Skolithos* are associated with environments characterized by

frequent high-energy events, drastic changes in the sedimentation rate and erosion of surface sediments (Walker and James, 1992; Singh *et al.* 2008).

The ichnospecies of Zote-Ngur section belong to *Trypanite, Skolithos, Cruziana* and mixing of both *Skolithos/Cruziana* ichnofacies. The *Skolithos* ichnofacies is related to relatively high levels of wave or current energy, and is commonly developed in clean, well sorted, loose or shifting particulate substrate. Such conditions commonly occur on the shoreface and sheltered foreshore, but similar conditions also occur in a wide range of high-energy shallow water environment. (Mac Eachern *et al*. 2007). The *Cruziana* ichnofacies is most characteristic of permanenetly subtidal, poorly sorted and unconsolidated muddy substrate in shallow marine settings with uniform salinity (singh *et al.,* 2008). The *Trypanite* ichnofacies grades seaward into the *skolithos* then to the *cruziana* (Singh *et al.*, 2012). Therefore, present ichnofossils assemblage indicates that the area was deposited under fluctuating energy conditions in intertidal to subtidal zone of shallow marine environment.

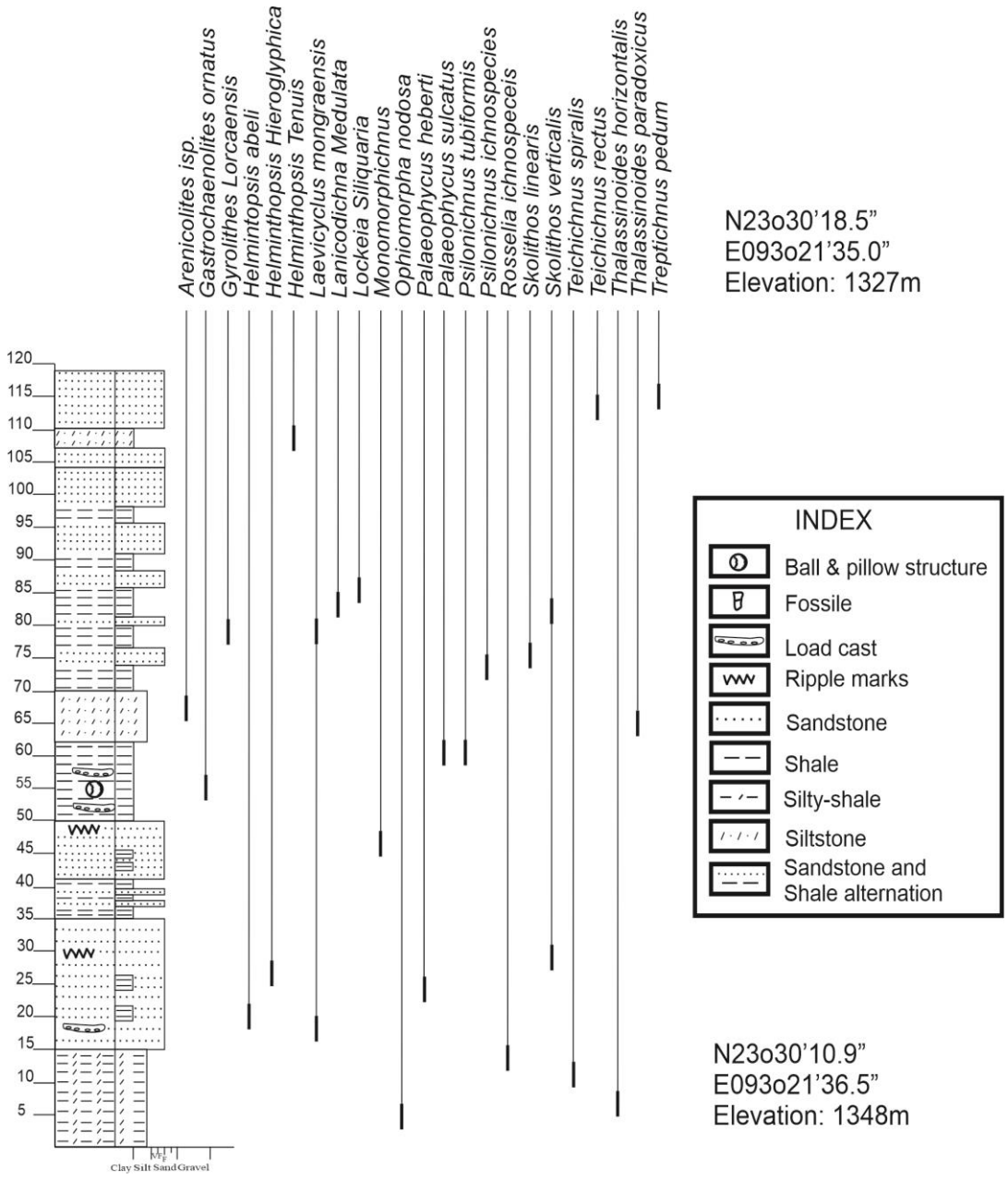


Figure 5.3: Litholoum of Zote- Ngur section, Barail Group, Champhai.

Name of ichnospecies	**Morphological (Simpson,1975)**	**Pre-Post origin (Tovar et al.,2010)**	**Ethological (Seilacher, 1964)**	**Ichnofacies (Seilacher, 1964,1967)**
Arenicolite ichnospecies	Shaft	Pre	Domichna	*Skolithos*
Gastrochaenolite ornatus.	Shaft	Pre	Domichnia	*Trypanite*
Gyrolith lorcaensis	Shaft	Pre	Domichna	*Skolithos*
Helminthospis abeli	Tunnel	Post	Pascichnia	*Cruziana*
H.hieroglyphica	Tunnel	Post	Pascichnia	*Cruziana*
Helminthospis tenuis	Tunnel	Post	Pascichnia	*Cruziana*
Laevicyclus mongraensis	Shaft	Pre	Domichna	*Skolithos*
Lanicodichna medulata	Shaft	Pre	Domichna	*Skolithos*
Lockeia siliquaria	Tunnel	Post	Cubichnia	*Cruziana*
Monomorphichnus isp.	Tunnel	Post	Pascichnia	*Cruziana*
Ophiomorpha nodosa	Shaft	Pre	Domichna	*Skolithos/Cruziana*
Palaeophycus heberti	Tunnel	Post	Fodinichnia	*Cruziana*

Paaeophucus sulcatus	Tunnel	Post	Fodinichnia	*Cruziana*
Psilonichnus tubiformis	Shaft	Pre	Domichna	*Skolithos*
Psilinichnus isp	Shaft	Pre	Domichna	*Skolithos*
Rosselia ichnospecies	Shaft	Pre	Domichna	*Skolithos*
Skolithos linearis	Shaft	Pre	Domichna	*Skolithos*
Skolithos verticalis	Shaft	Pre	Domichna	*Skolithos*
Teichichnus spiralis	Tunnel	Pre	Fodinichnia	*Cruziana*
Teichichnus rectus	Tunnel	Pre	Fodinichnia	*Cruziana*
Thalassinoides horizontalis	Tunnel	Pre	Fodinichnia	*Skolithos/Cruziana*
T. paradoxicus	Tunnel	Pre	Fodinichnia	*Skolithos/Cruziana*
Treplichnus pedum	Tunnel	Post	Fodinichnia	*Cruziana*

Table 5.2: Morphological, Pre-Post, Ethological and Facies classification of ichnospecies from Barail Group of Zote-Ngur section, Champhai, Mizoram.

5. 2.2.1: DIVERSITY OF TRACE FOSSILS FROM ZOTE-NGUR SECTION:

A total of 23 ichnospecies belonging to 16 ichnogenera have been recovered from this section. A number in diversity classification of Morphologcial, pre-post origin, ethological and ichnofacies of Zote-Ngur section also present in Fig. 5.4.

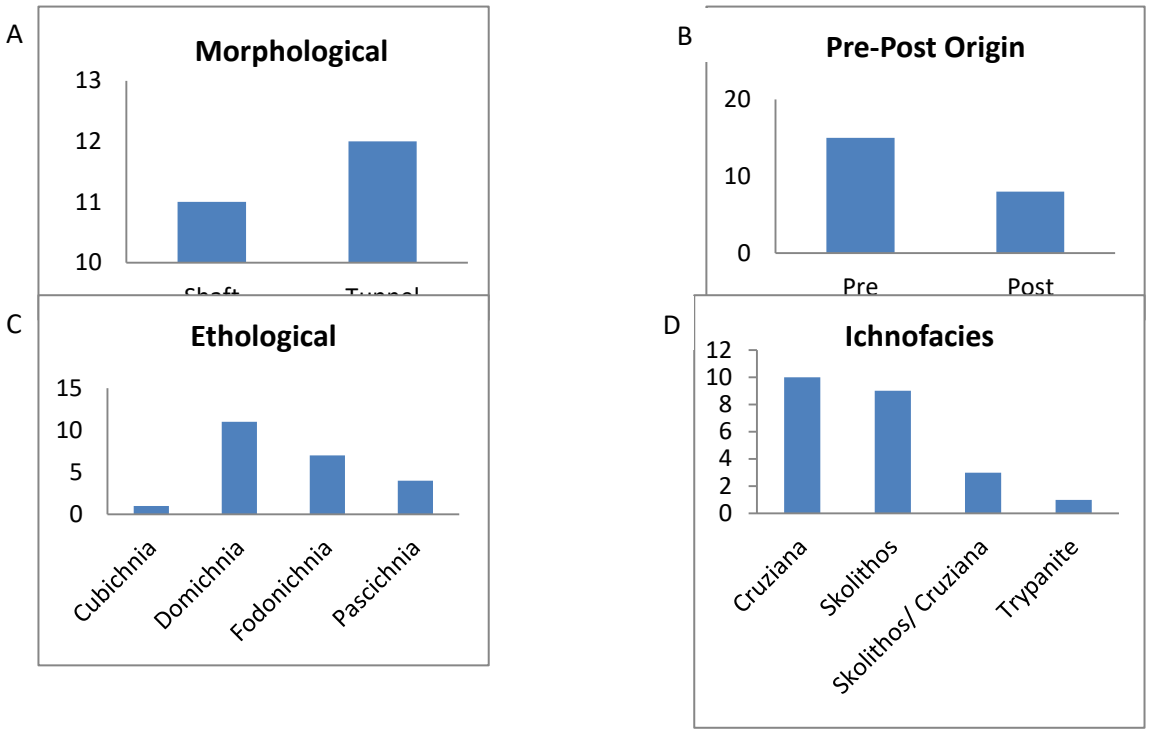


Fig: 5.4: The classification of 23 ichnospecies in (A) Morphological (B) Pre and Post origin (C) Ethological and (D) Ichnofacies of Mualkawi-Ruantlang section.

5.2.3 Ngur-Vapar section:

The 387m thick succession of Barail Group of Ngur-Vapar section comprises of sandstone, shale, silty-shale and their admixtures belonging to Barail Group (Figure 5.5). Very fine to fine grained sandstone, shale and silty-shale lithologies of this section are highly bioturbated and host a variety of trace fossils. A trace fossil assemblage consisting of 24 ichnospecies belonging to 19 ichnogenera have been recovered from these lithologies. (Table 5.3)

The ichnofossil assemblage recorded from this section shows a wide range of behavioural patterns but is dominated by domichnia and fodinichnia followed by cubichnia and repichnia. The fodinichnia signatures are clearly seen in ichnospecies like *Cochlichnus anguineus, Palaeophycus annulatus, Paleophycus striatus, Phycodes curvipalmatum, Planolite beverlyensis, Planolite montanus, Taenidium barretti, Thalassinoides horizontalis* and *Thalassinoides suevicus* while the domichnia features are reflected in *Arenicolite tenuis, Funalichnus bhubani, Gyrolithes mexicanus, Laevicyclus mongraensis, Ophiomorpha annulata, Psilonichnus upsilon, Psilonichnus ichnospecies, Rosselia isp.,* and *Skolithos verticalis.* A few resting traces of *Lockeia siliquaria, Rusophycus carbonarius* and *Rusophycus versan* and crawling tails like *Archaeonassa fossulata, Cruziana* isp. and *Didymaulichnus lyelli* are also present. Presence of *Didymaulichnus* represents the crawling or feeding trail of molluscan origin (Hantzschel, 1975) and commonly occurs in the shallow-marine environments. *Psilonichnus upsilon* suggest backfill marginal marine environment (Frey *et al*. 1984). *Phycodes* are the characteristic trace fossil of the *Cruziana* ichnofacies, mainly related with shallow marine environment (Han and Pickeril, 1994) and nutrient rich deposits (Seilacher 1955; Osgood, 1970; Fillion and Pickeril, 1990). Occurrence of *Planolites* indicate low energy condition, less abrupt shifting of sediments and normal salinity (Fursich and Heinberg, 1983; Patel *et al*., 2012). *Thalassinoides* is a facies-crossing form, most typical of shallow-marine environments (Singh *et al.*, 2010) mainly produced by crustaceans (Frey *et al.*, 1984; Bromley 1996) or other type of arthropods (Ekdale 1992). *Thalassinoides* is usually interpreted as a fodonichnia/domichnia structure, passively filled, but occasionally an agrichnial behavior has also been interpreted for the tracemaker

(Myrow 1995; Bromley 1996; Ekdale and Bromley 2003) frequently related to oxygenated situations and soft but fairly cohesive substrates (Kern and Warme 1974; Ekdale *et al.,* 1984; Bromley 1990)

The ichnospecies of Ngur-Vapar section belong to *Skolithos* and *Cruziana* ichnofacies but mixing of both *Skolithos* and *Cruziana* ichnofacies is also observed. The presence of *Skolithos* ichnofacies suggests the unconsolidated shifting substrate, high energy conditions and drastic changes in the sedimentation rate (Walker and James, 1992; Singh *et al.,* 2008; Tiwari *et al.* 2011) and *Cruziana* ichnofacies indicate deposition under low to moderate energy conditions, unstable and unconsolidated muddy substrate in offshore to transition shoreface environment. Therefore, the behavioural nature and distribution pattern of the ichnofossils as well as sedimentological attributes suggests that Barail succession exposed in Ngur-Vapar section was deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine environment with occasional storm event.

