ABSTRACT

ICHNOLOGICAL STUDIES OF UPPER BHUBAN UNIT OF BHUBAN FORMATION, SURMA GROUP IN THE VICINITY OF AIZAWL, MIZORAM.

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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MZU REGISTRATION NO. 720 of 2009-10

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DEPARTMENT OF GEOLOGY

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ABSTRACT

ICHNOLOGICAL STUDIES OF UPPER BHUBAN UNIT OF BHUBAN FORMATION, SURMA GROUP IN THE VICINITY OF AIZAWL, MIZORAM

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In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Geology of Mizoram University, Aizawl.

The Bhuban Formation of Surma Group (lower to middle Miocene) is well exposed in Aizawl district of Mizoram, India. This formation has been further divided into lower, middle and upper Bhuban units (Ganju, 1975; Tiwari and Kachhara, 2003). The present study has been conducted in Upper Bhuban units of Bhuban Formation exposed along three sections namely, Kulikawn – S. Hlimen, Temple – MZU and Ramrikawn to Sakawrtuichhun section.

A total of 32 ichnospecies belonging to 16 ichogenera have been identified from the collection, photographed and described. Out of these 32 ichnospecies, two ichnospecies could not be identified up to generic level owing to poor preservation and less numbers of specimens. The remaining 30 ichnospecies were already described by previous workers. The ichnospecies *Phycosiphon* isp. and *Ancorichnus* isp. are being reported for the first time from Miocene succession of Mizoram.

10 ichnospecies belonging to 9 ichnogenera have been described from Kulikawn – S. Hlimen section. These include *Ancorichnus* isp., *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Laevicyclus mongraensis*, *Pholeus abomasoformis*, *Rhizocorallium jenense*, *Rosselia* isp., *Skolithos* isp., *Taenidium* isp. and *Teichichnus rectus*.These ichnoassemblages represent *Skolithos* ichnofacies, *Cruziana* ichnofacies and at places mixed *Skolithos*-*Cruziana* ichnofacies. The members of the *Skolithos* ichnofacies *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Laevicyclus mongraensis*, *O. nodosa*, *O. borneensis*, *Laevicyclus mongraensis*, *Pholeus abomasoformis*, *Skolithos* isp. and. *Cruziana* ichnofacies is represented by *Rosselia* isp., *Taenidium* isp. and *Teichichnus rectus,* whereas mixed *Skolithos*-*Cruziana* ichnofacies is represented by *Rhizocorallium jenense* and *Rosselia* isp. Ethologically, the association belongs to domichnia and fodichnia.. Domichnian signature is present in *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Laevicyclus mongraensis*, *Rhizocorallium jenense*, *Skolithos* isp., *Pholeus abomasoformis* and fodichnian in *Rhizocorallium* isp., *Taenidium* isp. and *Teichichnus rectus*.The *Skolithos* ichnofacies is related to relatively high levels of wave or current energy and is typically developed in well-sorted, loose or shifting substrates. Such conditions commonly occur in the foreshore zones. The *Cruziana*

ichnofacies is most characteristic of poorly sorted, unconsolidated (muddy) substrates, uniform salinity and low energy conditions in the shoreface/offshore zones. Together these two ichnofacies indicate sandy shifting substrate and high energy conditions in foreshore to unconsolidated, poorly sorted soft substrate and low energy condition in shoreface/offshore zone of shallow marine environment for the deposition of the succession exposed in Kulikawn to S. Hlimen section.

A total of 20 ichnospecies belonging to 10 ichnogenera have been described from Temple to MZU section, which include The ichnofossil assemblages characteristically display the development of *Skolithos*, *Cruziana* and mixed *Skolithos*-*Cruziana* ichnofacies. The domichnian signatures are preserved in ichnospecies like *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Funalichnus bhubani*, *Laevicyclus mongranesis*, *Ophiomorpha annulata*, *Ophiomorpha borneensis*, *Ophiomorpha irregulaire*, *Ophiomorpha nodosa*, *Palaeophycus annulatus*, *Palaeophycus striatus*, *Palaeophycus sulcatus*, *Palaeophycus tubularis*, *Skolithos verticalis* and *Skolithos isp.* while the fodichnian features are clearly evident in *Cochlichnus anguineus*, *Planolites beverleyensis*, *Thalassinoides suevicus*, *Thalassionoides horizontalis*, *Thalassionoides paradoxicus* and *Thalassionoides* isp. *Funalichnus bhubani* isp. nov. occur in association with *Diplocraterion* and *Skolithos* which are endichnial burrows of chiefly suspension feeding organisms and are typical members of the *Skolithos* ichnofacies (Seilacher, 1967; MacEachern and Pemberton, 1992). The members of the *Skolithos* ichnofacies are, *Diplocraterion helmerseni*, *D. parallelum*, *Funalichnus bhubani* isp. nov., *Laevicyclus mongraensis*, *Ophiomorpha irregulaire*, *O. nodosa*, *O.annulata* and *Skolithos verticalis*. *Cruziana* ichnofacies is represented by *Palaeophycus sulcatus*, *P.tubularis*, *P. striatus*, *Planolites beverleyensis*, *Planolites monatus* and *Thalassinoides paradoxicus* whereas mixed *Skolithos- Cruziana* ichnofacies is represented by *Thalassinoides horizontalis* and *Thalassinoides suevicus*. The development of *Skolithos*, *Cruziana* and mixed *Skolithos-Cruziana* ichnofacies, indicates that the Upper Bhuban Formation of Temple-MZU section was deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine environment.

The Upper Bhuban unit of Bhuban Formation of Ramrikawn - Sakawrtuichhun section yielded trace fossil assemblage of 15 ichnospecies belonging to 7 ichnogenera. These include *Diplocraterion parallelum*, *Funalichnus bhubani*, *Ophiomorpha borneensis*, *Ophiomorpha nodosa*, *Palaeophycus tubularis*, *Palaeophycus sulcatus*, *Palaeophycus* isp., *Phycosiphon* isp., *Planolites beverleyensis*, *Planolites* isp., *Skolithos* isp., *Thalassinoides paradoxicus*, *Thalassinoides* isp. and Ichnospecies Type A. The ichnotaxa described from the studied succession are typical for the *Skolithos* and the *Cruziana* ichnofacies. The members of *Skolithos* ichnofacies are *Diplocraterion parallelum*, *Funalichnus bhubani*, *Ophiomorpha borneensis*, *Ophiomorpha nodosa* and *Skolithos* isp. *Cruziana* ichnofacies is represented by *Palaeophycus tubularis*, *Palaeophycus sulcatus*, *Palaeophycus* isp., *Phycosiphon* isp., *Planolites beverleyensis*, *Planolites* isp., *Skolithos* isp., *Thalassinoides paradoxicus*, *Thalassinoides* isp. and Ichnospecies Type A.. Etholoically, the assemblage belongs to domichnia and fodichnia groups. Domichnian signature is reflected in ichnospecies of *Diplocraterion parallelum*, *Funalichnus bhubani*, *Ophiomorpha borneensis*, *Ophiomorpha nodosa* and *Skolithos* isp. Fodichnian signature reflected by *Palaeophycus sulcatus*, *Palaeophycus tubularis*, *Palaeophycus* isp., *Planolites beverleyensis*, *Planolites* isp., *Thalassinoides paradoxicus* and *Thalassinoides* isp. The *Skolithos* and *Cruziana* ichnofacies indicates a foreshore to shoreface/offshore shallow-marine environment, with occasional high-energy depositional conditions.

Correlation of depositional environment of the studied sections has been attempted with the Miocene successions of other parts of India. Sudan *et al*. (2002) suggested that the Murree Group of Jammu and Kashmir was deposited in coastal environment under brackish to fresh water conditions. The Upper Bhuban successions in the studied sections may be broadly correlatable with the Murree Group of Jammu and Kashmir. The Ambalapuzha Formation in Kerela was deposited under shallow water near-shore marine environment with moderate to high energy conditions (Mude *et al*.,2012). All the three sections of the stud y area are broadly correlatable with the Ambalapuzha Formation (Mio-Pliocene) in terms of broad depositional environment. A high energy shallow marine depositional environment of the Tipam succession of upper Assam shelf inferred by Reddy *et al*. (1992) is broadly correlatable with the Upper Bhuban Formation of the study area. 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. Thus these formations are also broadly correlatable with the Upper Bhuabn Formation of the studied sections in terms of depositional environment.

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CERTIFICATE

This is to certify that the research work embodied in the accompanying thesis entitled **"Ichnological studies of Upper Bhuban Unit of Bhuban Formation, Surma Group in the Vicinity of Aizawl, Mizoram"** has been carried out entirely by Lalramengi Fanai as a research scholar under my direct supervision and that the candidate has fulfilled the requirements of the regulation laid down by Mizoram University for the degree of Doctor of Philosophy in Geology.

Date:

Place: Aizawl

Dr. PAUL LALNUNTLUANGA
(Supervisor)
Department of Geology
Mizoram University

Prof. R.P TIWARI
(Joint Supervisor)

DECLARATION

I, Lalramengi Fanai hereby declare that the matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to 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.

This is being submitted to Mizoram University for the Degree of Doctor of Philosophy in Geology.

Date: (LALRAMENGI FANAI)

Place: Aizawl

Head
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Place: Aizawl

CONTENTS	**PAGE NO.**

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 GENERAL REMARKS

Mizoram is one of the easternmost states of India. It covers an area of about 21,081 sq. km. between latitudes 22°00´ and 24°30´N and longitudes 92°15´ and 93°25´E. Mizoram was one of the districts of Assam state till 1972. It became a Union territory in 1972 and statehood was accorded to it with capital at Aizawl in 1986. The state of Mizoram is surrounded by Chin Hills of Myanmar to the east, Arakan Hill Tracts to the south, Tripura and Chittagong Hill Tracts of Bangladesh to the west, Cachar Valley of Assam to the north, and Manipur to the northeast. The study area falls under the Survey of India Topo Sheet No. 84 A/9 and 84 A/10.

Geologically, Mizoram is a part of the Neogene Surma Basin comprising a belt of a series of elongated folds having sub-meridional trends and arcuate shape with westward convexity. The Fold belt is elongated in the N-S direction almost parallel to the suture zone of the Arakan - Yoma subduction. The altitude varies between 900m to 1200m from MSL with several peaks attaining a height of more than 1800m. The elevation in the state rises towards the east, *i.e.* towards the Chin Hills of Myanmar (Karunakaran, 1974, Ganguly, 1975 and Nandy, 1982).

The rocks of Mizoram belong to the Surma Group (Lower to Middle Miocene) that are very well developed in the state. This Group covers about 75% of the territory of the state. Geological and/or palaeontological studies are inadequate in the state owing to the hostile nature of the terrain with dense impenetrable forests.

Mizoram can be approached by road through NH-54 which connects Silchar to Aizawl, the capital of Mizoram. Aizawl is also approachable from Kolkata, Guwahati, and Imphal by air. An inner Line Permit is necessary for entry or stays into Mizoram, which can be produced from the Mizoram Houses located in Delhi, Kolkata, Guwahati, and Silchar. The climate of Mizoram is quite pleasant. The temperature in the state normally ranges from 7°C to 30°C. It experiences monsoons from June to September with an annual average of 250 cm. Winter generally starts at the end of November and lasts till mid of February.

1.2 GEOMORPHOLOGY

Mizoram is a hilly terrain with an aerial extent of 21,081 sq. km. The Mizo Hills (=Lushai Hills) are trending approximately north-south with a tendency to taper at both ends. The average elevation of the hills is about 900m and it increases towards the east. Hills are generally steep and are separated by rivers forming deep gorges. Blue Mountain (Phawngpui) along the Myanmar border with an elevation of 2,065 m is the highest peak in Mizoram. Dhaleswari (Tlawng), Sonai (Tuirial), and Tuivawl rivers flow towards the North. These rivers originate in the central part of the state and drain water into the Barak Valley of Assam. Koladyne (Chhimtuipui) and Karnafuli. Koladyne, the main river in the state is the important southerly flowing river that originates from Myanmar and flows southerly through a distance of about 500 km in Mizoram and enters again in Myanmar. Karnafuli River originates at the southern tip of Mizoram, flows northerly up to the middle of the state, then takes a turn towards the west and enters Bangladesh.

Topographic features in the state show prominent relief, as the terrain is immature due to recent tectonics. The major geomorphic features of the area are the 3 structural and topographic 'highs' and 'depressions', 'flats', and 'slopes' that are arranged linearly. Topographic 'depressions' are, in all cases, in accordance with the normal first-order structural elements but topographic 'highs' are recorded both in structural 'highs' and 'depressions'. Physiographic expression of the state is characterized by approximately north-south trending steep, mostly anticlinal, longitudinal, parallel to sub-parallel hill ranges and synclinal narrow valleys. The anticlines and synclines are intersected by transverse faults. The difference in elevation between valley floors and hilltops varies greatly from west to east ranging from 200m to 600m (Karunakaran, 1974).

The area exhibits angular, sub-parallel, parallel, and dendritic drainage patterns. Lower-order streams run both parallel and across topographic ‘highs’ and ‘depressions’.

1.3. FLORA AND FAUNA

Since northeastern India is a meeting place of eastern and far-eastern floral and faunal species along with North Indian ones, the state is very rich in flora and fauna. The entire State abounds in subtropical trees, plants, bushes, grasses, and a variety of bamboo. Ferns and allies, soft-stemmed herbaceous plants; orchids, and other epiphytes make a long list of plants endemic to this area with a unique assemblage of non-tree floral species. Forests in Mizoram are house to a wide variety of animals like elephants, tigers, leopards, sambhar, deer, bears, wild pigs, Mithun, mountain goats, flying squirrels, monkeys, snakes, etc.

1.4 PREVIOUS WORK

Although ichnological research started late in India, many workers have contributed during the 1970s and 80s and showing considerable progress in recent years. Most of these studies focus on particular stratigraphic intervals, especially Precambrian-Cambrian, Palaeozoic, and Mesozoic. In the North-Western parts of India, ichnological studies have been carried out by Chiplonkar and Badve (1970), Kumar *et al*. (1975), Tandon and Bhatia (1978), Biswas (1981), Kumar *et al*. (1982), Shringarpure (1986), Patel and Shringarpure (1990, 1992), Srivastava and Kumar (1992), Borkar and Kulkarni (1992, 2006), Sanganwar and Kundal (1997), 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), Desai (2012), Mude (2012), Patel (2012, 2014) and Joseph *et al*. (2012). A little research work has been taken up in some parts of South-India by Chiplonkar and Ghare (1979) and Malarkodi *et al*. (2009). In the context of the North-Eastern India region, other than Mizoram, the trace fossils in cores of Kopili, Barail, and Tipam sediments of the Upper Assam shelf have been carried out by Reddy *et al*. (1992); 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 the deep marine environment mainly by turbidity currents. A detailed ichnological analysis, for the first time, has been performed on the Upper Eocene-Lower Oligocene Transition of Manipur, Indo-Myanmar Ranges by Singh *et al*. (2008). Ichnological research in various parts of Manipur has also been carried out by Singh *et al*. (2010) and Khaidem *et al*. (2015). 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 levels. A total of eight ichnospecies, which belong to *Skolithos* and/or *Cruziana* ichnofacies have been described and suggested that the probable depositional environment was a shallow-marine environment, with occasional high-energy conditions.

1.4.1 Miocene ichnological researches in India:

The Miocene ichnological research in India has been mostly carried out in northeastern India and South India. Important contributions were made by (Reddy *et al*., 1992; Mehrotra *et al*., 2001; Matin and Mukul, 2010; Singh *et al*., 2010; Kundu *et al*., 2012; Brahma *et al*., 2013; Chakraborty *et al*., 2013; Lokho and Singh, 2013) and Western areas (Patel, 1990, 1998; Patel and Shringarpure, 1990, 1992; Kundal *et al*., 2005; Kundal and Dharashivkar, 2006; Kundal and Mude, 2008; Mude, 2012a, b). Only punctual ichnological studies have been conducted in the North (Agrawal and Singh, 1983; Sudan *et al*., 2002) and South India (Mude *et al*., 2012). Recently, Tovar (2014) reviewed the ichnological studies carried out in the Miocene succession of India. He carried out this review based on the ichnological studies performed in Northeast India, Northern India, Southern India, and Western India. A summary of this review is presented in Table 1.1. The detail of this review is as under.

Table1.1. Published literature on Miocene ichnological research in India (Tovar, 2014).

Location	**Reference**	**State**	**Stratigraphic Horizon**	**Ichnotaxa**
Northern India				
(1)	Agrawal and Singh (1983)	Uttar Pradesh	Siwalik successions	*Heterocerus*
(2)	Sudan *et al*.(2002)	Jammu and Kashmir	Murree Group (late Eocene early Miocene)	*Chondrites* isp., *Cosmorhaphe fuchsi*, *Dendrotichnium* cf. *llarenai*, *Imbrichnus* cf. *wattonensis*, *Ophiomorpha* isp., *Planolites* isp., *Skolithos* isp., *Thalassinoides* isp.
Southern India				
(3)	Mude *et al*. (2012)	Kerala	Ambalapuzha Formation	*Planolites beverleyensis*, *Skolithos linearis*
N-E India				
(4)	Reddy *et al*. (1992)	Assam	Tipam successions	? *Muensteria* sp., *Planolites* sp., *Thalassinoides* sp., *Skolithos verticalis*

(5)	Mehrotra *et al*. (2001)	Mizoram	Bhuban Formation	*Teredolites clavatus*
(6)	Lokho and Singh (2013)	Mizoram	Bhuban Formation	*Ophiomorpha* isp., *Palaeophycus* isp., *Psilonichnus upsilon*, *Skolithos* isp., and *Teichichnus spiralis*
(7)	Singh *et al*. (2010)	Manipur	Bhuban Formation and Boka Bil Formation (Miocene)	*Ancorichnus ancorichnus*, *Arthrophycus* isp., *Diplocraterion* isp., *Fucusopsis angulatus*, *Gyrochorte comosa*, *Helminthoida* isp., *Lockeia siliquaria*, *Ophiomorpha nodosa*, *Palaeophycus alternatus*, *P. tubularis*, *Planolites beverleyensis*, *Phycodes* isp., *Psilonichnus upsilon*, *Rutichnus irregularis*, *Thalassinoides* isp.
(8)	Chakraborty *et al*. (2013)	Sikkim	Siwalik successions	*Cylindricum* isp., *Macanopsis* isp., *Naktodemasis* isp., *Planolites* isp.

(9)	Rajkonwar *et al.* (2015)	Mizoram	Bhuban Formation	*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*
Western India			Aquitanian, Burdigalian and Helvetian	
(10)	Patel and Shringarpure (1990)	Gujarat		*Arenicolites, Chondrites, Cylindricum, Monocraterion, Ophiomorpha, Palaeophycus, Planolites, Scolicia, Skolithos, Spongiliomorpha, Teichichnus, Thalassinoides*
(11)	Patel and Shringarpure(1992)	Gujarat	Vinjhanian stage	*Limulicubichnus*
(12)	Patel and Shringarpure(199	Gujarat	Babaguru Fm	*Lithophaga, Lithotrya* and micro-scale boring

	8)			
(13)	Kundal *et al*. (2005)	Gujarat	Neogene-Quaternary deposits	*Keckia annulata*, *Ophiomorpha nodosa*, *Palaeophycus tubularis*, *Planolites beverleyensis*, *Pl. montanus*, *Thalassinoides paradoxicus.*
(14)	Kundal and Dharashivkar (2006)	Gujarat	Dwarka Formation	*Cylindrichnus concentrichus*, *Keckia annulata*, *Laevicyclus mongraensis*, *Ophiomorpha borneensis*, *O. irregulaire*, *O. nodosa*, *Palaoephycus heberti*, *P. tubularis*, *Planolites annularis*, *Pl. beverleyensis*, *Pl. montanus*, *Psilonichnus upsilon*, *Rhizocorallium karaiensis*, *R. yelamensis*, *Skolithos* isp., *Thalassinoides paradoxicus*, *T. suevicus*
(15)	Kundal and Mude (2008)	Gujarat	Babaguru Fm	*Granularia* isp., *Ophiomorpha irregulaire*, *O.nodosa*, *Palaeophycus heberti*, *P. tubularis*, *Planolites berverleyensis*
(16)	Mude (2012a)	Gujarat	Kand Formation	*Laevicyclus mongraensis*, *Planolites beverleyensis*, *Skolithos linearis*, *S. verticalis*
(17)	Mude (2012b)	Gujarat		*Laevicyclus mongraensis*, *Planolites beverleyensis*, *Pl.*

				montanus, *Thalassinoides paradoxicus*, *T. Suevicus*.

1.4.1.1 Northern India:

In Northern India, few trace fossil studies were done in the states of Uttar Pradesh and Jammu, and Kashmir (Agrawal and Singh, 1983; Sudan *et al*. 2002). Agrawal and Singh (1983) described dwelling and feeding burrows mostly of insects and worms from the fluvial Middle Siwalik successions of Uttar Pradesh. In the state of Jammu and Kashmir, trace fossils of the Murree Group (late Eocene-early Miocene) have been described by Sudan *et al*., (2002). Ichnofossils, mainly corresponding to feeding-dwelling forms, are facies-related, allowing for the differentiation of four ichnofacies. These ichnofacies were used to interpret the environmental conditions during the late Palaeogene related to several settings in coastal environments (Sudan *et al*., 2002).

1.4.1.2 Southern India:

Ichnological research in Miocene successions from South India is very scarce, restricted to a recent study in Kerala state (Mude *et al*., 2012). Mude *et al*. (2012) reported ichnofossils from the Ambalapuzha Formation (Mio- Pliocene) which constitutes the first report from the Cenozoic successions of Kerala.
Only *Skolithos linearis* and *Planolites beverleyensis* were described which respectively belong to *Skolithos* and *Cruziana* ichnofacies, allowing interpretation of deposition in shallow water, near-shore marine environments with moderate to high energy conditions (Mude *et al*., 2012).

1.4.1.3 Northeastern India:

Reddy *et al*. (1992) first conducted an ichnological study on cores retrieved from the Assam State, describing several ichnogenera, with? *Muensteria* sp. occurring in the Tipam succession of the Mio-Pliocene age. This occurrence, together with that of trace fossils from the Kopili and Barail Groups (Palaeocene to Oligocene) served to differentiate ichnofacies and to interpret palaeoenvironmental conditions of the Upper Assam Shelf.

In the state of Manipur, ichnological research in the Miocene succession is limited to one study in the Bhuban and Boka Bil, comprising Oligocene-Miocene sediments of Bhuban and Boka Bil Formations in Manipur Wastern Hill by Singh *et al*. (2010). The authors described and integrated facies and ichnofossils to interpret palaeoenvironmental and palaeo-ecological conditions associated with both formations. Fifteen ichnospecies were identified revealing a mixture of domichnia and fodinichnia behaviors, of a variety of ichnofacies (*Skolithos*, *Cruziana*, *Skolithos*/*Cruziana*, and *Cruziana*/*Zoophycos* ichnofacies). Distribution patterns of trace fossils and sedimentary features point to fluctuating sea levels and varying levels of energy and nutrient availability in shallow marine conditions (subtidal to the lower intertidal environment) (Singh *et al*., 2010).

Within the state of Mizoram, trace fossil studies stem from the Bhuban Formation of the Surma Group of early-middle Miocene age (Mehrotra *et al*., 2001; Lokho and Singh, 2013). However, its rich and diverse assemblage of ichnofossils is not yet fully explored and the previous studies are meager. Mehrotra *et al*. (2001) for the first time reported *Teredolites clavatus* from the Upper Bhuban unit of Bhuban Formation, Ramrikawn area about 10 km west of Aizawl city, Mizoram, and inferred 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. Subsequently, Mehrotra *et al*. (2002) also described ichnogenus *Palaeophycus* from the Barail Group succession exposed at about 8.7 km from Champhai (a border town in the eastern part of Mizoram) on the Champhai-Aizawl road. This was considered the first record of *Palaeophycus* from the Tertiary succession of North-East India. The ichnogenus represents passive sedimentation.
Rajkonwar *et al*. (2015) studied the Bhuban succession of the Surma Group (early to Middle Miocene) which is well exposed in the Zuangtui section of the Aizawl district

of Mizoram and comprises ~40 m thick sequence of alternating sandstone, siltstone and shale, and their admixtures in various proportion. Highly bioturbated rocks of this section show behaviorally diverse groups of trace fossils. A total of 17 ichnospecies have been identified from this section. 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, *Skolitho*s isp., *Teredolites clavatus*, *T. longissimus*, *Thalassinoides horizontalis* and *T. suevicus*. These trace fossils represent the record of *Skolithos, Cruziana,* and *Teredolites* ichnofacies and at places the mixed *Skolithos-Cruziana* ichnofacies. *Teredolites* infested log-grounds and the other ichnological evidence indicates that the rocks of Bhuban Formation exposed in the Zuangtui area, Aizawl district of Mizoram were deposited under near-shore high energy conditions.