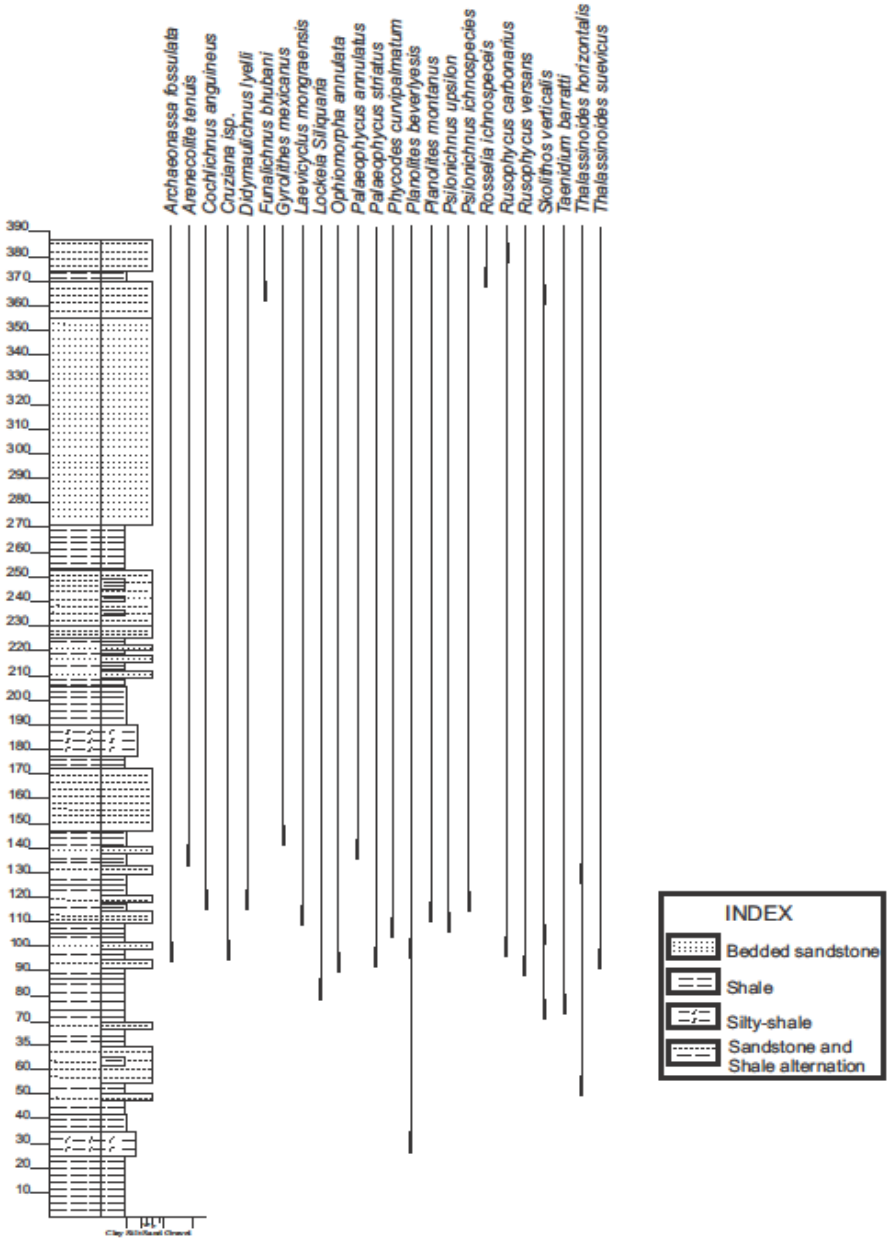


Figure 5.5: Lithocolumn of Ngur – Vapar section

Table 5.3: Morphological, pre-post origin, ethological and facies classification of ichnofossil assemblages from Ngur-Vapar section.

Name of Ichnospecies	**Morphological (Simpson, 1975)**	**Pre-Post origin (Tovar et al.,2010)**	**Ethological (Seilacher,1964)**	**Ichnofacies (Seilacher, 1964,1967)**
Archaeonassa fossulata	Tunnel	Post	Repichnia	*Cruziana*
Arenicolite tenuis	Shaft	Pre	Domichnia	*Skolithos*
Cochlichnus anguineus	Tunnel	Post	Fodinichnia	*Cruziana*
Cruziana isp.	Tunnel	Post	Repichnia	*Cruziana*
Didymaulichnus lyelli	Tunnel	Post	Repichnia	*Cruziana*
Funalichnus bhubani	Shaft	Pre	Domichnia	*Skolithos*
Gyrolithes mexicanus	Shaft	Pre	Domichnia	*Skolithos*
Laevicyclus mongraensis	Shaft	Pre	Domichnia	*Skolithos*
Lockeia siliquaria	Tunnel	Post	Cubichnia	*Cruziana*
Ophiomorpha annulata	Shaft	Pre	Domichnia	*Skolithos/Cruziana*
Palaeophycus annulatus	Tunnel	Post	Fodinichnia	*Cruziana*
Paleophycus striatus	Tunnel	Post	Fodinichnia	*Cruziana*

Phycodes curvipalmatum	Tunnel	Post	Fodinichnia	*Cruziana*
Planolite beverlyensis	Tunnel	Post	Fodinichnia	*Cruziana*
Planolite montanus	Tunnel	Post	Fodinichnia	*Cruziana*
Psilonichnus upsilon	Shaft	Pre	Domichnia	*Skolithos*
Psilonichnus ichnospecies	Shaft	Pre	Domichnia	*Skolithos*
Rosselia isp.	Shaft	Pre	Domichnia	*Skolithos*
Rusophycus carbonarius	Tunnel	Post	Cubichnia	*Cruziana*
Rusophycus versans	Tunnel	Post	Cubichnia	*Cruziana*
Skolithos verticalis	Tunnel	Pre	Domichnia	*Skolithos*
Taenidium barrette	Tunnel	Post	Fodinichnia	*Cruziana*
Thalassinoides horizontalis	Tunnel	Pre	Fodinichnia	*Skolithos/Cruziana*
Thalassinoides suevicus	Tunnel	Pre	Fodinichnia	*Skolithos/Cruziana*

5.2.3.1: DIVERSITY OF TRACE FOSSILS FROM NGUR-VAPAR SECTION:

A total of 24 ichnospecies belonging to 19 ichnogenera have been recovered from this section. A number in diversity classification of Morphologcial, pre-post origin, ethological and ichnofacies of Ngur-Vapar section also present in Fig.5.6.

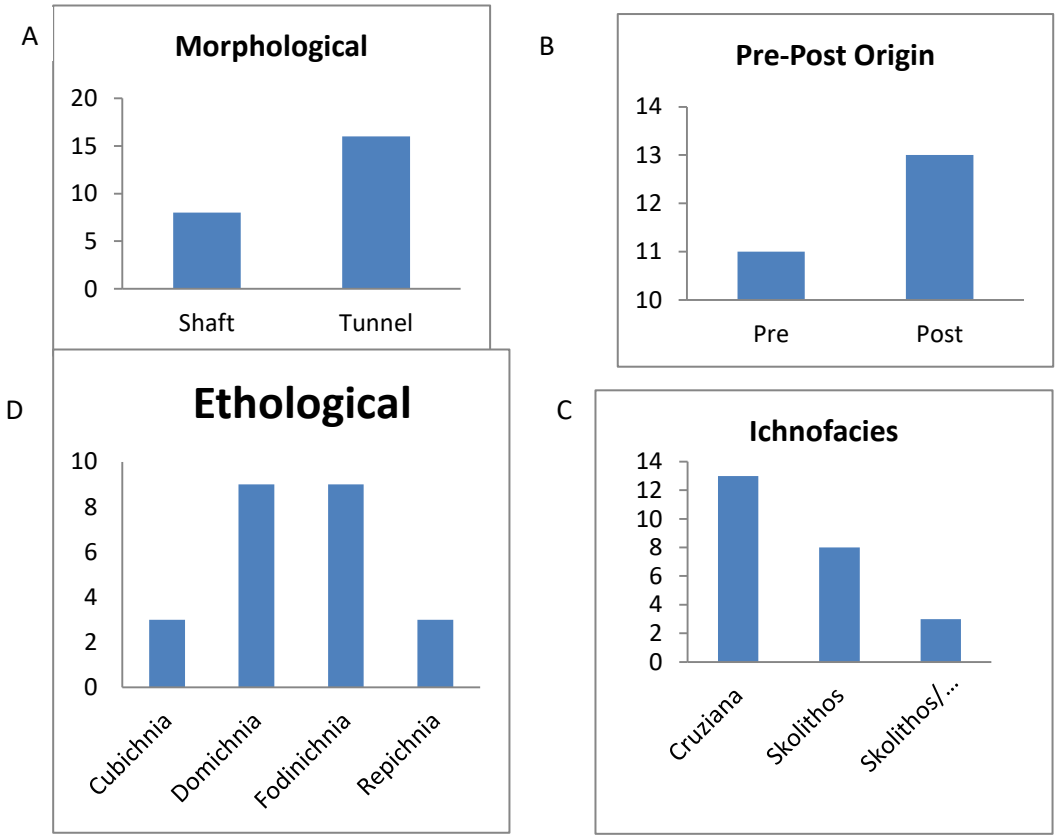
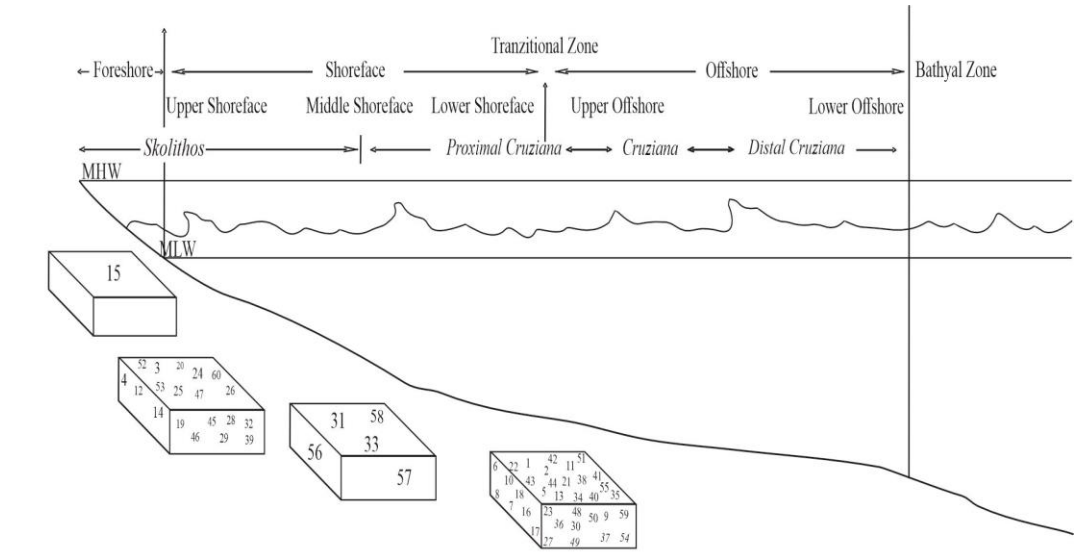


Figure 5.6: The classification of 24 ichnospecies in (A) Morphological (B) Pre and Post origin (C) Ethological and (D) Ichnofacies of Ngur-Vapar section.

5.3 CONCLUSION

The ichnofossils of the Barail Formation are rich in nature. A total of 60 ichnospecies belonging to 39 ichnogenera are identified and classified according to their morphological characters. The reoccur pattern of the ichnofossils assemblages consider the presence of deposit feeding and suspension animals throughout the sequences. Remote occurrence of resting traces reflect change in depositional system. Altogether, the ichnofossils assemblages of the Barail Group belongs to the *Trypanite, Skolithos, Cruziana* and mixed *Skolithos-Cruziana* ichnofacies (Fig.5.7) and shows fluctuating hydrodynamic environment as low current and wave energy conditions (*Skolithos* ichnofacies) and an in-between period of stressful condition. *Cruziana* ichnofacies implies permanently subtidal, poorly sorted and unconsolidated substrates in shallow marine environment with uniform salinity, usually from moderate to low energy conditions, lying below fair-weather wave base but above storm wave base. Therefore it can be concluded that the studied successions of Barail Group of Mizoram were deposited under high energy environments and sandy shifting substrate in foreshore to low energy environment and muddy substrate in shoreface/offshore zone of shallow marine setting with occasional deep water condition and storm event.

Schematic representation of ichnofacies and their depositonal environment is given in Fig.5.7.



Trypanite ichnofacies
15. Gastrochaenolites ornatua.

Skolithos ichnofacies
3. Arenicolite tenuis
4. Arenicolite isp.
12. Cylindrichnus isp..
14. Funalichnus bhubani
19. Gyrolithes lorcaensis
20. Gyrolithes mexicanus
24. Katbergia carltonichnus
25. Laevicyclus mongranensis
26. Lanicodichna medulata
28. Macanopsis paguei
29. Macanopsis isp.
32. Ophiomorpha irregulaire.
39. Pholeus bifurcatus.
45. Psilonichnus tubiformis.
46. Psilonichnus upsilon
47. Psilonichnus isp.
52. Skolithos linearis.
53. Skolithos verticalis.
60. Ichnospecies Type A

Skolithos- Cruziana mixed ichnofacies
31. Ophiomorpha annulata.
33. Ophiomorpha nodosa.
56. Thalassinoides horizontalis
57. Thalassinoides paradoxicus
58. Thalassinoides suevicus

Curziana ichnofacies.
1. Arcaheonassa fossulata
2. Arcaheonassa isp.
5. Asterosoma ichnospecies
6. Avetoichnus luisae
7. Chondrites intricatus
8. Chondrites recurvus
9. Circulichnus isp.
10. Cochlichnus anguineus.
11. Cruziana isp.
13. Didymaulichnus lyelli
16. Glaciichnium liebegastensis
17. Gordia carickensis
18. Gyrochorte comosa
21. Helminthopsis abeli
22. Helminthopsis hieroglyphica
23. Helminthopsis tenuis
27. Lockeia siliquaria
30. Monomorphicnus isp.
34. Palaeophycus annulatus
35. Palaeophycus heberti
36. Palaeophycus striatus
37. Palaeophycus sulcatus
38. Palaeophycus tubularis
40. Phycodes curvipalmatum
41. Planolites beverlyensis
42. Planolites montanus
43. Protovirgularia dichotoma
44. Protovirgularia nuculoidea
49. Rusophycus carbonarius
50. Rusophycus versans
51. Solicia stronzzii
54. Teichichnus spiralis
55. Teichichnus rectus
59. Treptichnus pedum

Figure 5.7: Schematic representation of Ichnofacies and their depositional environment.

CHAPTER-6

CORRELATION

6.1: GENERAL REMARKS

Trace fossils embedded in different lithostratigraphic units have been extensively used for local as well as regional correlation of rock successions. Trace fossils correlation is used to correlate with the depositional environment of different horizons. Correlation of the present succession is attempted in two different ways. One is attempt has been made in terms of depositional environment among various ichnoferous sequence of different sections of the study area and second is correlation of the studied sections with the coeval successions of other areas of Northeast India.

A detailed ichnological study of the Barail Group has been carried out in three sections around Champhai, Mizoram i.e. Mualkawi-Ruantlang section, Zote-Ngur section and Ngur-Vapar section. The lithostratigraphic units which carry these ichnospecies are mainly sandstone, siltstone, silty-shale, shale and their admixtures in varied proportion. Lithological variations and distribution of trace fossils have been discussed in Chapter-3.

A total of 60 ichnospecies belonging to 39 ichnogenera have been collected and described. Among these ichnospecies, 15 ichnospecies are found in more than one section. Six ichnospecies, namely, *Laevicyclus mongraensis, Lockeia siliquaria, Psilonichnus* isp. *Rosselia* isp., *Skolithos verticalis* and *Thalassinoides horizontalis* have been reported from all the three sections. On the basis of depositional envrironment, correlation among these three sections has been attempted to a fare degree of accuracy. Distribution of the described ichnospecies in the three studied sections is shown in table 6.1.

6.2: LOCAL CORRELATION

The correlation of the depositional environment of three studied sections has been attempted based on the identified ichnospecies.

A total of 40 ichnospecies belonging to 29 ichnogenera have been described from Barail Group of Mualkawi-Ruantlang section. These include, *Archaeonassa* ichnospecies, *Arenicolites* isp., *Asterosoma* ichnospecies, *Avetoichnus lusae, Chondrites intricatus, Chondrites recurvus, Circulonichnus* isp., *Coachlichnus anguenus, Cylindrichnus* isp., *Gastrochaenolites ornatus., Funalichnus bhubani, Glaciinium liebegastensis, Gyrochorte comosa, Gordia carickensis, Katbergia carltonichnus, Laevicyclus mongraensis, Lockeia siliquaria, Macanopsis pagueyi, Macanopsis* isp., *Ophiomorpha annulata, Ophiomorpha irregulaire, Ophiomorpha nodosa, Palaeophycus annulatus, Palaeophycus striatus, Palaeophycus tubularis, Pholeus bifurcates, Planolites beverlyensis, Planolites montanus, Protovirgularia dichotoma, Psilonichnus upsilon, Psilonichnus tubiformis, Psilonichnus* isp., *Scolicia stronzzii, Skolithos linearis, Skolithos verticals, Teichichnus spiralis, Thalassinoides horizontalis, Thalassinoides paradoxicus, Thalassinoides suevicus* and Ichnospecies Type A. These ichnoassemblages represent *Trypanite, Skolithos*, *Cruziana* and mixed *Skolithos/Cruziana* ichnofacies. The *Skolithos* ichnofacies is related to relatively high levels of wave or current energy, and is typically developed in clean, well sorted, loose or shifting particulate substrate. Such conditions commonly occur on the shoreface and sheltered foreshore, but similar conditions also occur in a wide range of high-energy shallow water environment. (Mac Eachern *et al*. 2007). The *cruziana* ichnofacies points towards offshore setting with relative nutrient rich, fine grained sediments deposited in low energy environment. *Trypanite* ichnofacies

grades seaward into the *skolithos* then to the *cruziana* (Rajkumar *et al*. 2012). Together these three ichnofacies and distribution of trace fossils suggest that the Barail succession exposed in Mualkawi to Ruantlang section was deposited under fluctuating energy condition within foreshore to shoreface/offshore zones of shallow marine environment with occasional deep water condition.

Twenty-three ichnospecies of 16 ichnogenera have been recovered from Oligocene succession of Barail Group, Zote-Ngur section which include *Arenicolite isp. Gastrochaenolites ornatus, Gyrolithes lorcaensis, Helminthopsis abeli, Helminthopsis hieroglyphica, Helminthopsis tenuis, Laevicyclus mongraensis, Lanicodichna medulata, Lockeia siliquaria, Monomorphichnus* isp., *Ophiomorpha nodosa, Palaeophycus heberti, Palaeophycus sulcatus, Psilonichnus tubiformis, Psilonichnus* isp.. *Skolithos linearis, Skolithos verticalis, Teichichnus rectus, Teichichnus spiralis, Thalassinoides horizontalis, Thalassinoides paradoxicus and Treptichnus pedum.* The ichnotaxa described from the studied succession are typical for the *Trypanite, Skolithos, Cruziana* and mixed *Skolithos-Cruziana* ichnofacies which indicate that the area was deposited under fluctuating energy conditions in intertidal to subtidal zone of shallow marine environment with nutrient rich.

A total of 24 ichnospecies belonging to 19 ichnogenera reported from Barail Group of Ngur-Vapar section. These include *Archaeonassa fossulata, Arenicolite tenuis, Cochlichnus* isp., *Cruziana* isp., *Didymaulichnus lyelli, Funalichnus bhubani, Gyrolithes mexicanus, Laevicyclus mongraensis, Lockeia siliquaria, Ophiomorpha annulata, Palaeophycus annulatus, Palaeophycus striatus, Phycodes curvipalmatum, Planolites beverlyensis, Planolites montanus, Psilonichnus upsilon, Psilonichnus* isp., *Rosselia* isp., *Rusophycus carbonarius, Rusophycus versan, Skolithos verticalis.*

Taenidium satanassi, Thalassinoides horizontalis and *Thalassinoides suevicus.* These ichnoassemblages represent the record of *Skolithos, Cruziana* and *Skolithos/Cruziana* ichnofacies. These ichnofacies together with distribution of trace fossils suggest Barail succession exposed in Ngur-Vapar section was deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine environment.

The rock succession of Barail Group of Mualkawi-Ruantlang, Zote-Ngur and Ngur-Vapar sections were deposited under similar depositional environment and therefore, they can be correlatable.

Table 6.1: Correlation of the Oligocene succession of Barail rocks of the studied sections (P=Present)

Trace fossils	**Localities**		
	Mualkawi-Ruantlang	**Zote-Ngur**	**Ngur-Vapar**
Archaeonassa fossulata			P
Archaeonassa ichnospecies	P		
Arenicolite tenuis			P
Arenicolite ichnospecies	P	p	
Asterosoma ichnospecies	P		
Avetoichnus luisae	P		
Chondrites intricatus	P		
Chondrites recurvus	P		
Circulichnus ichnospecies	P		

Cochlichnus anguineus	P		P
Cruziana isp.			P
Cylindrichnus ichnospecies	P		
Didymaulichnus lyelli			P
Funalichnus bhubani	P		P
Gastrochaenolites ornatus	P	p	
Glaciichnium liebegastensis	P		
Gordia carickensis	P		
Gyrochorte comosa	P		
Gyrolites lorcaensis		p	
Gyrolites mexcanus			P
Helminthopsis abeli		p	
Helminthopsis hieroglyphica		p	
Helminthopsis tenuis		p	
Katbergia carltonichnus	P		
Laevicyclus mongraensis	P	p	P
Lanicodichnas medulata		p	
Lockeia siliquaria	P	p	P
Macanopsis paquei	P		
Macanopsis ichnospecies	P		
Monomorphichnus isp,		p	
Ophiomorpha annulata	P		P
Ophiomorpha irregulaire	P		

Ophiomorpha nodosa	P	p	
Palaeophycus annulatus	P		P
Palaeophycus heberti		p	
Palaeophycus striatus	P		P
Palaeophycus sulcatus		p	
Palaeophycys tubularis	P	P	
Pholeus bifurcatus	P		
Phycodes curvipalmatum			P
Planolites beverlyensis	P		P
Planolites montanus	P		P
Protovirgularia dichcotoma	P		
Psilonichnus tubiformis	P	p	
Psilonichnus upsilon	P		P
Psilonichnus ichnospecies	P	p	P
Rosselia ichnospecies	P	p	P
Rusophycus carbonarius			P
Rusophycus versans			P
Scolicia stronzzii	P		
Slolithos linearis	P	p	
Skolithos verticalis	P	p	P
Taenidium barrette			P
Teichichnus spiralis	P	p	
Teichichnus rectus		p	

Thalasinoides horizontalis	P	p	P
Thalasinoides paradoxicus		p	
Thalasinoides suevicus	P		P
Treptichnus pedum		p	
Ichnospecies Type A	P		

6.3: CORRELATION WITH OLIGOCENE SUCCESSIONS OF NORTH EAST INDIA

Various researchers like Singh *et al.* 2008 and 2010, Kaidem *et al.* 2015, Kichu *et al.* 2018 and Rajkumar *et al.* 2019, reported traces fossils from Oligocene successions from various parts of northeast India. Therefore, correlation of depositional environment of the studied sections has been attempted with the rock successions of these areas.

6.3.1: Upper Eocene- Lower Oligocene deposits of Disang and Barail Group, Manipur, Indo- Myanmar Ranges.

Singh *et al.* (2008) described 8 ichnospeices like *Arenicolite ichnospecies, Helminthopsis tenuis, Ophiomorpha nodosa, Phycodes palmatum, Planolites montanus, Rhizocorallium jenense, Thalassinodes paradoxicus* and *Skolithos linearis* from Disang and Barail Group, Manipur. These ichno-assemblage represents the record of classical *Skolithos* and / or *Cruziana* ichnofacies. These ichnofacies broadly suggest that the sediments of Disang and Barail Group were deposited in shallow-marine environment, with occasional high-energy conditions. In the present study area, *Ophiomorpha nodosa, Skolithos linearis* and *Thalassinodes paradoxicus* are reported from Mualkawi-Ruantlang Section and Zote – Ngur section. *Planolites*

montanus is described from Mualkawi-Ruantlang and Ngut- Vapar Sections. In Mualkawi – Ruantlang Section *Arenicolites* ichnospecies is also observe. Therefore, in terms of broad depositional envrionement all the three sections of the study area are correlatable with the Disang and Barail Group (Upper Eocene-Lower Oligocene)

6.3.2: Oligocene-Miocene deposits of Bhuban and Boka Bil Formation, Manipur.

Singh *et al.* (2010) described 15 ichnospecies from Oligocene- Miocene deposits of Bhuban and Boka Bil Formations, Surma Group, Manipur. These ichnospecies have been further categorized into *Skolithos, Cruziana* and *Skolithos/Cruziana* ichnofacies. From the overall distribution pattern and behavioural nature of the ichnoassemblage and sedimentological attributes in the present study area, it has been suggested by them that the sediments of Bhuban and Boka Bil Formations were deposited under frequent changing sea level, moderate to strong energy condition, subtidal to lower intertidal environment, rich in organic nutrients. Mualkawi – Ruantlang section comprises 5 ichnospecies which were described by Singh *et al.* (2010). These are *Gyrochorte comosa, Opiomorpha nodosa, Palaeophycus tubularis, Planolites beverlyensis* and *Psilonichnus upsilon*. These ichnofossils are typical members of *Skolithos* and *Cruziana* ichnofacies. Two ichnospecies found in Zote-Ngur section have also been described by Singh *et al.* (2010) from the Bhuban and Boka Bil Formation of Manipur i.*e Lockeia siliquaria* and *Opiomorpha nodosa*. One ichnospecies, *Planolites beverlyensis,* found from Ngur – Vapar Section is also found in Bhuban and Boka Bil Formation, Manipur. Therefore, Oligocene – Miocene deposits of Manipur is broadly correlatable with the Barail Group of the study area.

6.3.3: Laisong flysch sediments, Manipur

33 ichnognera have been described by Khaidem *et al.* (2015) from Laisong flysch sediments of Disang and Barail Group, Manipur. The ichnospecies have been identified into different ichnofacies such as *Teredolites ichnofacies, Skolithos ichnofacies. Cruziana ichnofacies, Zoophycos* and *Nereites* ichnofacies. With the ichno-asseblage and sedimentary structures observed, they suggested that the Laisong sediments were formed in a tectonically active basin with varied bathymetric ranges indicating alternating transgression and regression nature. Among 36 ichnospecies belonging to 33 ichnogenera from Laisong sediments of Manipur, 5 ichnospecies namely, *Circulonichnus ichnospecies, Gyrochorte comosa, Opiomorpha nodosa* and *Skolithos linearis* are also recovered from Mualkawi-Ruantlang Section. And also *Helminthopsis tenuis, Ophiomorpha nodosa* and *Skolithos linearis* are found in the study area i.e Zote-Ngur section suggesting that the present study area and Laisong flysch sediments are broadly correlatable. Therefore, in terms of broad depositional environment Mualkawi-Ruantlang section and Zote-Ngur section of the study area are correlatable with the Disang and Barail Group (Upper Eocene-Lower Oligocene)

6.3.4: Oligocene, Barail sediment of Nagaland

Kichu *et al*. (2018) described 6 ichnospecies such as *Chondrites ichnospecies, Gyrochorte comosa, Ophiomorpha nodosa, Skolithos linearis, Planolites ichnospecies* and *Thalassinoides horizontalis*. The ichnospecies belong to either *Skolithos* or *Cruziana* ichnofacies. From the analysis of lithofacies identified suggested that the Oligocene, Barail sediments of Nagaland were deposited in shallow marine environment with fluctuating sea levels and energy within

tectonically unstable conditions. And also by the distribution pattern of the ichnofacies Kichu *et al.* (2018) suggests that the sediments of the study area were deposited under frequently fluctuating sea, having moderate to strong energy levels, within shoreface environment rich in nutrients. In the present study area i.e Mualkawi-Ruantlang section, Zote-Ngur section and Ngur- Vapar section ichnospecies of *Ophiomorpha nodosa, Skolithos linearis* and *Thalassinoides horizontalis* are also observed. All the three sections of the study area comprises *Thalassinoides horizontalis. Gyrochorte comosa* is also found in Mualkawi-Ruantlang section. Therefore, the depositional environment of the Barail Group in Mualkawi-Ruantlang, Zote-Ngur and Ngur–Vapar sections can be broadly correlatable with the shallow marine depositional environment of the Barail sediments of Nagaland.

6.3.5: Late Eocene to Early Oligocene, Upper Disang Formation and Lower Barail Formation of Nagaland

Rajkumar *et al.* 2019 reported *Bergaveria, Gyrochorte comosa, Ophiomorpha nodosa, Skolithos linearis, Thalassinoides paradoxicus. Curvolithus vertebralis, Treptichnus pedum, Taenidium diesingi, Palaeophycus tubularis, Chondrites targionii* and Paleomeandron elegans and further subdivided into *Skolithos, Cruziana* and *Nereites ichnofacies*. Five ichnospecies such as *Gyrochorte comosa, Ophiomorpha nodosa, Skolithos linearis, Thalassinoides paradoxicus and Palaeophycus tubularis* are also found in Mualkawi-Ruantlang section. Zote-Ngur section comprises ichnospecies of *Skolithos linearis, Thalassinoides paradoxicus* and *Treptichnus pedum*. Therefore, Upper Disang Formation and Lower Barail

Formation of Nagaland can be broadly correlatable to Mualkawi-Ruantlang and Zote-Ngur sections of the study area.