1.4.1.4 Western India:

The Miocene ichnological researches are comparatively extensive in Western India is mainly rooted in the state of Gujarat. Early ichnological research of Miocene successions in Gujarat was conducted in 1990 by Patel, Patel, and Shringarpure. In his unpublished Ph.D. Thesis, Patel (1990) studied trace fossils in carbonate rocks of the western Kutch-Gujarat state, recognizing in hard yellowish limestones of the Vinjhanian stage (early to middle Burdigalian; early Miocene) trace fossils including *Skolithos, Arenicolies, Planolites, Palaeophycus, Macanopsis,* and *Monocraterion*. A close examination of these rocks made it possible to identify boring activities, including those by bivalves (*Lithophaga* borings), barnacles (*Lithotrya* borings), and polychaete worms (microboring), giving rise to the interpretation of the typical *Glossifungites* ichnofacies developed in firm but unlithified substrates, most likely intertidal to subtidal (Patel, 1998). Patel and Shringarpure (1990) briefly described ichnogenera registered in Aquitanian, Burdigalian, and Helvetian rocks, their abundance, and their ethological significance. Ichnological data were used to interpret the depositional environments and parameters involved, such as energy and sedimentation rate (Patel and Shringarpure, 1990). Later, they recorded the presence of *Limulicubichnus* from early Miocene rocks in Western Kutch (Patel and Shringarpure, 1992). They differentiated two species, analyzed the behavior pattern of the trace maker, and interpreted the associated environmental conditions (Patel and Shringarpure, 1992). Ichnofossils from the late Eocene to early Miocene of the Cambay Basin were studied by Kundal *et al*. (2005), with the presence of

six ichnospecies from the Babaguru Formation (early Miocene). This ichnoassemblage was associated with the *Skolithos* and *Cruziana* facies and littoral to shallow sublittoral zones (Kundal *et al*., 2005). Ichnofossils from Neogene to Quaternary successions were studied by Kundal and Dharashivkar (2006) and Kundal and Mude (2008); in the Dwarka-Okha area, Kundal and Dharashivkar (2006) recognized a rich and diversified ichnofossil assemblage consisting of seventeen ichnospecies, some of them discovered for the first time in the studied area. The stratigraphic distribution of ichnotaxa is presented, as well as morphological, ethological, and ichnofacies classifications. The presence of *Skolithos*-*Cruziana* mixed ichnofacies is interpreted as indicating a littoral to shallow sublittoral sandy shore environment, with very high energy conditions (Kundal and Dharashivkar, 2006). At the Porbandar area, Kundal and Mude (2008) differentiated eight ichnospecies, six of them 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). Recently, Mude (2012a, b) highlighted 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/foreshore 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 behaviors, with a dominance of horizontal traces (Mude, 2012b). The trace fossils are associated with soft grounds, in a shallow water marine environment, with moderate to low energy conditions, and nutrient availability (Mude, 2012).

1.5 OBJECTIVES

Ichnology has become an important tool for deciphering depositional history and correlation. The objectives of the present study are, therefore, to study the ichnofossils from the Upper Bhuban rocks of the Aizawl area with the view to:

1. Demarcate lithic units and build stratigraphic sequence.
2. Systematically study the ichnofossils.
3. Attempt correlation of the Bhuban succession of the study area with the Miocene succession of other areas.
4. Work out the depositional environment and palaeoecology.

1.6 METHODOLOGY

The methodology employed in the present work has been broadly divided into two parts to achieve the objectives of the study. The first part deals with the field observations, data and sample collection, and preparation of the detailed lithologs while the second part deals with the laboratory works including the study of trace fossils, identification, and classification, and preparation of schematic diagrams.

1.6.1 Field Study

The extensive field work has been carried out along three sections of the Upper Bhuban Formation of the Surma Group of Aizawl district *viz.* Kulikawn – S. Hlimen, Temple – Mizoram University and Ramrikawn - Sakawrtuichhun sections. The Survey of India toposheet no. 84 A/9 and 84 A/10 on the 1:50000 scale were used for this study. Field data were collected in terms of lithological variations, physical characteristics of the lithologies, and sedimentary structures during field investigations, which enable to construction of systematic litho-logs along the three studied sections. Diverse assemblages of trace fossils and associated body fossils were collected along with field photographs of those trace fossils which could not be collected were taken. The position of occurrence of trace fossils was marked in the litho-logs in the field itself to show their distribution in the exposed thickness of the successions.

1.6.2 Laboratory Study

The trace fossils collected from the field were then cleaned in the laboratory. Lithologs of the studied sections were prepared and the distribution of trace fossils was marked in litho-column. Identification and systematical description of both the collected and photographed trace fossils were carried out with the help of available published work. The distribution of studied trace fossils in the Miocene succession of India was worked out. Ichnofacies and ethological grouping of the described trace fossils were accomplished. The depositional environment of the studied rock successions of the Bhuban Formation of the Surma Group was worked out based on such ichnofacies and ethological groupings. Finally, the correlation of the studied sections with the Miocene successions from other parts of India where ichnological studies have been performed by other workers has been attempted.

CHAPTER 2

GEOLOGY OF MIZORAM

2. GEOLOGICAL SETTING

2.1 GENERAL GEOLOGY OF MIZORAM

The Cenozoic rocks are well-developed in the northeastern part of India. They constitute one of the largest sedimentary basins, covering about 70% area of the northeast and have nearly 13km. thick sedimentary succession, which is known as the Surma basin. Geologically, Mizoram is a part of this Neogene Surma Basin comprising a belt of a series of elongated folds having sub-meridional trend and arcuate shape with westward convexity. It covers an area of about 21,081 sq. km. between latitudes 22˚00' and 24˚30'N and longitudes 92˚15' and 93˚25'E. The Fold belt is elongated in the N-S direction almost parallel to the suture zone of the Arakan-Yoma subduction. The Tertiary sedimentary succession of Mizoram has been grouped into the Barail (Oligocene), the Surma (Lower to Middle Miocene), and the Tipam Groups (Upper Miocene to early Pliocene) in the ascending order. The Lower-Middle Miocene rocks of Mizoram are represented by the Surma Group of rocks which has been subdivided into Bhuban and Bokabil Formations. Bhuban Formation is the best and thickest developed lithostratigraphic unit in Mizoram attaining a thickness of about 5000m. This Formation is further subdivided into Lower, Middle, and Upper Bhuban units. The entire sedimentary column of the formation is a repetitive succession of arenaceous and argillaceous rocks. The main lithologies exposed are sandstone, siltstone, shale, and mudstone and their admixtures in various proportions and a few pockets of shell limestone, calcareous sandstone, and intraformational conglomerate (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 2.1.

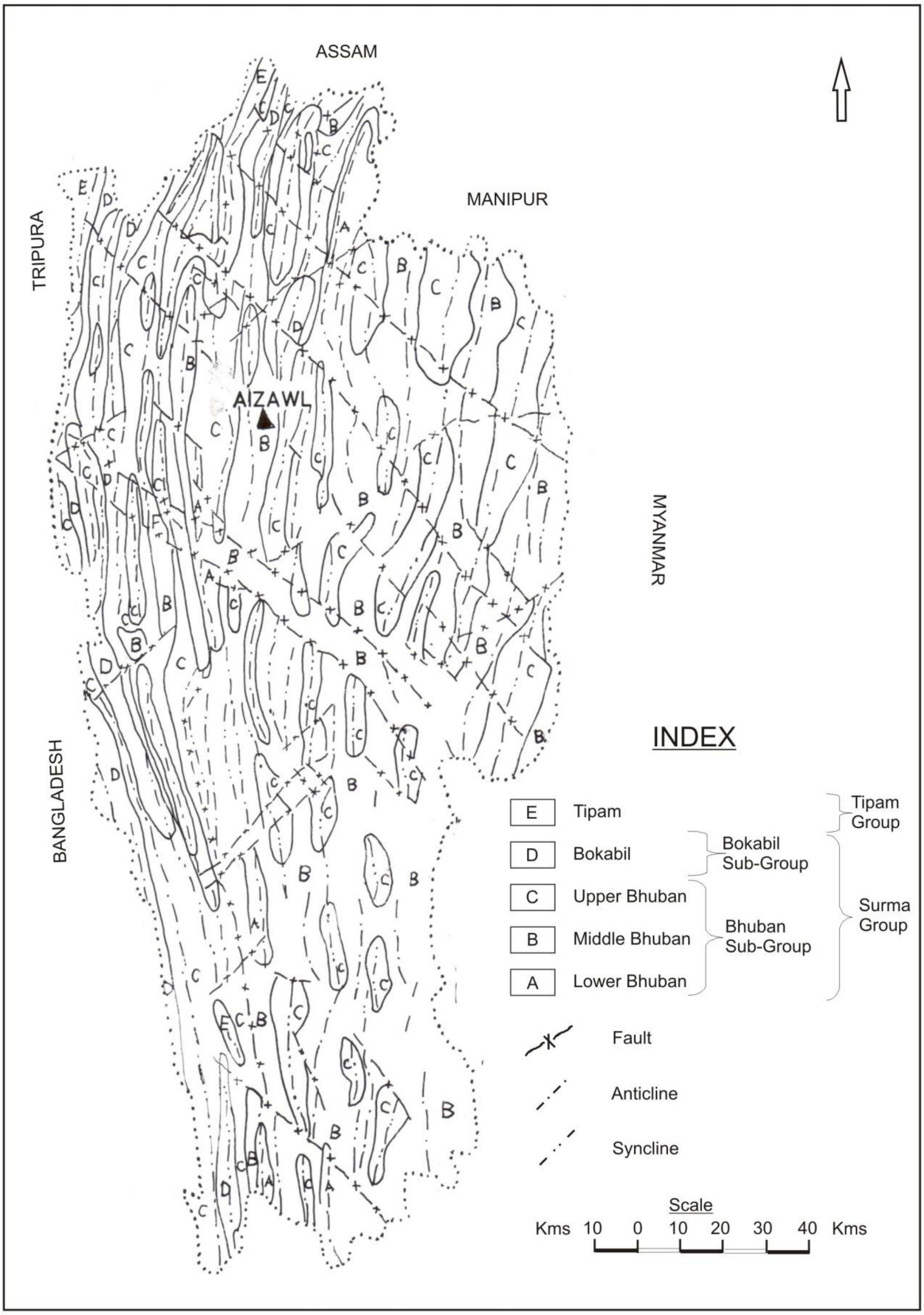


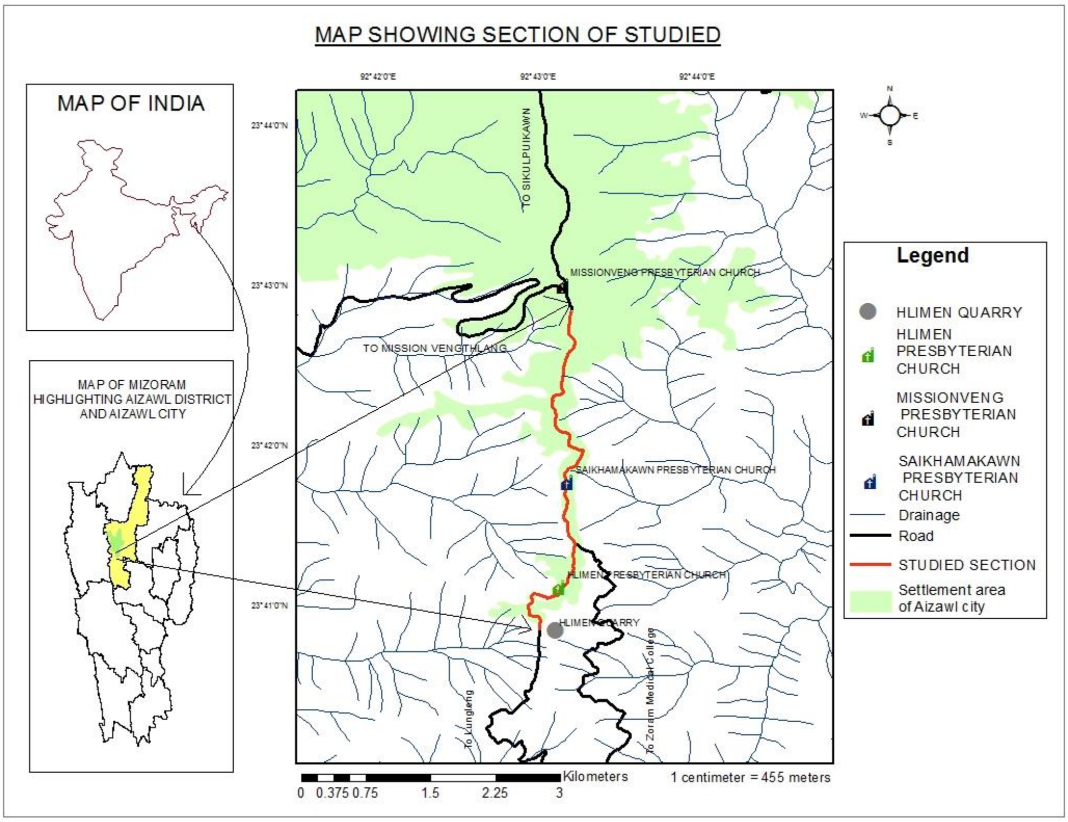
Figure 1: Geological map of Mizoram (after Ganju, 1975).