Spatial distribution of the ichnospecies from the study area in the Oligocene successions of Northeastern India is given in table 6.2.

Table 6.2: Section wise correlation of trace fossils of the present study with the Oligocene successions of other area of Northeast India (P=Present).

Mualkawi - Ruantlang	Upper Eocene -Lower Oligocene Transition of Manipur. Singh *et al*. 2008	Bhuban and Boka Bil Formation of Manipur. Singh *et al*. 2010	Laisong flysch sediments Manipur. Khaidem *et al.* 2015	Barail Sediment, Nagaland. Kichu *et al.* 2018	Upper Disang Formation Nagaland. Rajkumar *et al.* 2019
Archaeonassa isp.			P		
Arenicolites isp.	P				
Asterosoma isp.					
Aveitoichnus lusae					
Chondrites intricatus					
Chondrites recurvus					
Circulichnus isp.			P		
Cochlichnus anguineus					

Cylindrichnus isp.					
Funalichnus bhubani					
Gastrochaenolite ornatus					
Glaciinium Liebegastensis					
Gyrochorte comosa		P	P	P	P
Gordia carichkensis					
Katbergia carltonichnus					
Laevicyclus mongraensis					
Lockeia siliquaria					
Macanopsis pagueyi					
Macanopsis isp.					
Ophiomorpha annulata					
Ophiomorpha irregulaire					
Ophiomorpha nodosa	P	P	P	P	P
Palaeophycua annulatus					
Palaeophycua striatus					
Palaeophycys tubularis		P			P
Pholeus bifurcates					
Planolites beverlyensis		P			
Planolites montanus	P				
Protovirgularia dichcotoma					
Psilonichnus upsilon		P			
Psilonichnus tubiformis					

Psilonichnus isp.					
Rosselia isp.					
Scolicia stonzzii					
Skolithos linearis	P		P	P	P
Skolithos verticalis					
Teichichnus spiralis					
Thalassionoides horizontalis				P	
Thalasinoides suevicus					
Ichnospecies Type A					
Zote- Ngur Section					
Arenicolites isp.	P				
Gastrochaenolite ornatus					
Gyrolithes Lorcaensis					
Helminthospis abeli					
Helminthosis Hieroglyphica					
Helminthosis Tenuis	P		P		
Laecicyclus mongraensis					
Lanicodichna medulata					
Lockeia siliguaria		P			
Monomorphichnus isp.					
Ophiomorpha nodosa	P	P	P	P	
Palaeophycys heberti					

Palaeophycus sulcatus					
Psilonichnus tubiformis					
Psilonichnus isp.					
Rosselia isp.					
Skolithos linearis	P		P	P	P
Skolithos verticalis					
Teichichnus spiralis					
Teichichnus rectus					
Thalassinoides horizontalis				P	
Thalassinoides paradoxicus	P				P
Treptichnus pedum					P
Ngur- Vapar Section					
Archaeonassa fossulata					
Arenicolites tenuis					
Cochlichnus anguineus					
Cruziana ichnospecies					
Didymauchlichnus isp.					
Funalichnus bhubani					
Gyrolithes mexicanus					
Laevicyclus mongraensis					
Lockeia siliquaria					
Ophiomorpha annulata					
Palaeophycus annulatus					

Palaeophycus striatus					
Phycodes curvipalmatum					
Planolites beverlyensis		P			
Planolites montanus	P				
Psilonichnus upsilon					
Psilonichnus isp.					
Rosselia isp.					
Rusophycus carbonarius					
Rusophucus versans					
Skolithos verticalis					
Taenidium barratti					
Thalassinoides horizontalis				P	
Thalassinoides suevicus					

CHAPTER-7

SUMMARY AND CONCLUSIONS

1. The Barail Group is well exposed in Champhai district of Mizoram, India. This group is about 3000m (Ganju, 1975; Tiwari and Kachhara, 2003). The present study has been conducted in Oligocene successions of Barail Group exposed along three sections namely, Mualkawi-Ruantlang section, Zote-Ngur section and Ngur-Vapar section.

2. The main lithologies in the study areas are Sandstone, Siltstone, Shale and their admixture in various proportions. A 480 m thick succession exposed in Mualkawi-Ruantlang section, 119 m thick successions along Zote-Ngur section and 387m thick successions of Oligocene, Barail Group of Ngur- Vapar section has been measured to performed ichnological studies. Trace fossils mainly found in Sandstone, Shale and Siltstone and silty-shale.

3. A total of 60 ichnospecies of 39 ichnogenera have been described from the collection and photographed. Out of these ichnospecies, 1 ichnospeices could not be identified upto generic level due to poor preservation and less number of species. The remaining 59 ichnospecies were described.

4. The following 59 ichnospecies are being reported for the first time from Oligocene succession of Mizoram.

Archaeonassa fossulata, Archaeonassa ichnospecies, *Arenicolites tenuis, Arenicolites* isp., *Asterosoma* ichnospecies, *Avetoichnus luisae, Chondrites intricatus, Chondrites recurvus, Circulonichnus* isp., *Cochlichnus anguineus, Cylindrichnus* isp., *Cruziana* isp., *Didymaulichnus lyelli, Funalichnus bhubani,*

Gastrochaenolites ornatus, Glaciichnium liebegastensis, Gordia carickensis, Gyrochorte comosa, Gyrolithes lorcaensis, Gyrolithes mexicanus, Helminthopsis abeli, Helminthopsis hieroglyphica, Helminthopsis tenuis, Katbergia carltonichnus, Lanicodichna medulata, Lockeia siliquaria, Macanopsis pagueyi, Macanopsis isp., *Monomorphichnus* isp., *Ophiomorpha annulata, Ophiomorpha irregulaire, Ophiomorpha nodosa, Palaeophycus annulatus, Palaeophycus heberti, Palaeophycus sulcatus, Palaeophycus striatus, Palaeophycus tubularis, Pholeus bifurcates, Phycodes curvipalmatum, Planolites beverlyensis, Planolites montanus, Protovirgularia dichotoma, Psilonichnus upsilon, Psilonichnus tubiformis, Psilonichnus* isp., *Rosselia* isp., *Rusophycus carbonarius, Rusophycus versan, Scolicia stronzzii, Skolithos linearis, Skolithos verticalis. Taenidium barretti, Teichichnus recturs, Teichichnus spiralis, Thalassinoides horizontalis, Thalassinoides paradoxicus, Thalassinoides suevicus and Treptichnus pedum.*

5. The following 42 chnospecies are being reported for the first time from the Oligocene of Northeast India:

Archaeonassa fossulata, Arenicolite tenuis. Asterosoma isp., *Avetoichnus luisae, Chondrites intricatus, Chondrites recurvus, Cochlichnus anguineus, Cruziana* isp., *Cylindrichnus* isp., *Didymaulichnus lyelli, Funalichnus bhubani, Gastrochaenolites ornatus, Glaciichnium liebegastensis, Gordia carickensis, Gyrochorte comosa, Gyrolithes lorcaensis, Gyrolithes mexicanus, Helminthopsis abeli, Helminthopsis hieroglyphica, Katbergia carltonichnus, Lanicodichnus medulata, Laevicyclus mongraensis. Lockeia siliquaria, Macanopsis paguei, Macanopsis* ichnospecies, *Monomorphichnus* isp., *Ophiomorpha annulata, Ophiomorpha irregulairre, Palaeophycus annulatus, Palaeophycus heberti,*

Palaeophycus striatus, Palaeophycus sulcatus, Pholeus bifurcates, Protovirgularia dichotoma, Psilonichnus tubiformis, Psilonichnus isp., *Rosselia* isp., *Rusophycus carbonarius, Rusophycus versans, Scolicia stronzzii, Taenidium baratti, Teichichnus rectus, Teichichnus spiralis* and *Thalassinoides suevicus.*

6. All the identified ichnofossils belong to *Trypanite, Skolithos, Cruziana* and mixed *Skolithos/ Cruziana* ichnofacies. Ethologically, the assemblage is widely distributed, reflect mostly Domichnia and Fodichnia followed by Repichnia, Pascichnia, Cubichnia and Agrichnia.

7. A total of 40 ichnospecies belonging to 29 ichnogenera have been described from Barail Group of Mualkawi-Ruantlang section. These include, *Archaeonassa* ichnospecies, *Arenicolites* isp., *Asterosoma* ichnospecies, *Avetoichnus lusae, Chondrites intricatus, Chondrites recurvus, Circulonichnus* isp., *Cochlichnus anguineus, Cylindrichnus* isp., *Gastrochaenolites ornatus, Funalichnus bhubani, Glaciinium liebegastensis, Gyrochorte comosa, Gordia carickensis, Katbergia carltonichnus, Laevicyclus mongraensis, Lockeia siliquaria, Macanopsis pagueyi, Macanopsis* isp., *Ophiomorpha annulata, Ophiomorpha irregulaire, Ophiomorpha nodosa, Palaeophycus annulatus, Palaeophycus striatus, Palaeophycus tubularis, Pholeus bifurcates, Planolites beverlyensis, Planolites montanus, Protovirgularia dichotoma, Psilonichnus upsilon, Psilonichnus tubiformis, Psilonichnus* isp., *Rosselia isp., Scolicia stronzzii, Skolithos linearis, Skolithos verticals, Teichichnus spiralis, Thalassinoides horizontali, Thalassinoides suevicus* and Ichnospecies Type A. These ichnoassemblage represent *Trypanite, Skolithos, Cruziana* and *Skolithos/Cruziana* mixed ichnofacies. Ichnogenus *Gastrochaenolites* represents the *Trypanites* ichnofacies. *Skolithos* ichnofacies is represented by ichnofossils like

Arenicolite isp., *Cylindrichnus isp., Funalichnus bhunani Katbergia carltonichnus, Laevicyclus mongraensis, Macanopsis pagueyi, Macanopsis* isp., *Ophiomorpha irregulairre, Psilonichnus upsilon, Psilonichnus tubiformis, Psilonichnus* isp., *Skolithos linearis* and *Skolithos verticalis whereas, Archaeonassa* isp., *Asterosoma* isp., *Avetoichnus luisae, Chondrites intricatus, Circulonichnus* isp., *Coachlichnus anguineus, Glaciinium liebegastensis, Gyrochorte comosa, Gordia carickensis, Lockeia siliquaria, Palaeophycus annulatus, Palaeophycus striatus, Palaeophycus tubularis, Planolites beverlyensis, Planolites montanus, Protovirgularia dichotoma. Protovirgularia nuculoidae, Scolicia stronzzii, Teichichnus spiralis and* Ichnospecies Type A belongs to *Cruziana* ichnofacies. Mixed *Skolithos/Cruziana* ichnofacies is represented by *Ophiomorpha annulata, O.nodosa, Pholeus bifurcatus, Thalassinoides horizontalis, T.paradoxicus* and *T.suevicus*. Ethologically, the ichnoassemblages belongs to Agrichnia, Cubichnia, Domichnia, Fodinichnia, Paschichnia and Repichnia. Domichnian signature is present in *Arenicolite* isp., *Cylindrichnus* isp., *Gastrochaenolites ornatus, Funalichnus bhubani, Katbergia carltonichnus, Laevicyclus mongraensis, Macanopsis pagueyi, Macanopsis* isp., *Ophiomorpha annulata, O. irregulairre, O.nodosa, Psilonichnus upsilon, Psilonichnus tubiformis, Psilonichnus* isp., *Skolithos linearis, Skolithos verticalis,* Fodichnian in *Asterosoma* isp., *Chondrites intricatus, Chondrites recurvus, Cochlichnus anguineus, Palaeophycus annulatus, P.striatus, P.tubularis, Pholeus bifurcates, Planolites montanus, Teichichnus spiralis, Thalassinoides horizontalis, T.paradoxicus and T.suevicus,* Repichnian in *Archaeonassa* isp., *Glaciinium liebegastensis, Gyrochorte comosa, Protovirgularia dichotoma, Protovirgularia*

nuculoidea and Scolicia stronzzii , Cubichnian *in Lockeia siliquaria,* Paschichnia in *Circulichnus* isp. and *Gordia carickensis* and agrichnion in *Avetoichnus luisae.*

Skolithos ichnofacies is related to relatively high level of wave or current energy and typically develop in clean, well sorted, loose or shifting particulate substates. Such conditions commonly occur on the shoreface and sheltered foreshore, but similar conditions also occur in wide range of high energy shallow water environment (Mac Eachern *et al.* 2007). The *Cruziana* ichnofacies implies offshore setting with relative nutrient rich, poorly sorted, unconsolidated (muddy) substrates deposited in low energy environment having uniform salinity. The *Trypanite* grades seaward into the *Skolithos* then to the *Cruziana* ichnofacies. Together these three ichnofacies indicate sandy shifting substrate and high energy conditions in foreshore to poorly sorted, unconsolidated soft substates and low energy condition in shoreface/offshore zone of shallow marine environment with occasional deep water condition for the deposition of the succession exposed in Mualkawi-Ruantlang section.

8. Twenty-three ichnospecies of 16 ichnogenera have been recovered from Oligocene succession of Barail Group, Zote-Ngur section which include *Arenicolite* isp. *Gastrochaenolites ornatus, Gyrolithes lorcaensis, Helminthopsis abeli, Helminthopsis hieroglyphica, Helminthopsis tenu is, Laevicyclus mongraensis, Lanicodichna medulata, Lockeia siliquaria, Monomorphichnus* isp., *Ophiomorpha nodosa, Palaeophycus heberti, Palaeophycus sulcatus, Psilonichnus tubiformis, Psilonichnus* isp.. *Skolithos linearis, Skolithos verticalis, Teichichnus rectus, Teichichnus spiralis, Thalassinoides horizontalis, Thalassinoides paradoxicus and Treptichnus pedum.* The ichnotaxa described from the studied succession are typical

for the *Trypanite*, *Skolithos*, *Cruziana* and mixed *Skolithos-Cruziana* ichnofacies. Occurrence of mixed assemblage of *Ophiomorpha nodosa*, *Thalassinoides horizontalis* and *Thalassinoides paradoxicus* possibly imply a mixed *Skolithos-Cruziana* ichnofacies, *Gastrochaenolites ornatus* represent Trypanite ichnofacies; *Arenicolite* isp., *Gyrolith lorcaensis*, *Laevicyclus mongraensis*, *Lanicodichna medulata*, *Psilonichnus tubiformis*, *Psilonichnus* isp., *Rosselia* isp., *Skolithos linearis* and *Skolithos verticalis* represent the *Skolithos* ichnofacies. Occurrence of *Helminthopsis abeli*, *H.hieroglyphica*, *H.tenuis*, *Lockeia siliquaria*, *Monomorphichnus* isp., *Palaeophycus heberti*, *P.sulcatus*, *Teichichnus rectus*, *T.spiralis* and *Treptichnus pedum* imply *Cruziana* ichnofacies.