Table 2.1: Stratigraphic succession of Mizoram (Modified after Karunakaran, 1974 and Ganju, 1975 modified by Tiwari and Kachhara, 2003)

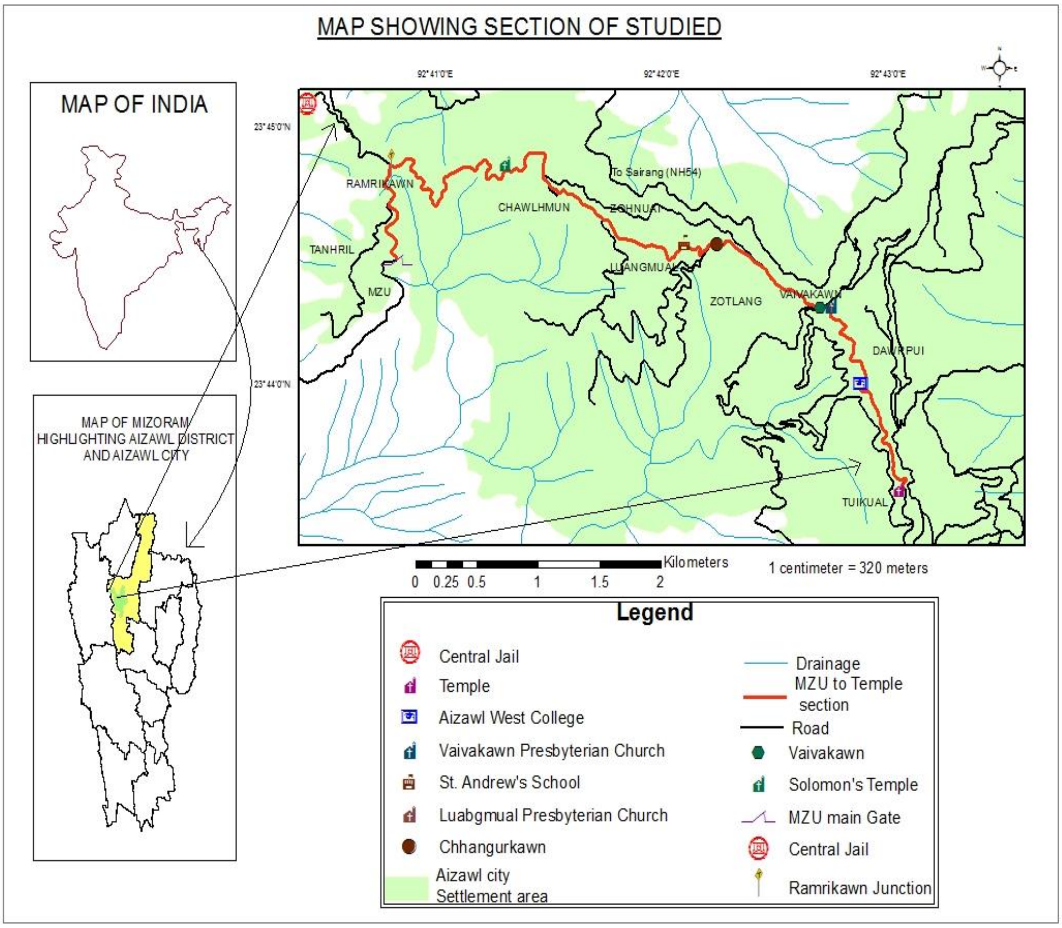
Age	*Group*	*Formation*	*Member*	*Generalized Lithology*
Recent	Alluvium			Silt, clay and gravel
-----Unconformity-----				
Early Pliocene to Late Miocene	Tipam (+900 m)			Friable sandstone with occasional clay bands
-----Conformable and transitional contact-----				
Miocene to Upper Oligocene	S U R M A (+5950 m)	Bokabil (+950 m)		Shale, siltstone and sandstone
		-----Conformable and transitional contact-----		
		B H U B A N (5000 m)	Upper Bhuban (1100m)	Arenaceous predominating with sandstone, shale and siltstone
			-------Conformable and transitional contact--	
			Middle Bhuban (3000m)	Argillaceous predominating with shale, siltstone-shale alternations and sandstone
			-------Conformable and transitional contact--	
			Lower Bhuban (900m)	Arenaceous predominating with sandstone and silty-shale
-----Unconformity obliterated by faults-----				
Oligocene	Barail (+3000 m)			Shale, siltstone and sandstone
-----Lower contact not seen-----				

2.2 GEOLOGY OF THE STUDY AREA

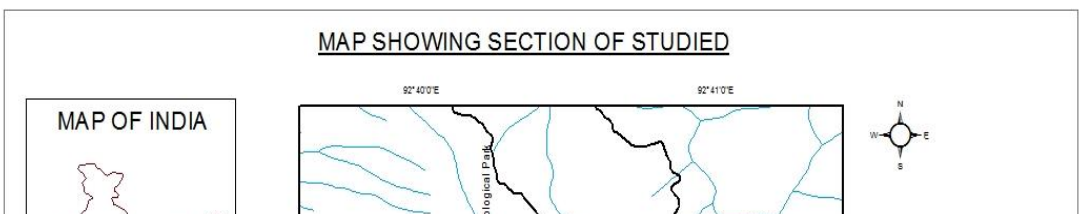
The Upper Bhuban rocks exposed in Kulikawn –Hlimen locality that lies between geographical co-ordinates 23°41’ 52.65” N to23° 41’ 52.65” N and 92° 43’ 04.10” to E 92° 42’ 43.83” E, Temple – Mizoram University between latitudes 23° 43’ 37.17” N to 23°44’ 01.47” N and longitudes 92° 42’ 03.70” E to 92° 40’ 05.40” E and Ramrikawn – Sakawrtuichhun between latitudes 23° 44’ 50.93” N to 23°46’ 01.16” N and longitudes 92° 40’ 47.68” E to 92° 40’ 22.84” E comprises a fossiliferous succession of alternation of sandstone and shale, sandstone bed, siltstone, and their admixtures in various proportion dominated by sandstone. Sandstones are thin-bedded to massive, grey, fine-grained, silty, and poorly sorted and are characterized by small to medium-scale cross-stratification. Shales are light grey to dark grey and contain numerous calcareous concretions. Geologically, this succession belongs to the Upper Bhuban Units of the Bhuban Formation.



(a) Kulikawn- Hlimen Section



(b) Temple-Mizoram University section.



(c) Ramrikawn – Salkawrtuichhun section.

Figure 2: Maps showing the location of the studied sections.

2.2.1 Description of litho-columns:

The rock succession belonging to the Upper Bhuban Formation of the Surma Group has good exposures along three sections, namely, Kulikawn – S. Hlimen, Temple- MZU, and Ramrikawn - Sakawrtuichhun. Extensive fieldwork was carried out along these sections to construct litho-columns, describe sedimentological details, interpret the palaeo-environment, and work out the distribution pattern of trace fossils. A description of litho-columns along these sections is here under.

2.2.1.1 Kulikawn – S. Hlimen:

Rocks of the Upper Bhuban Formation of the Surma Group are studied in Kulikawn – S. Hlimen section, Aizawl. The thickness of the rock succession yielding trace fossils exposed along this section is ~14m. (Fig.2.1). Three major litho-units have been delineated, which comprise sandstone, shale, and shale laminated sandstone bed. Sandstones are grey to buff-colored, thickly bedded, highly bioturbated, and medium to fine-grained. Sedimentary structures such as ripple marks are observed at sandstone beds. Shales are grey to dark grey and are thinly laminated. The lowermost bed comprises grey-colored, medium-grained sandstone about 3 m thick. The overlying sandstone–shale alternation bed is about 2m thick and ripple marks are present at the bedding plane between the sandstone and shale bed. This bed is overlain by a 4 m massive sandstone bed and yielded trace fossil assemblages such as *Anchorichnus* isp., *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Laevicyclus mongraensis*, *Rhizoorallium jenense*, *Rosselia* isp., *Skolithos* isp., *Taenidium* isp. and *Teichichnus rectus*. Ripple marks separated this fossil-bearing sandstone bed from a 2m thick bed of sandstone bed that yield trace fossil *Pholeus abomasoformis* which is then overlain by a 3m thick shale laminated sandstone bed which overlain and underlain by ripple marks. The laminated muddy sandstone facies is interpreted as having been deposited in a tidal-flat environment. The rock succession at the S.Hlimen quarry is highly bioturbated and contains rich assemblages of body fossils.

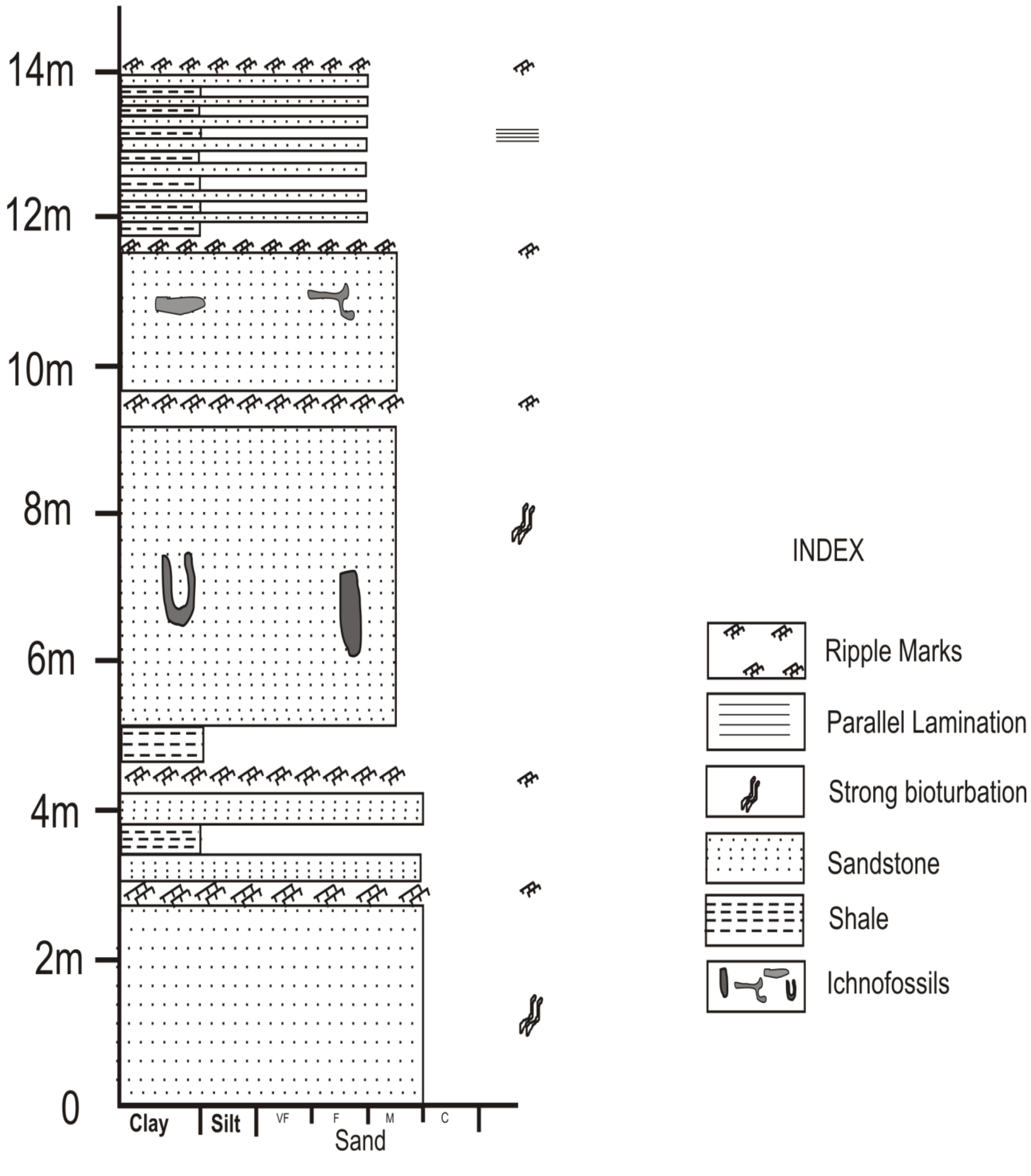


Figure 2.1: Lithocolumn of the Upper Bhuban Formation in Kulikawn – S. Hlimen Section, Aizawl.