The *Trypanite*, *Skolithos* and *Cruziana* ichnofacies, developed in Barail Group in Zote-Ngur section indicates a sub-tidal to intertidal zone of shallow marine setting.

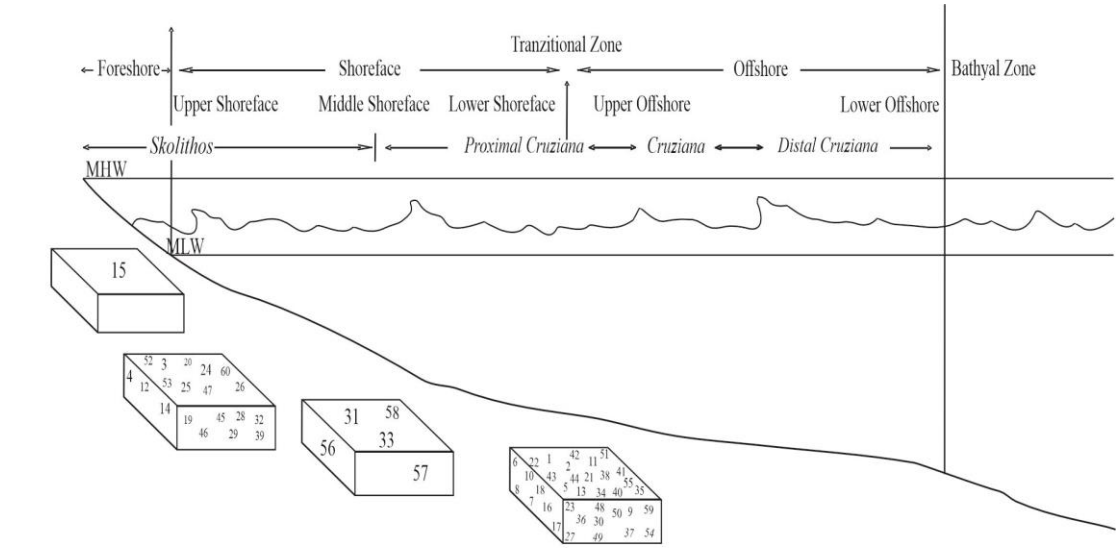
9. A total of 24 ichnospecies belonging to 19 ichnogenera reported from Barail Group of Ngur-Vapar section. These include *Archaeonassa fossulata*, *Arenicolite tenuis*, *Cochlichnus* isp., *Cruziana* isp., *Didymaulichnus lyelli*, *Funalichnus bhubani*, *Gyrolithes mexicanus*, *Laevicyclus mongraensis*, *Lockeia siliquaria*, *Ophiomorpha annulata*, *Palaeophycus annulatus*, *Palaeophycus striatus*, *Phycodes curvipalmatum*, *Planolites beverlyensis*, *Planolites montanus*, *Psilonichnus upsilon*, *Psilonichnus* isp., *Rosselia* isp., *Rusophycus carbonarius*, *Rusophycus versan*, *Skolithos verticalis. Taenidium barretti*, *Thalassinoides horizontalis* and *Thalassinoides suevicus.* These ichnoassemblages represent the record of *Skolithos*, *Cruziana* isp. and mixed *Skolithos-Cruziana* ichnofacies. *Skolithos* ichnofacies is represented by *Arenicolite tenuis*, *Funalichnus bhubani*, *Gyrolithes mexicanus*,

Laevicyclus mongraensis, Psilonichnus upsilon, Psilonichnus isp., *Rosselia* isp. and *Skolithos verticalis* while *cruziana* ichnofacies is represented by *Archaeonassa fossulata, Cochlichnus anguineus. Cruziana problematica, Didtmaulichnus lyelli, Lockeia siliquaria, Palaeophycus annulatus, P.striatus, Phycodes curvipalmatum, Planolites beverlyensis, P.montanus, Rusophycus carbonarius, R.versans and Taenidium barrette* whereas *Ophiomorpha annulata, Thalassinoides horizontalis* and *T.suevicus* imply a mixed *Skolithos-Cruziana* ichnofacies.

Thus, Ngur-Vapar section was deposited under fluctuating energy condition, foreshore to offshore zones of shallow marine environment with occasional storm event.

10. Overall, *Trypanite, 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 mid period of stressful environment. Thus, it can be worked out that the studied successions of Barail Group of Mizoram were deposited under high energy condition and sandy shifting substrate in foreshore to low energy condition and poorly sorted, unconsolidated substrate in shoreface/offshore zone of shallow marine setting with occasion deep water condition and storm event.

11. Out of 60 ichnospecies, 15 ichnospecies are found in more than one section. Six ichnospecies, namely, *Laevicyclus mongraensis, Lockeia siliquaria, Psilonichnus* isp., *Rosselia* isp., *Skolithos verticalis* and *Thalassinoides horizontalis* have been reported from all the three sections. Correlation among the three studied sections has been attempted.



Trypanite ichnofacies
15. Gastrochaenolites ornatua.

Skolithos ichnofacies
3. Arenicolite tenuis
4. Arenicolite isp.
12. Cylindrichnus isp..
14. Funalichnus bhubani
19. Gyrolithes lorcaensis
20. Gyrolithes mexicanus
24. Katbergia carltonichnus
25. Laevicyclus mongranensis
26. Lanicodichna medulata
28. Macanopsis paguei
29. Macanopsis isp.
32. Ophiomorpha irregulaire.
39. Pholeus bifurcatus.
45. Psilonichnus tubiformis.
46. Psilonichnus upsilon
47. Psilonichnus isp.
52. Skolithos linearis.
53. Skolithos verticalis.
60. Ichnospecies Type A

Skolithos- Cruziana mixed ichnofacies
31. Ophiomorpha annulata.
33. Ophiomorpha nodosa.
56. Thalassinoides horizontalis
57. Thalassinoides paradoxicus
58. Thalassinoides suevicus

Curziana ichnofacies.
1. Arcaheonassa fossulata
2. Arcaheonassa isp.
5. Asterosoma ichnospecies
6. Avetoichnus luisae
7. Chondrites intricatus
8. Chondrites recurvus
9. Circulichnus isp.
10. Cochlichnus anguineus.
11. Cruziana isp.
13. Didymaulichnus lyelli
16. Glaciichnium liebegastensis
17. Gordia carickensis
18. Gyrochorte comosa
21. Helminthopsis abeli
22. Helminthopsis hieroglyphica
23. Helminthopsis tenuis
27. Lockeia siliquaria
30. Monomorphicnus isp.
34. Palaeophycus annulatus
35. Palaeophycus heberti
36. Palaeophycus striatus
37. Palaeophycus sulcatus
38. Palaeophycus tubularis
40. Phycodes curvipalmatum
41. Planolites beverlyensis
42. Planolites montanus
43. Protovirgularia dichotoma
44. Protovirgularia nuculoidea
49. Rusophycus carbonarius
50. Rusophycus versans
51. Solicia stronzzii
54. Teichichnus spiralis
55. Teichichnus rectus
59. Treptichnus pedum

Figure 7.1: Schematic representation of ichnofacies and their depositional environment.

12. As discussed earlier, Oligocene, Barail Group of Mualkawi-Ruantlang section was inferred to have been deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine environment with occasional deep water event. Barail Group along Zote-Ngur section has been assigned to subtidal to intertidal zones of shallow-marine environment. Barail Group of Ngur-Vapar section was interpreted as to have been deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine settings with occasional storm event.

Therefore, the rock successions of Barail Group of Mualkawi-Ruantlang, Zote-Ngur and Ngur–Vapar sections were deposited under similar depositional set-up and as such these rock successions are correlatable.

13. Correlation of depositional environment of the studied sections has been attempted with the Oligocene successions of other parts of North East India. Singh *et al*. (2008) suggested that the Upper Eocene-Lower Oligocene Transition of the Manipur was deposited shallow marine environment, with occasional high energy condition. The Barail successions in the studied sections may be broadly correlatable with the Upper Eocene-Lower Oligocene Transition of Manipur. Singh *et al*. (2010) suggested that the Bhuban and Boka Bil Formations in Manipur were deposited under frequent fluctuating sea level, moderate to strong energy condition, subtidal to lower intertidal environment rich in organic nutrients. All the three sections of the study area are broadly correlatable with the Boka Bil Formation in Manipur in terms of depositonal condition. Khaidem *et al*. (2015) suggested that Laisong Flysch sediments in Manipur was deposited under fluctuation in the basin depth that is shallower and deepening. Thus, it can be broadly correlatable with the deposition of

Barail Group of Mualkawi –Ruantlang section and Zote-Ngur section. The Barail successions in the studied sections are also inferred to be deposited in a similar depositonal set-up and thereby correlatable with Oligocene Barail sediment in and around Jotsoma, Kohima, Nagaland. Kichu *et al*. (2018) suggested that the sediments of the study area were deposited under frequently fluctuating sea, having moderate to strong energy levels, within shoreface environment rich in nutrients. Thus, it can be correlatable with the depositon of Barail Group in the studied sections. Rajkumar *et al*. (2019) suggested a foreshore-shoreface/offshore setting of the deposition for the Upper Disang formation and Lower Barail Formation of Nagaland, which is broadly correlatable with Mualkawi-Ruantlang section and Zote-Ngur section.

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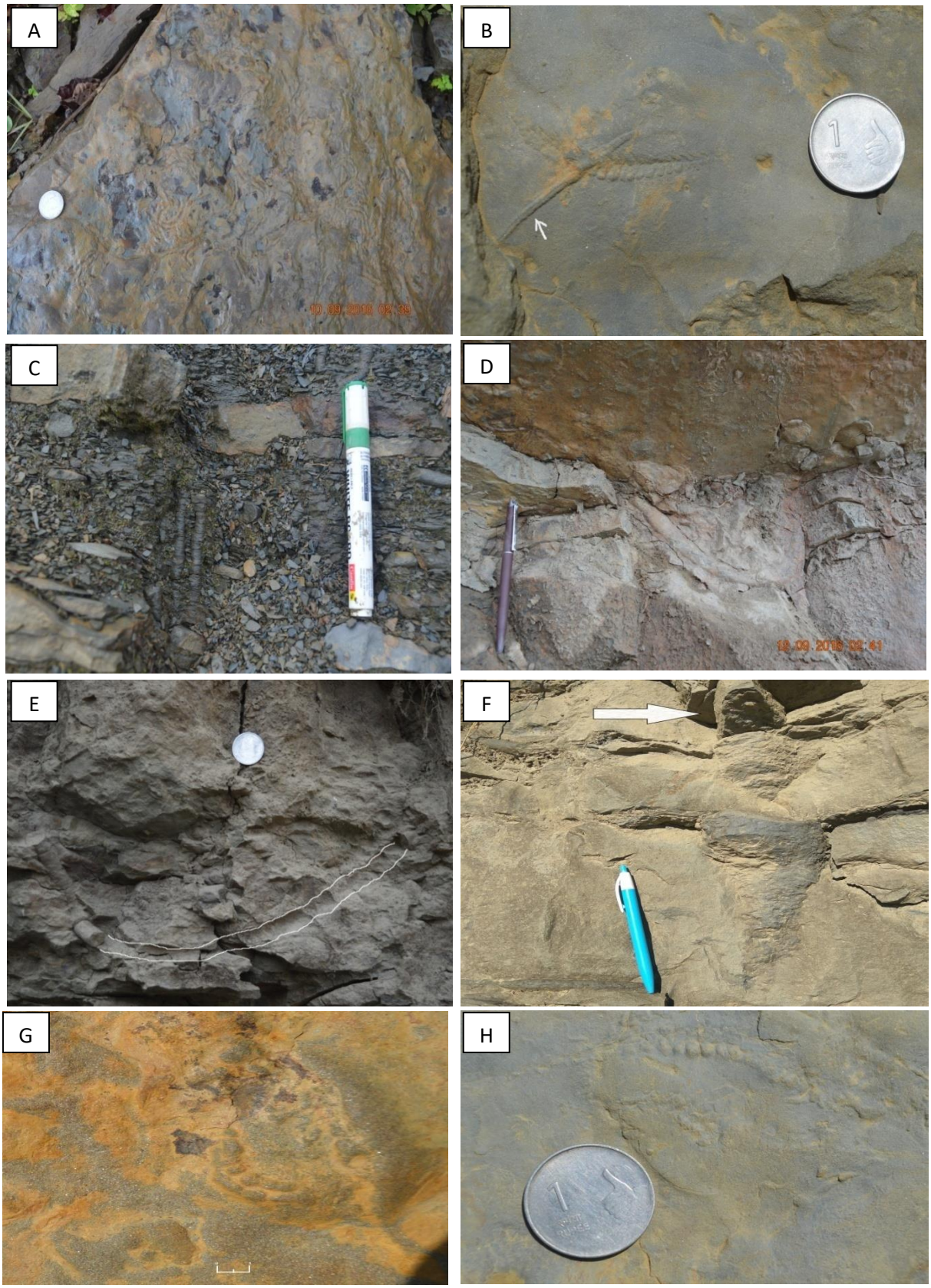
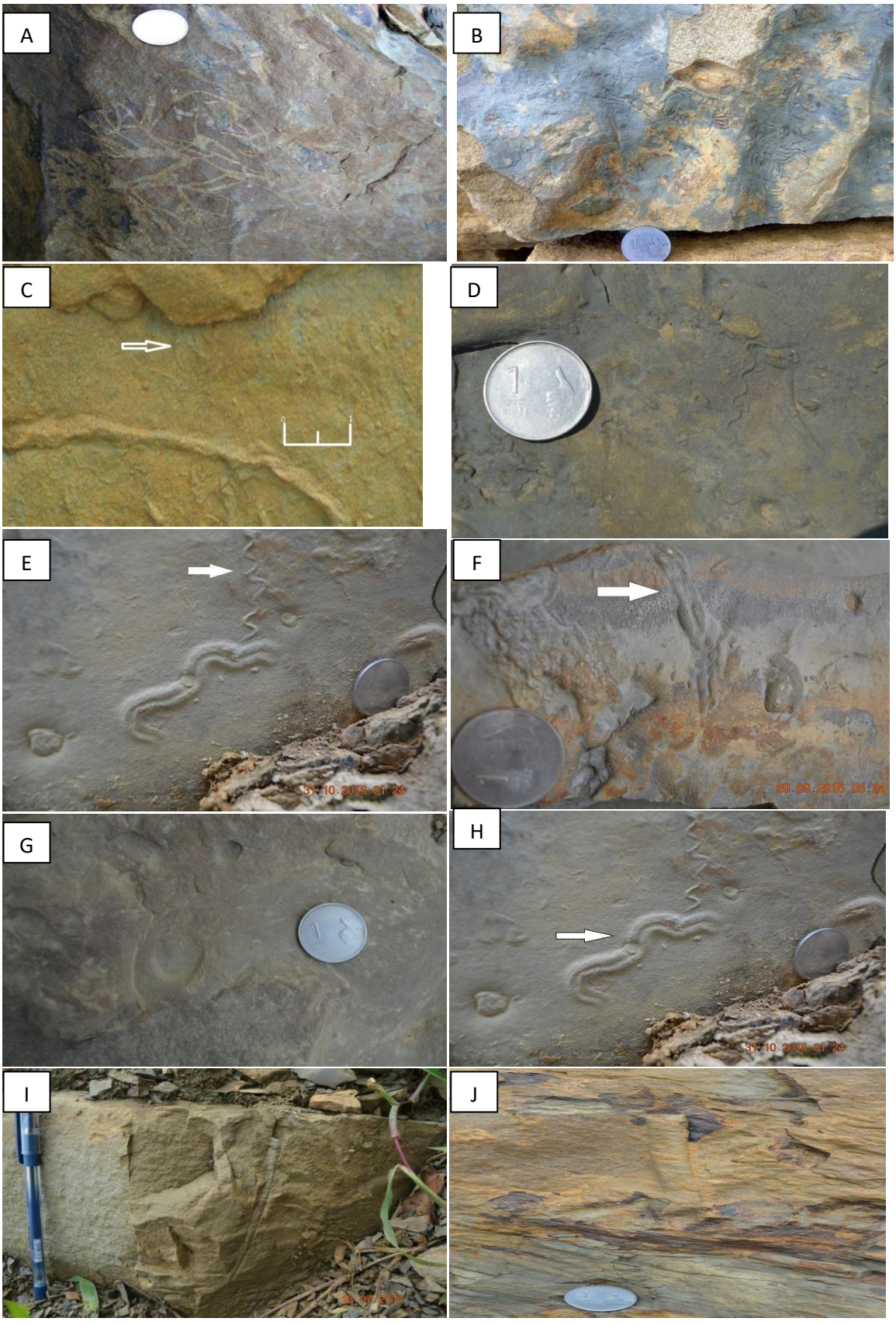
PLATE I



EXPLANATION OF PLATE-1

Figure No.	Explanation	Page No.
A	*Archaeonassa fossulata* Fenton and Fenton (1937), Bed no. 6; 30-23v Ngur to Vapar section, Barail Group	37-38
B	*Archaeonassa* isp., Bed no.6; Mualkawi-Ruantlang section, Barail Group.	38-39
C	*Arenicolite tenuis* Kulkarni, Borkar and Petare (2008), Bed no.8 Ngur-Vapar section, Barail Group	40-41
D & E	*Arenicolite* isp., Bed no.18 in Mualkawi-Ruantlang Section and Bed no. 6 in Zote –Ngur section	41-42
F	*Asterosoma* isp. , Bed no. 55; Mualkawi- Vapar section, Barail Group	42-43
G & H	*Avetoichnus luisae* Uchman & Rattazzi (2011) Bed no.3 and 5 in Mualkawi-Vapar section, Barail Group	43-44

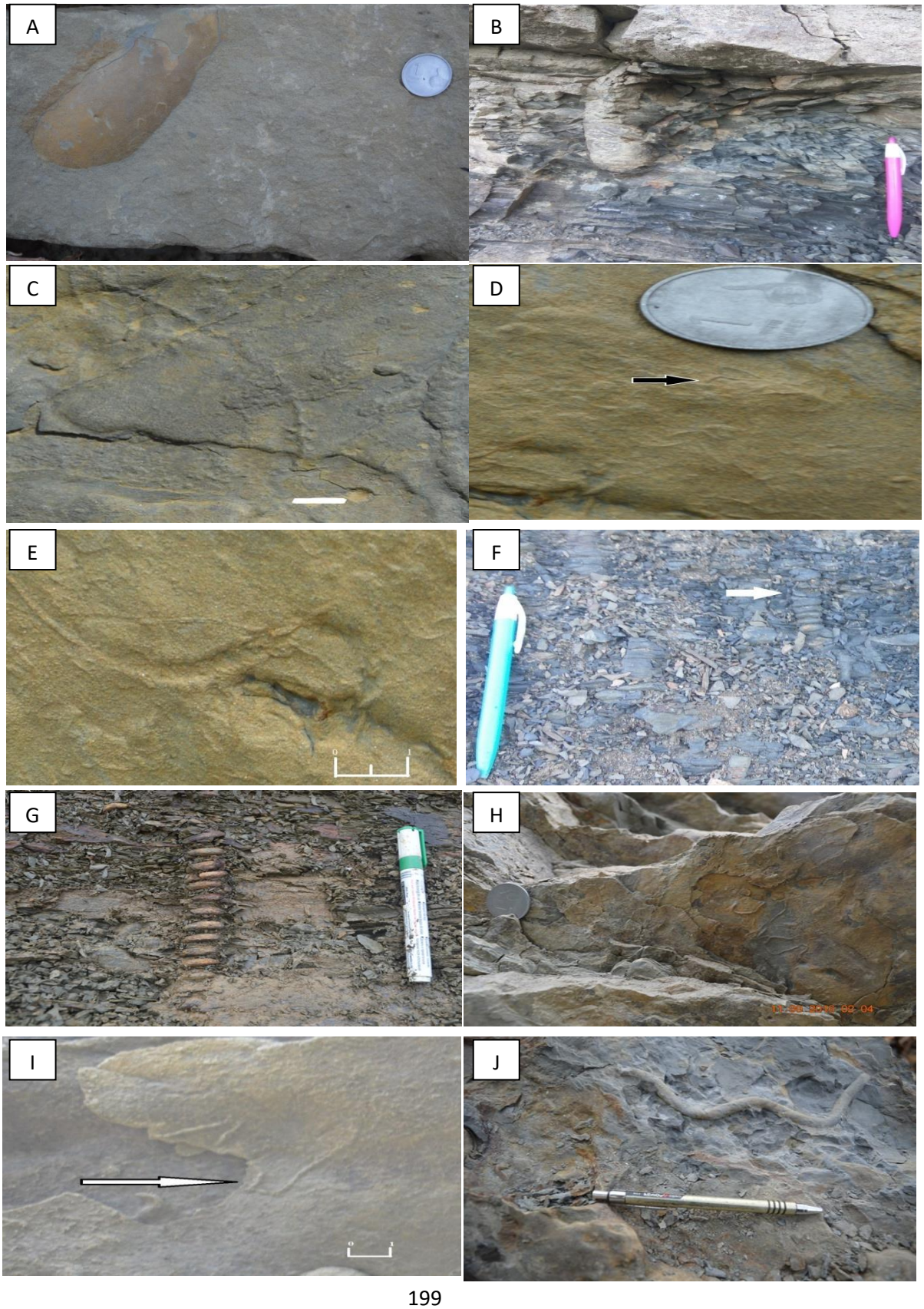
PLATE II



EXPLANATION OF PLATE-2

Figure No.	Explanation	Page No.
A	*Chondrites intricatus* Brongniart (1823) Bed no.5; Mualkawi-Ruantlang Section, Barail Group.	45
B	*Chondrites recurvus* Von Sternberg (1833) Bed no.5; Mualkawi-Ruantlang Section, Barail Group.	45-46
C	*Circulichnus* isp., Bed no.5; Mualkawi-Ruantlang Section, Barail Group.	46-47
D & E	*Coachlichnus anguineus* Hitchcock (1858), Bed no. 21 In Mualkawi-Ruantlang section and bed no.8 in Ngur-Vapar Section, Barail Group.	48-49
F	*Cruziana* isp., Bed no.8; Ngur-Vapar section, Barail Group.	49-50
G	*Cylindrichnus* isp., Bed no. 5; Mualkawi-Ruantlang section, Barail Group.	50-51
H	*Didymaulichnus lyelli* Rouault (1850), Bed no. 8; Ngur-Vapar Section, Barail Group.	51-52
I & J	*Funalichnus bhubani*, Bed no. 3 & 23; Mualkawi-Ruantlang section, Barail Group.	53-54

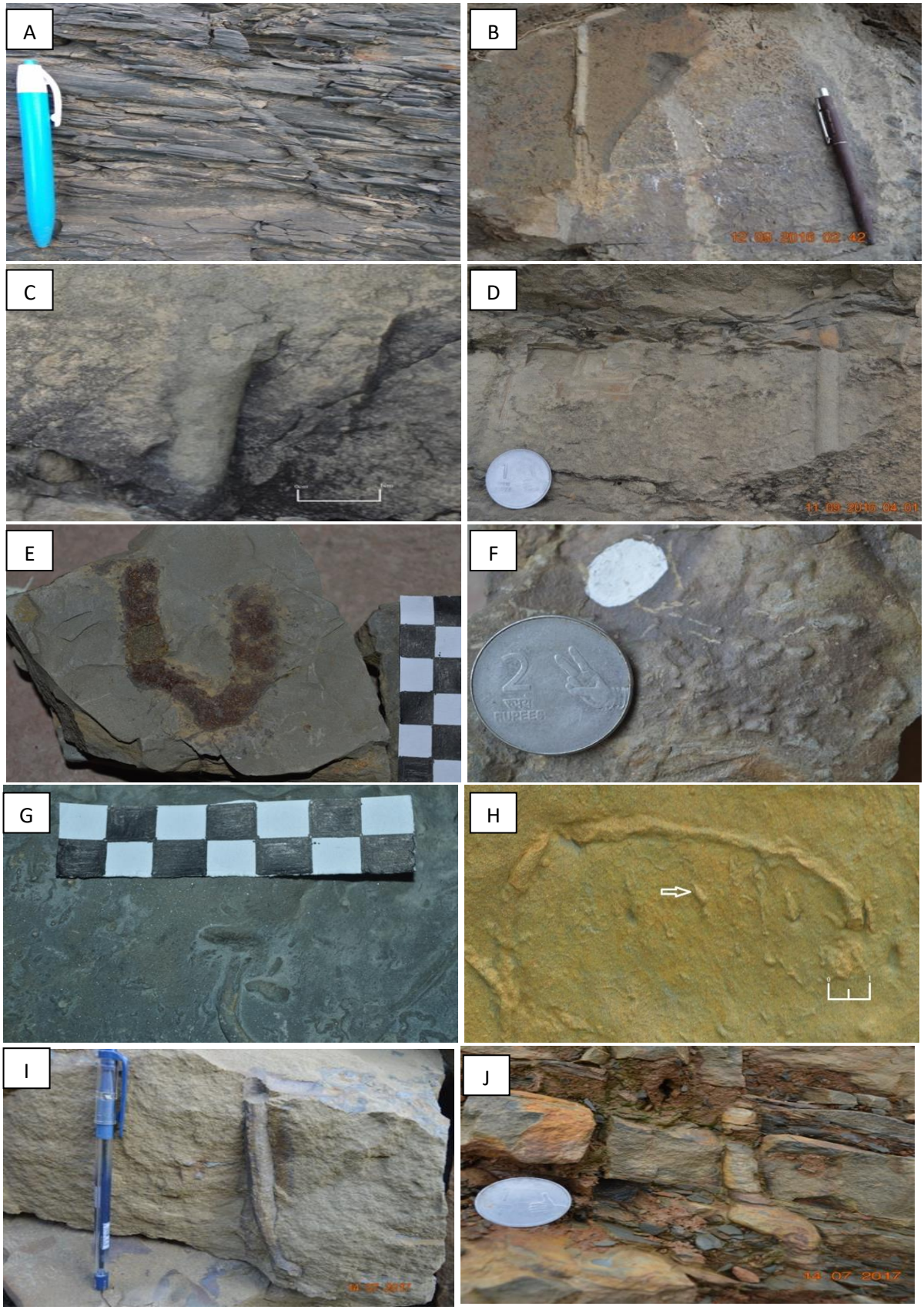
PLATE III



EXPLANATION OF PLATE-3

Figure No.	Explanation	Page No.
A & B	*Gastrochenolites ornatus* Kelly & Bromley (1984), Bed no.18 in Mualkawi- Ruantlang Section and Bed no. 5 in Zote-Ngur section, Barail Group.	54-55
C	*Glaciichnium liebegastensis* Walter (1985), Bed no. 3; Mualkawi-Ruantlang Section, Barail Group.	55-56
D	*Gordia carickensis* Smith (1909), Bed no.3; Mualkawi-Ruantlang section Barail Group.	56-57
E	*Gyrochorte comosa* Heer (1865), Bed no.3; Mualkawi-Ruantlang section Barail Group.	57-58
F	*Gyrolithes lorcaensis* Saporta (1884), Bed no.7; Zote- Ngur section, Barail Group	59
G	*Gyrolithes mexicanus* Saporta (1884), Bed no.8; Ngur-Vapar section, Barail Group	60
H	*Helminthopsis abeli* Ksiaziewicz (1977), Bed no.2; Zote-Ngur section	61-62
I	*Helminthopsis hieroglyphica* Heer (1887), Bed no. 2; Zote-Ngur section	62-63
J	*Helminthopsis tenuis* Ksiaziewicz (1968), Bed no.10; Zote-Ngur section	63-64