2.2.1.2 Temple – Mizoram University:

The study area is situated in the western part of Aizawl City (latitude 23°43'37" N to 23°44'01" N and longitude 92°43'00" E to 92°40'05" E). About 70.2 m (fig.2.2) thick succession belonging to the Upper Bhuban unit of the Bhuban Formation (Lower to Middle Miocene) is well exposed in this section, which comprises sandstone, siltstone, shale, and their admixtures. Ichnological studies have been carried out in three localities along Temple-Mizoram University road where the rock successions are well exposed.

a) Ropaiabawk section:

This section lies at geographical coordinates of 23°44'47.65" N to 23°44'49.05" N and 92°41'28.28" E to 92°41'27.96" E. A 13.8m thick rock succession exposed at Ropaiabawk comprises two major litho units- sandstone bed at the lowermost part of the Formation which is ~ 7m thick and is then overlain by 4.5m thick sandstone-shale alternation characterized by ichnospecies *Palaeophycus* isp, *Planolites monatus*, *Planolites* isp., *Skolithos* isp., and *Thalassinoides \suevicus*. The uppermost part of the succession comprises a fine-grain sandstone bed devoid of ichnofossils. Sandstones are grey to buff in color, thickly bedded, ill-sorted, and medium to coarse-grained. Shales are buff-colored and alternating buff-colored sandstone are of medium grain size. Wave ripples are present at the interface between sandstone and shale bed.

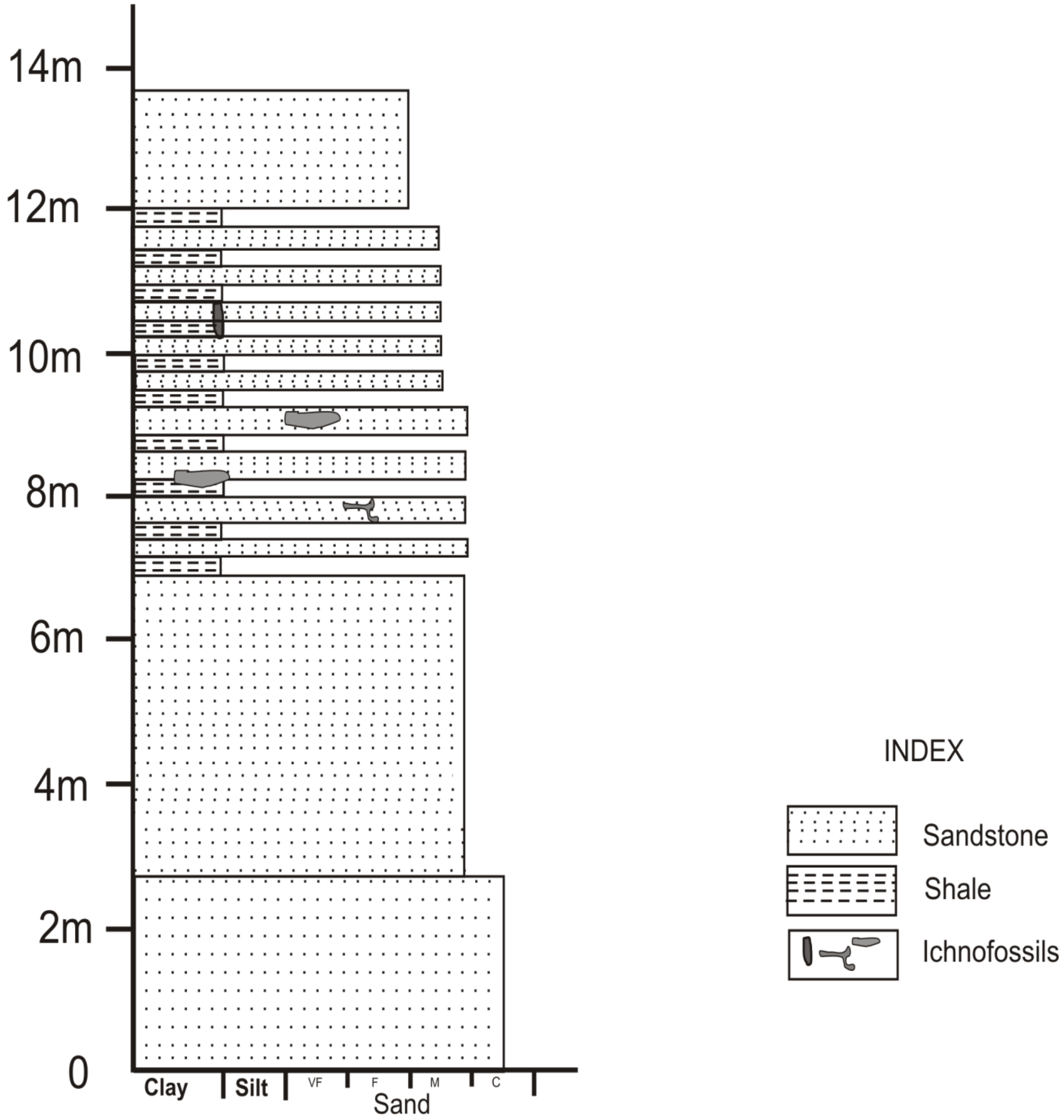


Figure 2.2: Lithocolumn of the Upper Bhuban Formation in Temple - MZU Section Aizawl. (Ropaiabawk area).

b). Tuivamit section

This section lies at geographical coordinates of 23°44’49.50” N to 23°44’51.51” N and 92°41’51.88” E to 92°40’54.02” E. A 38m thick succession (fig.2.3) at the Tuivamit locality has been studied for its ichnofossil distribution. The lithology in this section mainly comprises a 4m thick medium-grained grey-colored sandstone bed overlain by a 2m thick shale bed that is grey and yielded trace fossil *Palaeophycus striatus*. This shale bed is overlain by a 2m thick grey-colored sandstone bed. The middle part of the litho-column is comprised of a 1.8m thick shale laminated sandstone bed, 7 thick sandstone-shale alternations, and a 5m thick brown-colored sandstone bed of medium grain size. Ichnofossils such as *Planolites beverlyensis, Ophiomorpha nodosa*, *Laevicyclus mongraensis*, and horizontal burrows are present. Fossil-bearing sandstone bed is then overlain by a 3.2m thick sandstone-shale alternation and above that is a 3m thick grey-colored sandstone bed which is grey. A 10m thick sandstone-shale alternation bed is present at the uppermost part of the litho-column which is well exposed along the Tuivamit Section and is devoid of ichnofossil.

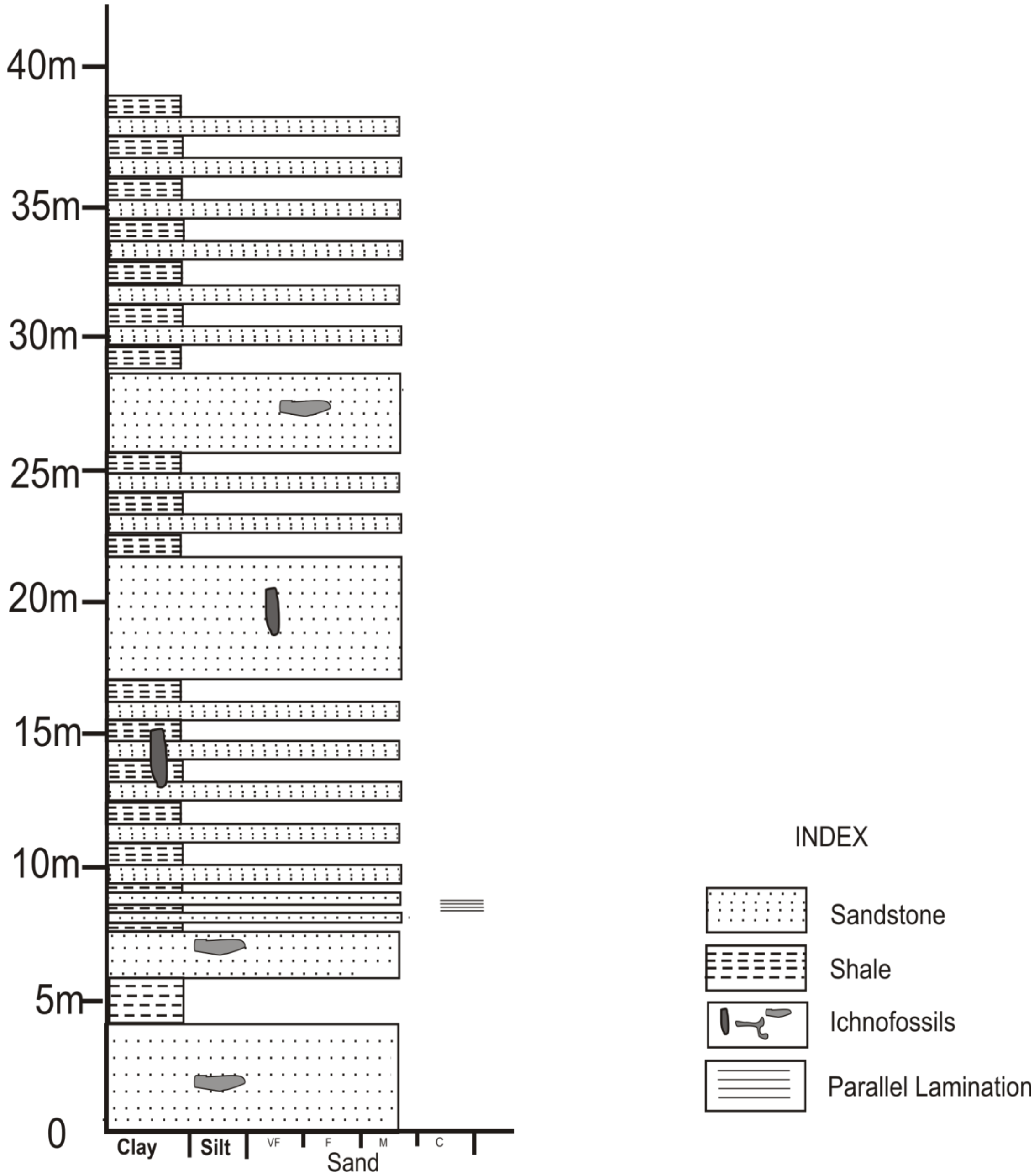


Figure 2.3: Lithocolumn of the Upper Bhuban Formation in Temple – Mizoram University section, Aizawl (Tuivamit area).

2.2.1.3: MZU Road near 6 miles

In this section, the study is carried out at geographical coordinates of 23°44’01.47” N and 92°40’22.74” E the Upper Bhuban Formation is represented by a 18.2 m thick succession of argillites and arenites (Fig. 2.4). The rock types exposed in the study area are sandstone, shale, and their admixtures. Lenticular bedding is observed in the lower part of rock succession, indicating deposition at low energy zones on intertidal flats. Pulmose structure is observed at a thickly bedded sandstone indicating that the rock bed is under tension when fractures rapidly.

The lowermost bed comprises grey colored shale bed which is approximately 2.8m thick, containing trace fossil *Funalichnus bhubani*. Sedimentary structure such as lenticular bedding is observed in shale bed. This bed is overlain by a 6.2m thick brown sandstone bed which is of medium-grained size yielding ichnospecies *Diplocraterion helmerseni*, *Ophiomorpha nodosa*, and *Palaeophycus* isp. Wavy sedimentary structures (mud layer in sand) are observed within this bed. The sandstone bed is then overlain by a 4m thick bed of sandstone-shale alternation characterize by wavy sedimentary structures (sand layer in mud) containing ichnospecies *Cochlichnus anguineus*, *Diplocraterion helmerseni*, *Thalassinoides horizontalis*, *Thalassinoides paradoxicus*, and *Thalassinoides* isp. which is then followed by a 2.2m thick bed of medium-grained sandstone bed and contains ichnospecies *Diplocraterion helmerseni*, *Skolithos* isp. and *Thalassinoides paradoxicus*. The uppermost bed in this section is of 2.2m thick sandstone-shale alternation which is completely devoid of ichnofossil.