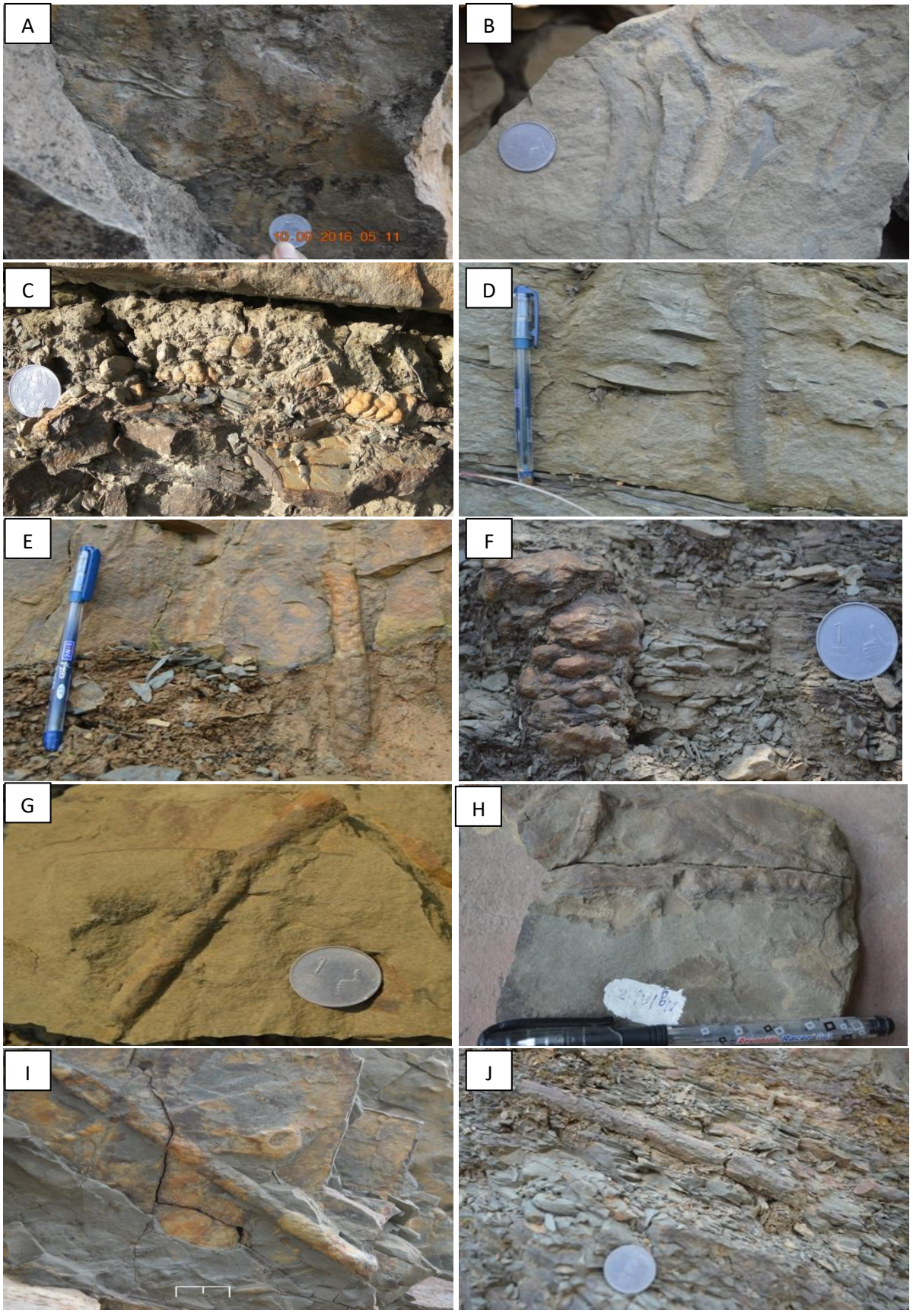
PLATE IV



EXPLANTION OF PLATE-4

Figure No.	Explanation	Page No.
A	*Katbergia carltonichnus* Gastaldo & Roberson (2008), Bed no.83; Mualkawi-Ruantlang section	64-65
B-D	*Laevicyclus mongraensis*, Verma (1971), Bed no.23 in Mualkawi-Ruantlang section, bed no.2 in Zote-Ngur section and bed no.8 in Ngur-Zote section, Barail Group.	65-67
E	*Lanicodichnas mendulata* Chamberlain (1971), Bed no.7 in Zote-Ngur section, Barail Group	67-68
F-H	*Lockeia siliquaria* James (1879), Bed no.5 in Mualkawi-Ruantlang Section and Bed no.7 in Zote-Ngur section, Barail Group.	68-69
I	*Macanopsis paguei* MacSotay (1967), Bed no.3; Mualpui-Ruantlang section	69
J	*Macanopsis* isp., Bed no.23; Mualkawi-Ruantlang section	70

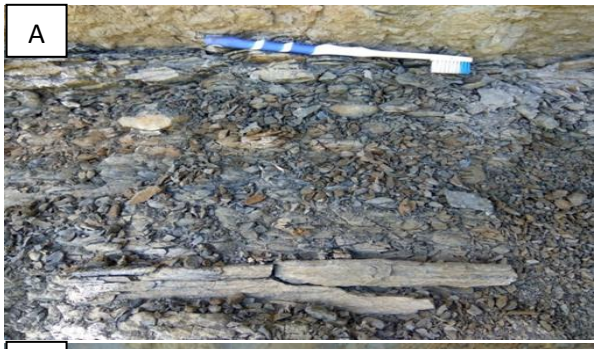
PLATE V

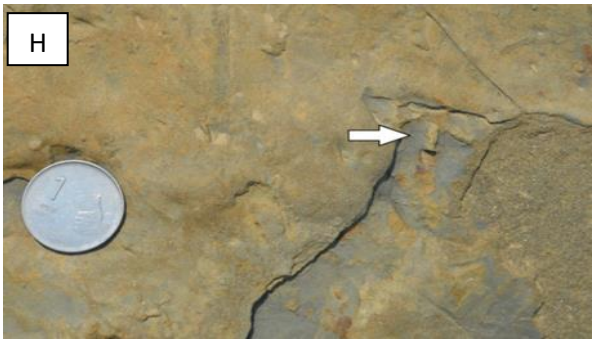


EXPLANATION OF PLATE- 5

Figure No.	Explanation	Page No.
A	*Monomorphichnus* isp. Crimes (1970) , Bed no.4; Zote-Ngur Section, Barail Group	70-71
B & C	*Ophiomorpha annulata* Ksiazkiewicz (1977); Bed no. 3 in Mualkawi-Ruantlang section and bed no.6 in Ngur-Vapar section, Barail Group	72
D	*Ophiomorpha irregulaire* Frey, Howard and Pryor (1978), Bed no.23 E & F*Ophiomorpha nodosa* Lundgren (1891), Bed no.23 in Mualkawi-Ruantlang section and Bed no.1 in Zote-Ngur section, Barail Group	73-74
E & F	*Ophiomorpha nodosa* Lundgren (1891), Bed no.23 in Mualkawi-Rantlang section and Bed no.1 in Zote-Ngur section, Barail Group.	74-75
G & H	*Palaeophycus annulatus* Badve (1987), Bed no.23 in Mualkawi -Ruantlang section and Bed no.8 in Ngur-Vapar section, Barail Group.	76-77
I	*Palaeophycus heberti* Saporta (1872); Bed no.2; Zote-Ngur section, Barail Group.	77-78
J	*Palaeophycus striatus* Hall (1852); Bed no. 83 in Mualkawi- Ruantlang section, Barail Group	78-79

PLATE VI

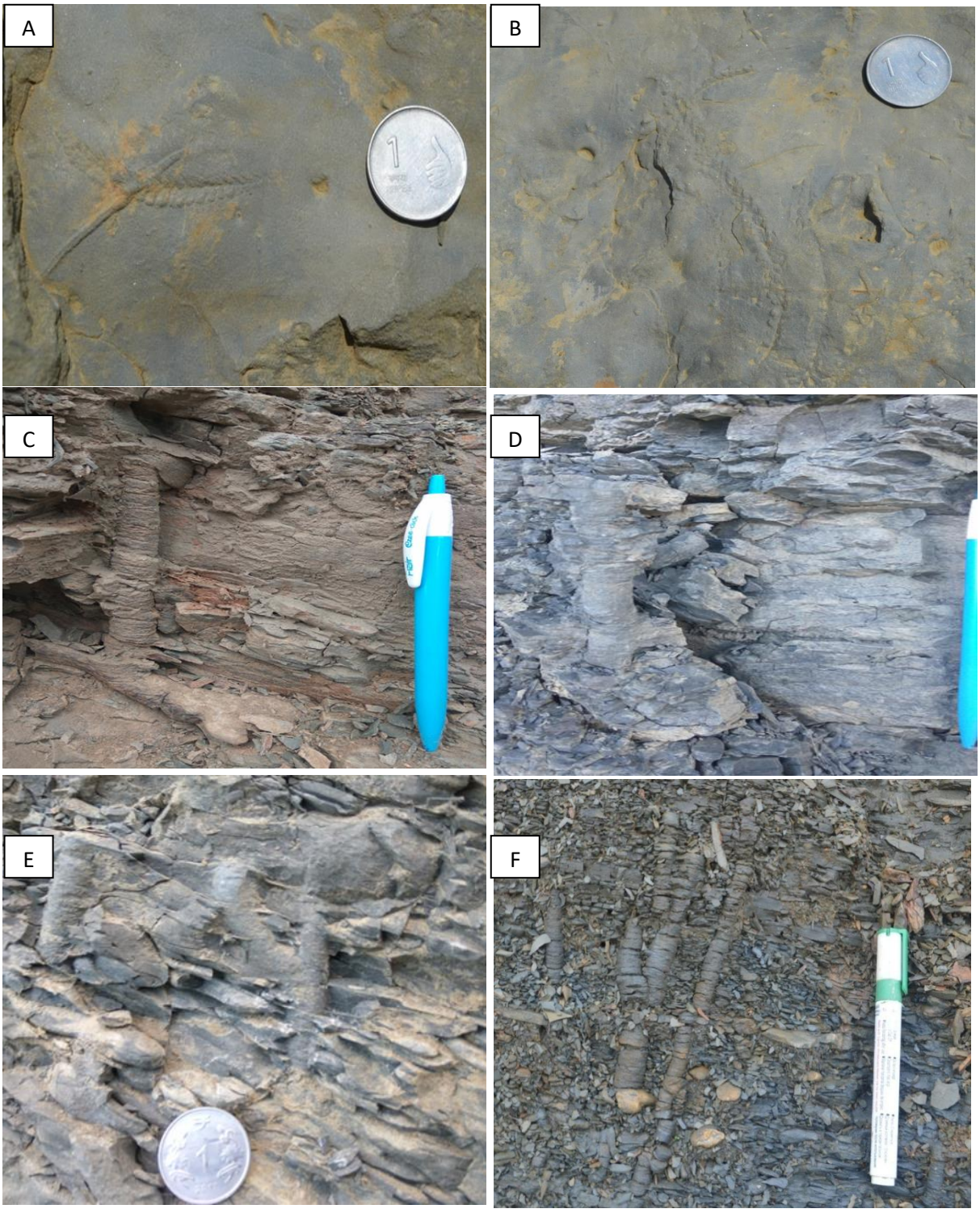




EXPLANATIN OF PLATE-6

Figure No.	Explanation	Page No.
A	*Palaeophycus striatus* Hall (1852); bed no.6 in Ngur-Vapar section, Barail Group	78-79
B	*Palaeophycus sulcatus* Miller and Dye (1878); Bed no: 5 in Zote-Ngur section, Barail Group.	79-80
C	*Palaeophycus tubularis* Hall (1852); Bed no.23; Mualkawi-Ruantlang section, Barail Group.	80-81
D	*Pholeus bifurcates* Knaust (2002), Bed no: 87; Mualkawi-Ruantlang section, Barail Group.	81-82
E	*Phycodes curvipalmatum* Hall (1852), Bed no: 7; Ngur-Vapar section, Barail Group.	82-84
F & G	*Planolites beverlyensis* Billings (1862), Bed no.35 in Mualkawi-Ruantlang section and bed no.5 in Ngur-Vapar section, Barail Group.	84-86
H & I	*Planolites montanus* Richter, Bed no.5 in Mualkawi-Ruantlang section and bed no.7 in Ngur-Vapar section, Barail Group.	86-87
J	*Funalichnus bhubani*, Bed no. 18 in Ngur – Vapar section, Barail Group.	53-54

PLATE VII



EXPLANATION OF PLATE-7

Figure No.	Explanation	Page No.
A-B	*Protovirgularia dichotoma* M'coy (1850), bed no.5; Mualkawi-Ruantlang section, Barail Group.	88
C & D	*Psilonichnus tubiformis*, bed no.49 in Mualkawi-Ruantlang section and bed no. 6 in Zote-Ngur section, Barail Group.	89-90
E & F	*Psilonichnus upsilon* Frey et al. (1984), Bed no. 83 in Mualkawi-Ruantlang section and bed no.7 in Ngur-Vapar section, Barail Group	90-91

PLATE VIII

EXPLANATION OF PLATE-8

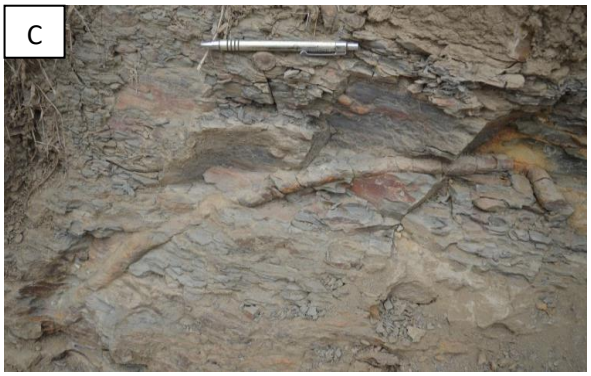
Figure No.	Explanation	Page No.
A-C	*Psilonichnus* isp. Fursich (1981), bed no. in Mualkawi section; bed no.6 in Zote-Ngur section and bed no.8 in Ngur-Vapar section, Barail Group.	91-92
D-F	*Rosselia* isp. Dahmer (1937), bed no.55 in Mualkawi-Ruantlang Section, bed no.1 In Zote-Ngur section, Barail Group and bed no.in Ngur-Vapar section.	92-93
G	*Rusophycus carbonarius* Dawson (1864), bed no. 6; Ngur-Vapar section, Barail Group	93-94
H	*Rusophycus versans* Schlirf & Uchman (2001), bed no 8; Ngur-Vapar section, Barail Group.	95
I& J `	*Skolithos linearis* Haldemann (1840), Bed no.46 In Mualkawi-Ruantlang section and bed no.7 in Zote-Ngur section, Barail Group.	97-98

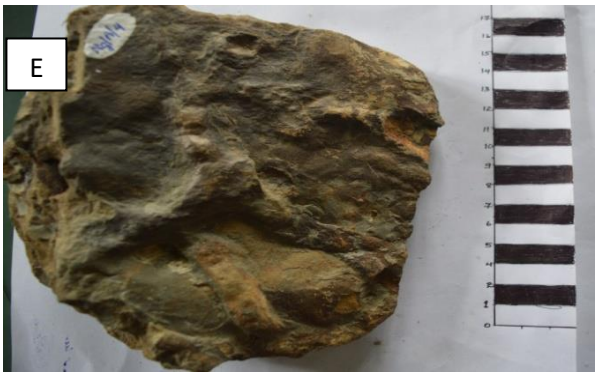
PLATE IX

EXPLANATION OF PLATE-9

Figure No.	Explanation	Page No.
A -C	*Skolithos verticalis* Hall (1843), bed no.56 in Mualkawi-Ruantlang section, bed no.2 in Zote-Ngur section and bed no.8 in Ngur-Vapar section, Barail Group.	98-99
D & E	*Scolicia stronzzii* Savi & Meneghini (1850), bed no.56; Mualkawi-Ruantlang section, Barail Group	96
F	*Taenidium baratti* Bradshaw (1981), bed no.5; Ngur-Vapar section, Barail Group	99-100
G & H	*Teichichnus spiralis* Mikulas (1990), bed no.18 in Mualkawi-Ruantlang section and bed no.1 in Zote-Ngur section, Barail Group.	100-101
I	*Teichichnus rectus* Frey & Bromley (1985), bed no.8 in Zote-Ngur section, Barail Group.	101-102
J	*Thalassinoides horizontalis* Myrow (1995), bed no.18 In Mualkawi-Ruantlang section, Barail Group.	103-104