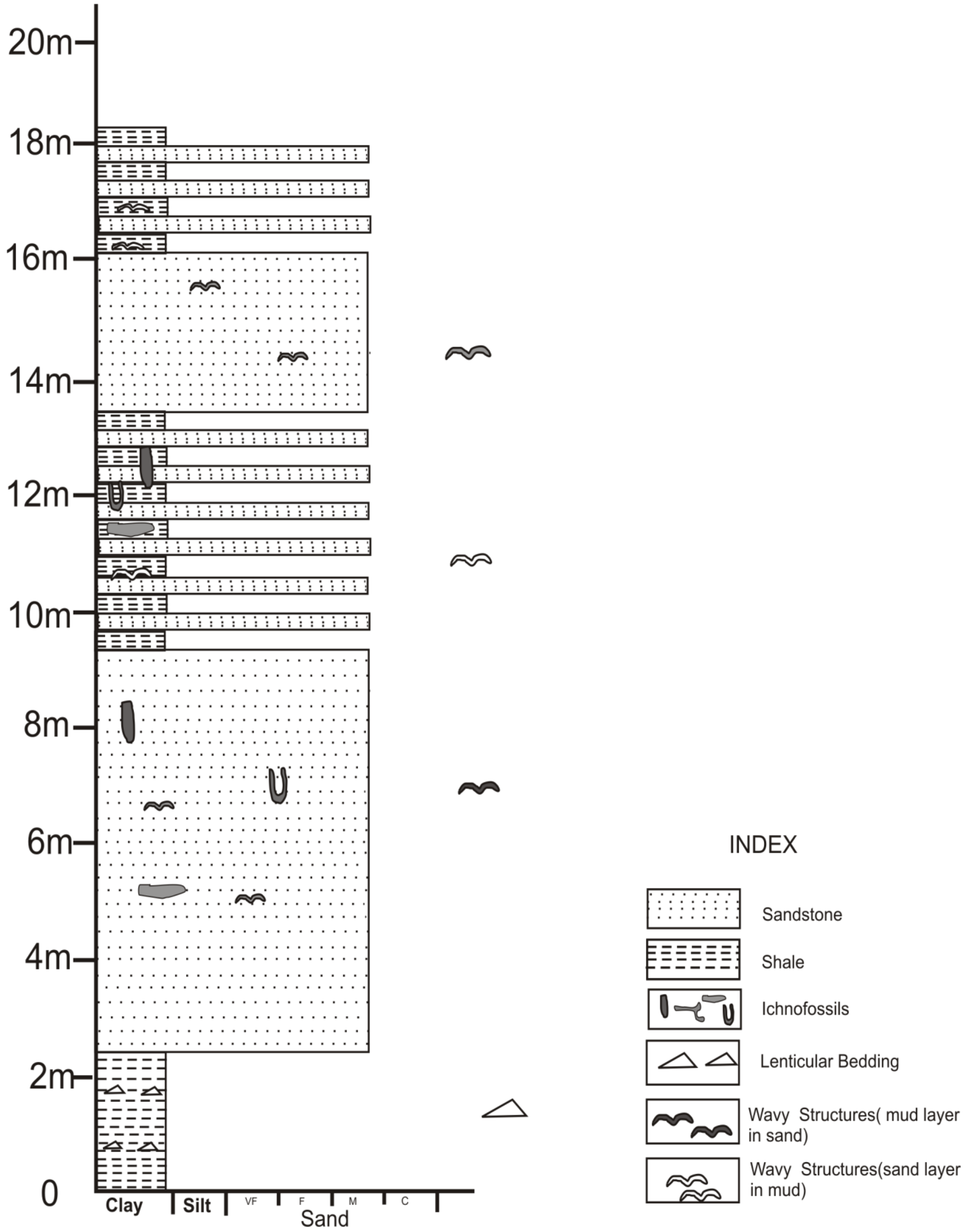


Figure 2.4: Lithocolumn of the Upper Bhuban Formation in Temple- MZU road Section (near 6 miles)

2.2.1.4 Ramrikawn to Sakawrtuichhun Section:

This section lies at geographical coordinates of 23°44’49.50” N to 23°44’51.51” N and 92°41’51.88” E to 92°40’54.02” E. A good exposure of rock-bearing trace fossil si studied along three quarries.

Quarry 1: The litho-column at this section comprises a 3.2m thick sandstone bed at lowermost that contains ichnofossils *Funalichnus bhubani*, *Ophiomorpha nodosa*, *Phycosiphon* isp., *Planolites* isp., *Skolithos* isp and Ichnospecies Type A. This ichnoferous sandstone bed is overlain by a 1m thick shale laminated sandstone bed and contains ichnofossil *Palaeophycus* isp. which is then overlain by 1m thick sandstone bed and 0.8m thick shale laminated sandstone devoid of trace fossil. The thickly bedded, fine to medium-grained sandstone lithology of this succession is highly bioturbated and hosts trace fossils. A 3.8 m of grey-colored, sandstone bed occurs on the top of the shale laminated sandstone bed. Sedimentary structures such as parallel lamination is observed at the rock succession along Quarry 1 of Sakawrtuichhun area (fig. 2.5).

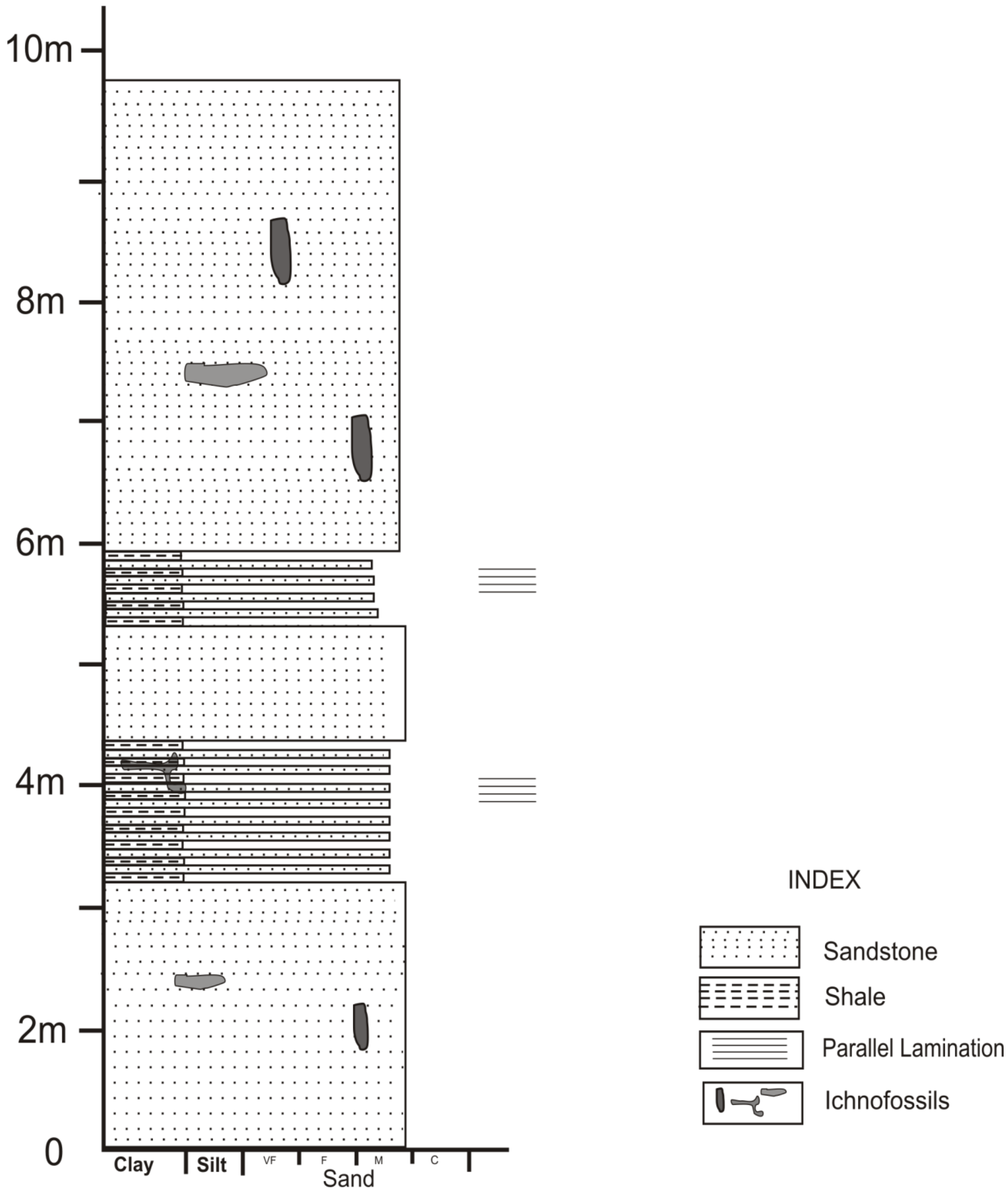


Figure 2.5: Lithocolumn of the Upper Bhuban Formation in Ramrikawn to Sakawrtuichhun Section (Quarry 1).

ii) Quarry 2: Two rock units assigned to the Upper Bhuban Unit of Bhuban Formation, Surma Group are exposed in the quarry. The Upper unit is composed of 5m thick medium to fine-grained sandstone while the lower unit comprises silty-sandstone which is approximately 8m thick. Sedimentary structures such as wavy and cross-stratified nature are present in silty-sandstone beds and are completely devoid of fossils. A 5m thick sandstone bed which is light grey yields ichnofossils *Diplocraterion parallelum, Funalichnus bhubani, Ophiomorpha borneensis, Ophiomorpha nodosa, Palaeophycus tubularis, P. sulcatus, Planolites beverleyensis, Planolites* isp, *Thalassinoides paradoxicus,* and *Thalassinoides* isp. (fig.2.6).

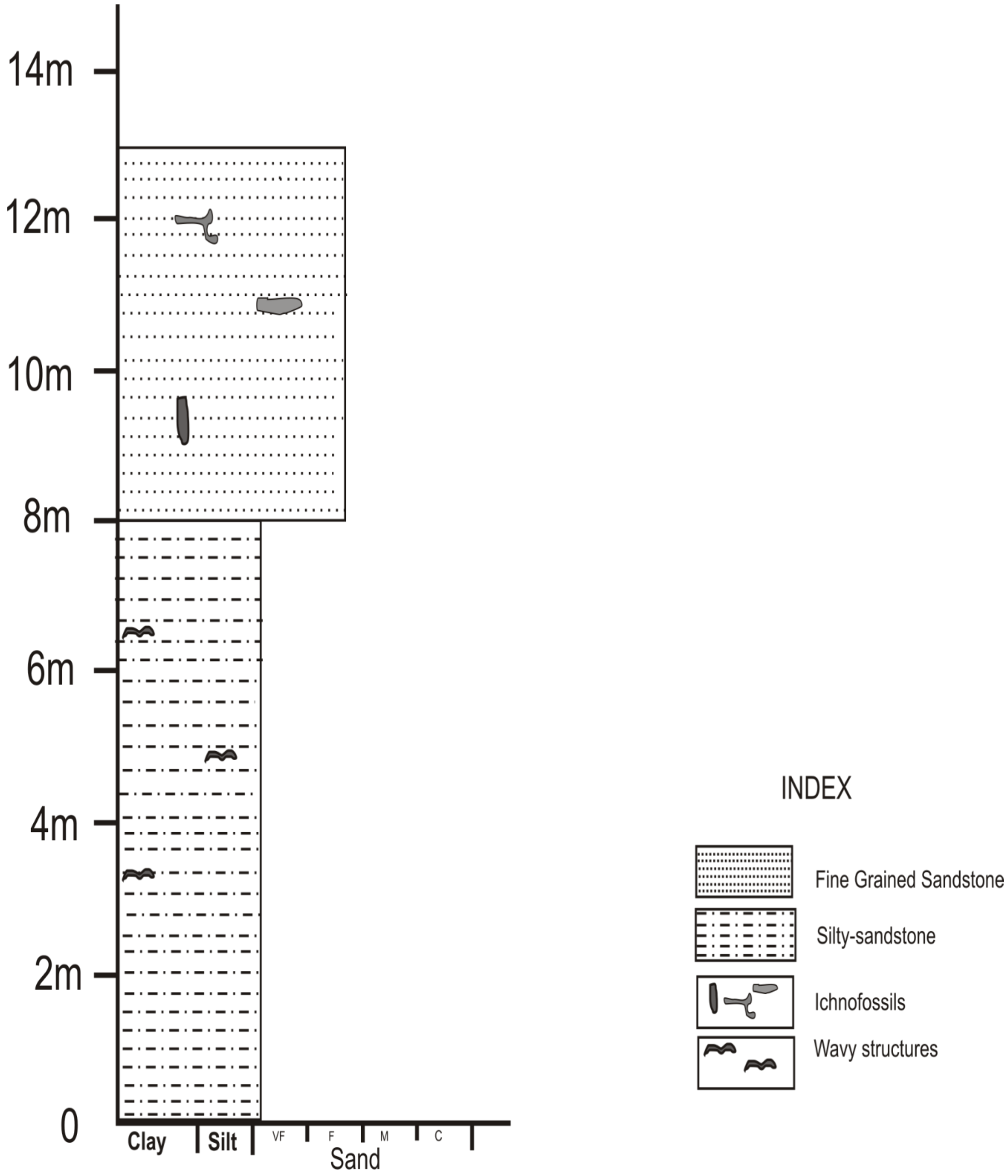


Figure 2.6: Lithocolumn of the Upper Bhuban Formation in Ramrikawn to Sakawrtuichhun Section (Quarry 2).

iii) **Quarry 3:** The lithocolumn comprises two rock units – a 6m thick sandstone bed which is grey at the lower succession overlain by a 1m thick shale laminated sandstone bed. The sandstone bed at the lower unit is of medium grain size and contains ichnofossils such as *Funalichnus bhubani, Ophiomorpha nodosa, Skolithos* isp, and *Thalassinoides paradoxicus.* Shale laminated sandstone bed at the upper unit is devoid of ichnofossils and the sandstone bed is brown in color (fig. 2.7).