PLATE X





EXPLANATION OF PLATE-10

Figure No.	Explanation	Page No.
A-B	*Thalassinoides horizontalis* Myrow (1995), Bed no.8; Ngur-Vapar Section and Bed no.1 in Zote-Ngur section, Barail Group.	103-104
C	*Thalassinoides paradoxicus* Woodward (1830), bed no, 6 in Zote-Ngur section, Barail FGroup.	104-105
D & E	*Thalassinoides suevicus* Rieth (1932), bed no. 23 in Mualkawi-Ruantlang section, bed no.6 in Ngur-Vapar section, Barail Group.	106
F	*Treptichnus pedum* Seilacher (1955), bed no.7 in Zote-Ngur section, Barail Group.	106=107
G	Ichnospecies Type A, bed no.40; Mualkawi-Ruantlang section, Barail Group.	107-108

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DEPARTMENT : GEOLOGY

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DATE OF ADMISSION *: 9TH SEPTEMBER, 2013*

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ABSTRACT

PALAEOENVIRONMENTAL SIGNIFICANCE OF THE ICHNOFOSSIL ASSEMBLAGES FROM OLIGOCENE, BARAIL GROUP, CHAMPHAI DISTRICT, MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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ABSTRACT

PALAEOENVIRONMENTAL SIGNIFICANCE OF THE ICHNOFOSSIL ASSEMBLAGES FROM OLIGOCENE, BARAIL GROUP, CHAMPHAI DISTRICT, MIZORAM

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Submitted

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1.1 INTRODUCTION

Trace fossil, also called Ichnofossils, are fossilized equivalents of the structures produced in rocks or sediments by the life processes of an organisms. The study of trace fossil is called ichnology, it is concerning with understanding the disturbance of the sediments by living organisms. Trace fossils are important paleoecological and paleoenvironmental indicators as they are preserved in situ, or in the life position of the organism that made them. They record behavioural, ecological and sedimentological events which body fossils and other sedimentary structures cannot highlight directly (Seilacher,1967; Pemberton *et al.*,1990; Bromley,1996). It also record important information for environmental interpretation in terms of water depth, salinity, energy level, oxygenation variation etc.

In the thesis "Trace fossils" are used to tell palaeoenvironmental condition for the deposition of the sediments of the study area.

1.2 OBJECTIVES

The objectives of the present study are therefore, to study the ichnofossils from the Barail Group of rocks of Champhai District with the view to:

1) demarcation of lithic units and building of statifigraphic sequence.
2) systematic description of ichnofossils.
3) correlation of Barail succession of study area with coeval successions in other areas of Northeast India.
4) palaeoenvironmental signification of the ichnofossil assemblages.

1.3 METHODOLOGY

The research methodology employed in the study area has been broadly classified into following three categories:-

1.6.1 Literature survey: At the outset a survey of pertinent literatures has been undertaken in order to gather available information about the local as well as regional geology, especially the palaeontology of the region and adjoining areas with the help of available literature. For this purpose various published papers has been downloaded.

1.6.2 Field investigation: The field investigation included the following steps:

i) Collection of field data along the studied sections

ii) Preparation of lithologs.

iii) Field photographs of those ichnofossils with the host rocks which could not be collected were taken.

iv) Collection of trace fossils along with the enclosing rocks.

v) Marking of fossil yielding horizons in litho-logs.

vi) Field checks of data obtained through laboratory investigations.

1.6.3 Laboratory investigation: This include the following steps:

i) Cleaning of the collected trace fossils.

ii) Photograph of the specimens for preparation of plates.

iii) Plotting of position of trace fossils in litho-logs.

iv) Identification and systematic description of both the collected and photographed trace fossils was carried out with the help of available published work

v) Geographical distribution of the present collection was worked out, i.e. occurrence of the genus or species in other Oligocene exposures in India.

vi) Ichnofacies and ethological grouping of the described trace fossils was accomplished.

vii) Depostional environment of the studied rock successions of Barail Group was worked out on the basis of such ichnofacies and ethological groupings.

viii) Finally, correlation of the studied sections with the Oligocene successions from other parts of Northeast India where ichnological studies have been performed by other workers has been attempted.

1.4 STRUCTURE OF THE THESIS

The thesis is divided into the following Chapters:

1. **Chapter I- Introduction**:

   This chapter gives an outline introduction of the physical features, physiography, climate, flora and fauna of Mizoram, it also contains objective and methodology of the study and the entire structure of the thesis.

2. **Chapter II-Review of Literature**:

   This chapter contains review of existing literature from northern India, southern India, western India and Northeast India.

3. **Chapter III-Geological setting of the area:**

   Chapter three of the thesis covers general geology of Mizoram and Geology of the study area along with description of lithocolumn of different sections of the study area.

4. **Chapter IV-Systematic description:**

   The fourth chapter covers the details on systematical description of trace frossils collected from the study area and their ethological diversity along with analysis of the identified tracefossils.

5. **Chapter V- Depositional environment**:

   The fifth chapter discusses the depositional environment of the study area on the basis of the recovered trace fossils.

6. **Chapter VI-Correlation**:

   Chapter six is divided into two, local correlation and correlation of the studied sections with Oligocene successions of Northeast India on the basis of depositional environment.

7. **Chapter VII-Summary and conclusions:**

   This chapter summarizes the findings of the thesis.

1.5 REVIEW OF LITERATURE

Ichnological researches in India started in the early seventies and subsequently there was a considerable progress. Many workers have put up important works in various features of the ichnological studies. A little research work have been taken up in North India by Patel (1998) and Kundal *et al*. (2005). While in the North-Western parts of India these works have been carried out by Rajnath

(1942), Chiplonkar and Badve (1970), Kumar *et al*. (1975), Tandon and Bhatia (1978), Biswas (1981), Kumar *et al*. (1982), Shringarpure (1984, 1986), Patel and Shringarpure (1990, 1992), Srivastava and Kumar (1992), Borkar and Kulkarni (1992, 2006), Sanganwar and Kundal (1998), Kundal and Sanganwar (1998, 2000), Kundal and Dharashivkar (2006), Kundal and Mude (2008), Desai *et al*. (2008), Patel *et al*. (2008), Desai and Patel (2008) and Patel and Desai (2009). Desai (2012), Mude (2012), Patel (2012, 2014), Joseph *et al*. (2012) and Ahmad and Kumar (2015). In some parts of South-India these work have been taken up by Chiplonkar and Ghare (1979), Malarkodi *et al*. (2009) and study in Kerala state by Mude *et al*. (2012). In North-Eastern India region, apart from Mizoram, the trace fossils study has been carried out by Reddy *et al.* (1992) in cores of Kopili, Barail and Tipam sediments of Upper Assam shelf; Bandopadhyay *et al*. (2009) worked on the Namunagarh grit of Eocene age in South Andaman island and suggested that the island is a submarine fan deposit where sedimentation occurred in deep marine environment mainly by turbidity currents. A detailed ichnological analysis, for the first time, has been performed on Upper Eocene-Lower Oligocene Transition of Manipur, Indo-Myanmar Ranges by Singh *et al.* (2008). The Cenozoic sediments from the Disang and Barail groups of the area contain a relatively abundant and moderately diverse trace fossil assemblage that has been characterized at the ichnogenus and ichnospecies level. A total of eight ichnospecies, which belong to *Skolithos* and/or *Cruziana* ichnofacies have been described and suggested that the probable depositional environment was shallow-marine environment, with occasional high-energy conditions. The Oligocene-Miocene sediments of Bhuban and Boka Bil Formations in Manipur Wastern Hill have been studied by Singh *et al*.

(2010). These formations are represented by eight lithofacies consist of fifteen ichnospecies belongs to *Skolithos, Cruziana* and *Skolithos/Cruziana* ichnofacies. Khaidem *et al*.(2015) studied trace fossils from Laisong flysch sediments, Manipur, India. The Oligocene Barail sediments in and around Jotsoma , Kohima in Nagaland have been studied by Kichu *et al*. (2018) and Rajkumar *et al*. (2019) worked out from Upper Disang Formation & Lower Barail Formation (Late Eocene to Early Oligocene) of Nagaland. Mizoram is well known for its mega-biota content. However, its rich and diverse assemblage of ichnofossils is not yet fully explored and the previous studies are inadequate. Recently, Ichnological researches in Mizoram have gained momentum. Important contribution in this field are made by Mehrotra *et al.* (2001, 2002), Tiwari *et al*. (2011, 2013), Rajkumar *et al* (2012), Lokho and Singh (2013), and Rajkonwar *et al.* (2013, 2014a and 2014b and 2015).

1.6 GEOLOGY OF THE STUDY AREA

The Barail rock exoposed in Mualkawi-Ruantlang, Zote-Ngur and Ngur-Vapar sections comprises a fossiliferous succession of alternating sanstone, siltstone, silty-shale and shale and their admixture in varied proportion. The study area begins from the southern part of Champhai town from Mualkawi-Ruantlang section and in the northern part from Zote-Ngur and Ngur – Vapar sections. Geologically, this succession belong to Barail sediments which are the only paleogene succession found in Mizoram and are of Oligocene age. The presence of Barail succession in Mizoram is controversial. Nandy (1972, 1982) of the Geological Survey of India have shown the occurrence of Barail sediments in the eastern part of the State around Champhai. Ganju (1975), Ganguly (1975), Ram and Venkataraman (1984) of Oil and Natural Gas Corporation of India, on the other hand, belief that the Barails do

not occur in Mizoram and the rocks around Champhai should be included in the Surma Group only. Sandstone rock found in the study area are very fine to fine grained and are of brown to grey in colour. Shale are light to dark grey in colour. The study area falls under survey of India Topo Sheet No. 84 A/7.

1.7 FINDINGS

A total of 60 ichnospecies belonging to 39 ichnogenera have been identified from the collection, photographed and described. Out of these ichnospecies, one ichnospecies could not be identified up to generic level owing to poor preservation and less number of specimens. The remaining 59 ichnospecies were described.

Total ichnospecies described and illustrated in this thesis include *Archaeonassa fossulata, Archaeonassa ichnospecies, Arenicolite tenuis, Arenicolites* isp., *Asterosoma ichnospecies, Avetoichnus lusae, Chondrites intricatus, Chondrites recurvus, Circulonichnus* isp., *Cochlichnus* isp., *Cruziana* isp., *Cylindrichnus* isp., *Didymaulichnus lyelli, Funalichnus bhubani, Gastrochaenolites* isp., *Glaciinium liebegastensis, Gordia carickensis, Gyrochorte comosa, Gyrolithes lorcaensis, Gyrolithes mexicanus, Helminthopsis abeli, Helminthopsis hieroglyphica, Helminthopsis tenuis, Katbergia carltonichnus, Laevicyclus mongraensis, Lanicodichna medulata, Lockeia siliquaria, Macanopsis pagueyi, Macanopsis* isp., *Monomorphichnus* isp., *Ophiomorpha annulata, Ophiomorpha irregulaire, Ophiomorpha nodosa, Palaeophycus annulatus, Palaeophycus heberti, Palaeophycus sulcatus, Palaeophycus striatus, Palaeophycus tubularis, Pholeus bifurcates, Phycodes curvipalmatum, Planolites beverlyensis, Planolites montanus, Protovirgularia dichotoma, Psilonichnus upsilon, Psilonichnus tubiformis, Psilonichnus* isp., *Rosselia* isp., *Rusophycus carbonarius, Rusophycus versan,*

Scolicia stronzzii, Skolithos linearis, Skolithos verticalis. Taenidium barretti, Teichichnus rectus, Teichichnus spiralis, Thalassinoides horizontalis, Thalassinoides paradoxicus, Thalassinoides suevicus and Treptichnus pedum.

Overall, above ichnospecies belong to *Trypanite, Skolithos, Cruziana* and Mixed *Skolithos-Cruziana* ichnofacies. Ethologically, the ichno-assemblage is dominated by fodinichnia and domichnia followed by repichnia, pascichnia, cubichnia and agrichnia members are also present. *Trypanite, 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 mid period of stressful environment. Thus, it can be worked out that the studied successions of Barail Group of Mizoram were deposited under high energy condition and sandy shifting substrate in foreshore to low energy condition and poorly sorted, unconsolidated substrate in shoreface/offshore zone of shallow marine setting with occasion deep water condition and storm event.

Out of 60 ichnospecies, 15 ichnospecies are found in more than one section. Six ichnospecies, namely, *Laevicyclus mongraensis, Lockeia siliquaria, Psilonichnus* isp.*, Rosselia* isp.*, Skolithos verticalis* and *Thalassinoides horizontalis* have been reported from all the three sections. Correlation among the three studied sections has been attempted. The rock successions of Barail Group of Mualkawi-Ruantlang, Zote-Ngur and Ngur –Vapar sections were deposited under similar depositional set-up and as such these rock succession are correlatable. Correlation of depositional environment of the studied sections has been attempted with the Oligocene successions of other parts of North East India. Singh *et al*. (2008) suggested that the

Upper Eocene-Lower Oligocene Transition of the Manipur was deposited under shallow marine environment, with occasional high energy condition. The Barail successions in the studied sections may be broadly correlatable with the Upper Eocene-Lower Oligocene Transition of Manipur. Singh *et al*. (2010) suggested that the Bhuban and Boka Bil Formations in Manipur were deposited under frequent fluctuating sea level, moderate to strong energy condition, subtidal to lower intertidal environment rich in organic nutrients. All the three sections of the study area are broadly correlatable with the Boka Bil Formation in Manipur in terms of depositonal condition. Khaidem *et al*. (2015) suggested that Laisong Flysch sediments in Manipur was deposited under fluctuation in the basin depth that is shallower and deepening. Thus, it can be broadly correlatable with the deposition of Barail Group of Mualkawi –Ruantlang section and Zote-Ngur section. The Barail succession in the studied sections are also inferred to be deposited in a similar depositonal set-up and thereby correlatable with Oligocene Barail sediment in and around Jotsoma, Kohima, Nagaland. Kichu *et al*. (2018) suggested that the sediments of the study area were deposited under frequently fluctuating sea, having moderate to strong energy levels, within shoreface environment rich in nutrients. Thus, it can be correlatable with the depositon of Barail Group in the studied sections. Rajkumar *et al*. (2019) suggested a foreshore-shoreface/offshore setting of the deposition for the Upper Disang formation and Lower Barail Formation of Nagaland, which is broadly correlatable with Mualkawi-Ruantlang section and Zote-Ngur section.

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