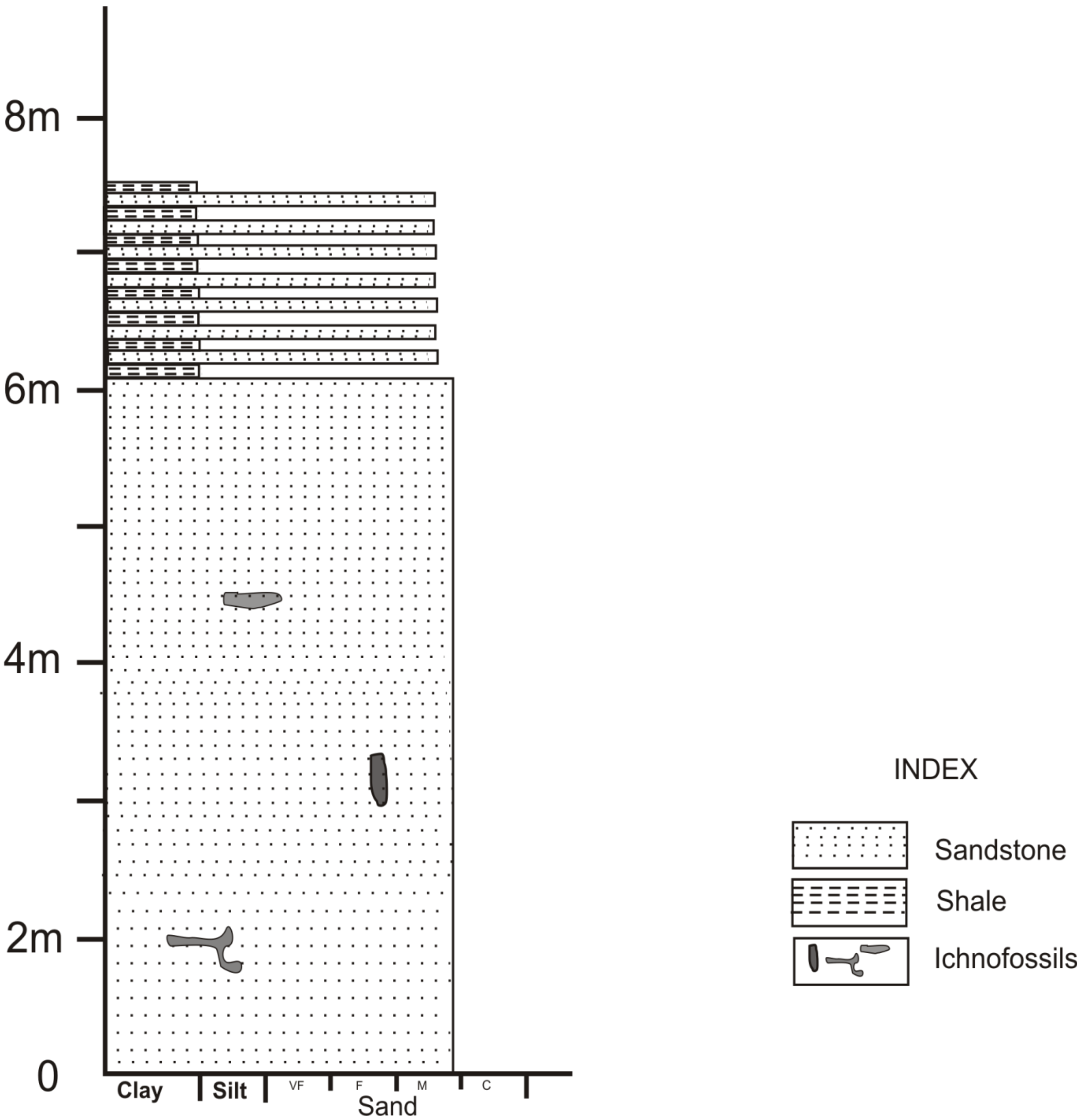


Figure 2.7: Lithocolumn of the Upper Bhuban Formation in Ramrikawn to Sakawrtuichhun Section (Quarry 3).

CHAPTER 3

SYSTEMATIC DESCRIPTION

3. SYSTEMATIC DESCRIPTION OF TRACE FOSSILS

3.1 GENERAL REMARKS:

All the ichnospecies described and illustrated in this thesis are archived in the Palaeontology Laboratory of the Department of Geology, Mizoram University, Aizawl, Mizoram. These include *Anchorichnus* isp., *Cochlichnus anguineus, Diplocraterion helmerseni, Diplocraterion parallelum, Funalichnus bhubani* isp. nov., *Laevicyclus mongraensis, Ophiomorpha annulata, Ophiomorpha borneensis, Ophiomorpha irregulariae, Ophiomorpha nodosa, Palaeophycus tubularis, Palaeophycus striatus, Palaeophycus sulcatus*, *Palaeophycus* isp., *Pholeus abomasoformis, Phycosiphon* isp., *Planolites annularis, Planolites beverlyensis, Planolites* isp., *Rhizocorallium jenense*, *Rosselia* isp., *Skolithos verticalis, Skolithos* isp., *Taenidium isp, Teichichnus rectus, Thalassinoides horizontalis*, *Thalassinoides paradoxicus, Thalassinoides suevic*us, *Thalassinoides* isp, Horizontal burrows, and Ichnospecies Type A. In the present study, complex burrow systems, ichnogenera, and ichnospecies are named according to I.C.Z.N. Rules, using the binomial system of nomenclature and described alphabetically.

3.2 SYSTEMATIC DESCRIPTION:

1. Ichnogenera *Anchorichnus* Heinberg, 1974

Ichnospecies: *Anchorichnus isp*

(Plate 1, fig. A)

Material: Field photograph of grey-colored sandstone with a burrow.

Occurrence: Sandstone bed at the middle part of the lithocolumn at South Hlimen Quarry.

Description: Straight, lined, unbranched burrow, disposed sub-horizontal to the bedding plane. Burrow consists of a central cylindrical meniscus. The outer layer of the burrow is separated from the host rock by sharp discontinuities.

Remarks: The present burrow resembles that of Ichnogenus *Anchorichnus* Heinberg 1974 in morphological character. The presence of mantle distinguished *Ancorichnus* from morphologically similar ichnogenera such as *Beaconites*. It has been documented from the inner-shelf environment (Knightley & Pickerill 1994). Due to the lack of more detailed character, species level cannot be identified and hence is kept under open nomenclature.

Distribution: Frey & Howard (1990) described *Ancorichnus* from the Upper Cretaceous of Utah. M. Chandra Singh *et al*.(2010) Identified and described *Ancorichnus* from the Upper Member of the Bokabil Formation exposed near the Kaiphunda village, Manipur. The present study is the first record of *Ancorichnu*s isp from the Surma Succession of Mizoram.

2. Ichnospecies: *Cochlichnus anguineus* Hitchcock (1858)

(Plate 1, fig. B)

Material: Field photograph of brown and grey colored sandstone with a burrow.

Occurrence: Shale laminated sandstone bed at the uppermost unit of the lithocolumn in Kulikawn – S. Hlimen section and grey colored sandstone-shale alternation at the middle unit of the lithocolumn along MZU section near 6miles
Of Upper Bhuban Unit, Aizawl, Mizoram.

Description: Smooth, sinusoidal, horizontal, unornamented, unlined, and unbranched feeding trails which are preserved as convex epirelief and consisting of identical filled sediments to the host rock. Regular meanders resemble sine. The length of the larger trail is more than 30 cm and the diameter is 2.0cm whereas the smaller trail has a length of 16 cm and a diameter of 1.7cm.

Remarks: Differentiation among the hitherto known species of *Cochlichnus* namely *C.anguineus* Hitchcock (1858), *C. kochi* Ludwig (1869) and *C. serpens* Webby (1970) in the available literature is confusing and these can at best be regarded as conspecific. The present specimen shows regular sinuosity in structures which is identical to *C.*

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

Distribution: Patel *et al*. (2012) reported this ichnospecies from the Jurassic rocks of Gangta Bet, Eastern Kachchh of Western India. *Cochlichnus anguineus* was also reported from the Kaladongar Formation, Patcham Island of Kachchh by Joseph *et al*. (2012). This ichnospecies is being reported for the first time from the Surma succession of Northeast India.

3. Ichnogenera: *Diplocraterion* Torell (1870)

Although some spreite structures in U-shaped burrows are considered to be an expression of sediment feeding, *Diplocraterion* is convincingly interpreted as a burrow of suspension feeders (Seilacher, 1967; Cornish, 1986; Fu¨rsich 1974b). The spreite in *Diplocraterion* most probably reflects animal growth or adjustment to sedimentation and erosion processes (Bromley, 1996). Thus, it can be interpreted as a dwelling tube or an equilibrium structure of a suspension-feeding organism. Bromley (1996), however, noted that *Diplocraterion*-like structures in recent muddy substrates are produced by detritus-feeding amphipods. Assignment to *Diplocraterion* is based on disturbed sediment between circular openings of the burrow interpreted as the expression of the spreite.

Ichnospecies: *Diplocraterion helmerseni* Őpik (1929)

(Plate 1, fig. C & D)

Material: Field photograph of grey-colored sandstone with a burrow.

Occurrence: Sandstone bed at the middle unit of the lithocolumn in Kulikawn – S. Hlimen section and grey colored sandstone at the middle unit of the lithocolumn along MZU section near 6miles of Upper Bhuban Unit, Aizawl, Mizoram.

Description: Vertical U-shaped burrow with protrusive spreiten and broad base; tubes are not parallel to each other and their diameter is also variable (0.7 to 1.4 cm). The burrow penetrates 15 cm in the sediment; the distance between the tubes increases downward and their maximum diameter (1.4 cm) was observed at the base of the burrow. Burrow-filled sediments are darker than the host sediments but spreiten are light-colored.

Remarks: *Diplocraterion helmerseni* differs from the *D. parallelum* by the expanded base and *Corophioide cincinnatiensis* based on the greater regularity of the spreiten. *D.hemerseni* is first recorded from the Surma succession of North-East India by Rajkonwar *et al.*(2013).

Ichnospecies: *Diplocraterion parallelum* Torell (1870)

(Plate 1, fig. E, F & G)

Material: Field photograph of grey-colored sandstone and sandstone-shale alternation with a full relief burrow.

Occurrence: Fine to medium-grained, grey-colored sandstone bed at S. Hlimen Quarry, Sandstone-shale alternation bed at MZU road section near 6 miles, fine to medium grain sandstone bed at Sakawrtuichhun Quarry 1 and Quarry 2 at the Upper Bhuban unit of Aizawl, Mizoram.

Description: Vertical U-shaped spreiten burrow with parallel tubes. Tubes occur cylindrical and circular in cross-section. Burrows are thinly lined and infill sediments are darker than the host sediments but spreiten is light colored. The diameters of burrow tubes are 0.6 cm to 0.8 cm and are 5 cm apart from each other. The burrow appears like a dumbbell in cross-section.

Remarks: *Diplocraterion parallelum* differs from other *Diplocraterion* species by the parallel nature of the burrow tubes with an entire burrow distance. *Diplocraterion* is considered to be a sediment-feeding burrow of suspension feeders (Seilacher, 1967;

Fursich, 1974b) and its spreite most probably reflects animal growth or adjustment to sedimentation and erosional processes (Bromley, 1996).

Distribution: *Diplocraterion parallelum* is earlier described by Fursich (1998) from the Bathonian of Sadhra dome and the Callovian of Habo dome. Desai (2012) and Joseph *et al*. (2012) described this ichnospecies from the Kaladongar Formation of Kachchh. It has been inferred that this ichnospecies is made by a suspension feeder in high energy conditions (Fursich, 1974 a, b and 1975). The present specimen is the first record of *Diplocraterion parallelum* from the Surma succession of Northeast India.

4. Ichnnogenus: *Funalichnus* Pokorny (2008)

Sub-vertical to vertical, straight, simple burrows, ovoid 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 in structureless, homogenous, and finer than the surrounding rock. The ethologic interpretation of the traces of *Funalichnus* is unclear, but they could be dwelling burrows, 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, on the sea floor. The presence of *Skolithos* shafts also suggests a moderate to the high-energy sandy littoral environment, representing the Skolithos ichnofacies. The presence of *Thalassinoides* tunnels can be explained by later sediment accumulation, probably after the change of the environment i.e., a sea-level rise and subsequent decrease in environmental energy (Pek and Mikul´aˇs, 1996).

Ichnospecies: *Funalichnus bhubani* isp. nov.

(Plate 3, fig. H, I, J & K)

Material: Field photograph of sandstone bed and sandstone-shale alternation with a full relief burrow.

Occurrence: Fine to medium-grained, grey-colored sandstone bed in all the Quarries of Sakawrtuichhun section and MZU road section near 6 miles, Upper Bhuban unit, Aizawl, Mizoram.

Description: Endichnial, long, unbranched, vertical to steeply inclined, straight to gently curved, and unlined burrow. The burrow consists of several small cylindrical segments imparting a twisted rod-like structure to the burrow. The interspaces between the cylindrical bodies form curved depressions. The cylindrical bodies of the burrow mostly have uniform dimensions but also show slightly variable dimensions along the length and occasionally also display irregular form. The individual bodies are smooth and are slightly higher as compared to the interspaces, which are usually parallel to the bedding plane and are inclined to the right or left sides. The cross-section of the shaft is circular to subcircular in outline. The maximum observed length of the burrow is 180 mm whereas the diameter of the burrow varies from 12 to 35 mm. Burrow fill is identical to the host sediments.

Remarks: *Funalichnus*, as a new ichnogenus was described by Pokorny (2008) from the Upper Cretaceous of the Bohemian Basin, Czech Republic, and includes the type ichnospecies *Funalichnus strangulatus*. Earlier, it was described as *Hamites intermedius* (Geinitz, 1842 and 1850), *H. strangulatus* (d'Orbigny, 1850; Fritsch and Schoenbach, 1872) and *Fucoides strangulatus* (Fritsch, 1883). Pokorny (2008) described the ichnogenus *Funalichnus*, based on the type material and the additional materials from the subsequent collections from the Upper Cretaceous of the Bohemian Basin, as the small burrow with a maximum length of 51 mm that is characterized by closely spaced swollen ribs with lower termination of the burrow tapering downwards to one side and smooth on the surface. *Funalichnus bhubani* isp. nov. differs from the type ichnospecies of Pokorny (2008) in general morphologic features and dimensions; it is relatively a large burrow with observed length in the range of 120-200 mm and diameter in the range of 10-36 mm. Cylindrical bodies are either symmetrical or asymmetrical and individual segments show slight variation in their morphology and interspaces between them are either horizontal or inclined towards the right or the left side and in some cases diameter gradually increases downwards. *Ichnogyrus nididens* described by Bown and Kraus (1983) shows tight coiling and is symmetrical forming a closed spiral in which successive whorls are in contact. It is a very large burrow; even incomplete burrow with only six preserved whorls measures 22.2 cm in length and 4.6 cm in diameter. The overall architecture of *Ichnogyrus nididens* (Bown and Kraus, 1983) is also different from that of *Funalichnus bhubani* isp. nov. The vertical nature and cylindrical segmented form of *Funalichnus bhubani* isp. nov. indicates that the animal excavated the surrounding compact sediments to its body length and pushed the sediments periodically downward to maintain its position. The nearly uniform nature of the segments points to the systematic work of the animal and also reveals the body size of the burrower.

Periodically filled structures are interpreted as a dwelling structure that may have had some combined feeding habits. Dwelling/feeding structures like *Ophiomorpha* and *Thalassinoides* are abundantly found associated with the described new ichnospecies indicating behaviourally restricted structures that may be interpreted as crustacean burrows. The vertical nature and cylindrical segment form of *Funalichnus bhubani* indicates that the animal excavated the surrounding compact sediments to its body length and pushed the sediments periodically downward to maintain its position. Periodically filled structures are interpreted as a dwelling structure that may have had some combined feeding habits.

5. Ichnogenera: *Laevicyclus* Quensdet (1879)

The ichnogenus *Laevicyclus* is vertical to slightly inclined burrows perpendicular to the bedding planes, scraping circles surrounding a central vertical shaft, two distinct circles visible in transverse section. They are morphologicaly shaft and ethologicaly domichnia. *Laevicyclus* is regarded as the feeding burrow of trace fossil comparable with recent annelid *Scolecolepis* (Seilacher, 1953).

Ichnospecies: *Laevicyclus mongraensis* Verma (1971)

(Plate 2, fig. A & B)

Material: Field photograph of grey-coloured sandstone with a burrow.

Occurrence: Fine to medium-grained, grey colour sandstone bed in Tuivamit section; Fine to medium-grained grey-colored sandstone bed in S. Hlimen Quarry of Upper Bhuban unit, Aizawl, Mizoram.

Description: Endichnical, full relief, vertical cylindrical body making a right angle to the bedding plane and appearing as regular concentric circles. The outer ring is thick and prominent and encloses the inner tube. The burrow shows a maximum outer diameter of 8cm, the central tube is large and prominent with diameter of 2.6cm. The burrow is half cut and exposed due to the erosional factor. The sediment fill is identical to surrounding.

Remarks: Diameter of central shaft and scraping circles show close similarities with *Laevicyclus mongraensis*, Verma (1971).

Distribution: Verma (1971) originally described it from Nimar Sandstone at Mongra, Amba Dongar area, Gujarat. Sanganwar and Kundal (1997) described this ichnospecies from Nimar sandstone Formation, Bagh Group of Madhya Pradesh. Kundal and Dharshivkar (2006) described *L. mongraensis* from Dwarka-Okha area of Jamnagar district, Gujarat. *Laevicyclus mongraensis* also reported from the Jurassic rocks by Patel *et al*. (2008) in mainland Kachchh. Patel *et al*. (2012) also reported it from Jurassic rocks of Gangta Bet of eastern Kachchh. Joseph *et al*. (2012) described this ichnospecies from Kaladongar Formation of Kachchh. This ichnospecies is being reported for the first time from the Surma succession of Northeast India.

6. Ichnogenus: *Ophiomorpha* Lundgren (1891)

Ichnospecies: Ophiomorpha annulata Ksiazkiewicz (1977)

(Plate 2, fig. C)

Material: Field photograph of sandstone with burrow.

Occurrence: Fine to medium grained sandstone bed at MZU road Section near 6 miles, Upper Bhuban unit, Aizawl, Mizoram.

Description: Sub-horizontal, branched burrow. The length of the burrows is up to 20 cm, with a diameter of about 2.0 cm and diameter of the central shaft is 0.4 cm. Branches are slightly winding without enlargement at the bifurcation point. The burrow material is similar with the surrounding sediments.

Remarks: The basic morphological arrangement of the present specimen described herein resembles the ichnogenus Ophiomorpha. The ichnospecies of Ophiomorpha can be differentiate from the other branching burrows on the basis of shape, nature of the lining and the distribution pellets (Frey et al., 1978; Howard and Frey, 1984; Uchman, 2001). Therefore, the wall morphology and horizontal branching structure of the present burrow is similar to Ophiomorpha annulata Ksiazkiewicz (1977).

Distribution: Giannetti and McCann (2010) decribed this ichnospecies from the Palecene rocks of the Zumaya Section, Northern Spain.

Ichnospecies: *Ophiomorpha borneensis* Keij (1965)

(Plate 2, fig. D)

Material: Field photograph of Sandstone with burrow.

Occurrence: Grey coloured sandstone bed of Upper Bhuban unit, Sakawrtuichhun Quarry 2 section, Aizawl, Mizoram.

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

Remarks: According to Frey *et al*. (1978), the morphology of this form is like *O. nodosa* and *O. irregularie* which could be genetically related. Fursich (1973) regarded *O. borneensis* to be synonym of *Spongiliomorpha saxonica* but failed to consider the bilobate pellets.

Distribution: Kundal and Dharashivkar (2006) reported this species from Neogene and Quaternary deposits of Dwarka-Okha area of Gujarat. Mude *et al*. (2012) described this ichnospecies from Mesozoic Jaisalmer basin of Rajasthan and Mude (2011) from the Chaya Formation, Porbandar Group of southwest coast of India. Kundal and Mude (2008) described *O. borneensis* from the Neogene-Quaternary sediments of Porbandar area, Gujarat.

Ichnospecies: *Ophiomorpha nodosa* Lundgren (1891)

(Plate 2, fig. F, G, H & I)

Material: Field photograph of brown coloured sandstone with a burrow.

Occurrence: Fine to medium grained, buff coloured sandstone bed in
MZU road section; Fine to medium grained, grey coloured sandstone in Sakawrtuichhun section; grey coloured sandstone bed in Tuivamit section, UpperBhuban unit, Aizawl, Mizoram.

Description: Endichnial, lined, nranched to unbranched, vertical to inclined burrows. The walls of the burrows consist of regularly distributed discoid pellets. The depths of the burrows are ranges from 20 cm in observed specimens but it also penetrates to more depth. Diameter of the burrow and pellets ranges from 1.5 to 25 cm and 05 to 1 cm respectivly. The burrow fill is same as the host rock but pellet lined structures consist of darker material (muddy clastic sediment) than the host sediment.

Remarks: The morphological characters of the present burrows are similar to *O. nodosa* Lundgren (1891). Different ichnospecies of *Ophiomorpha* are differentiated on the basis of variations in burrow configuration, shape and distribution of the pellets (Frey *et al*., 1978; Howard and Frey, 1984; Uchman, 2001).

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 Quaternary 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 Singh *et al*. (2008, 2010) and Kheidem *et al*. (2015) reported this ichnospecies from the Bhuban Formation of various parts of Manipur.

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

(Plate 2, fig. E)

Material: Field photographs of buff coloured sandstone with two full relief burrows.

Occurrence: Sandstone-shale alternation bed at MZU road section, Middle Bhuban unit, , Aizawl, Mizoram.

Description: Full relief and endichnial burrows with vertical shafts; lined and packed with the different sized pellets which are irregularly distributed over burrow tubes. Merging of pellets make an irregular form of lined structures, thickened the wall and also form mud lumps at lower end.. The wall of the burrow is composed of ferruginous and argillaceous material and shows distinctly irregular rugose exterior surface. The burrow fill and the host rock are composed of contrasting material.

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

Distribution: Kundal and Dharashivkar (2006) reported this species from Neogene and Quaternary deposits of Dwarka-Okha area of Gujarat. *Ophiomorpha irregulaire* has also been described by Patel et al. (2012) from the Jurassic rocks Gangta Bet, Kachchh. Kundal and Mude (2008) described *O. irregulaire* from the Neogene-Quaternary sediments of Porbandar area, Gujarat and Mude (2011) from the Chaya Formation, Porbandar Group of southwest coast of India.

7. Ichnogenus: ***Palaeophycus*** Hall (1847)

Palaeophycus is essentially cylindrical, predominantly horizontal, straight, slightly curved or undulating, ornamented or smooth, branched or unbranched, lined burrow. Bifurcations are irregular and without swelling. Filling typically massive, similar to the host rock (compiled after: Pemberton and Frey, 1982; Fillion and Pickerill, 1984, 1990; Keighley and Pickerill, 1995). *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). *Palaeophycus* is interpreted as structures produced by deposit-feeders or predators, usually moving parallel to the sediment surface (Pemberton and Frey, 1982).

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

(Plate 2 J & K)

Material: Field photograph of sandstone bed withburrow.

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

Description: Endichnial, full relief, long, horizontal, smooth, straight and cylindrical, unbranched, unornamented and lined burrow. Maximum observed length of the burrow is 7 cm and diameter is 0.8 to 1.3 cm; burrow is compressed, appears as elliptical in cross section and filled with the same sediment as the host rock.

Remarks: 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). Present form is classified as *P. tubularis* on account of the horizontal smooth, straight, long and unbranched burrows with distinct lining.

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-Quarternary 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 Surma Group of Manipur (Singh *et al*., 2010).

Ichnospecies: *Palaeophycus striatus* Hall (1852)

(Plate 2, fig. L)

Material: Field photograph of grey coloured sandstone with burrow.

Occurrence: Fine to medium grained, grey coloured sandstone bed at Upper Bhuban unit, Tuivamit section, Aizawl, Mizoram.

Description: Horizontal, straight, unbranched, full relief, thinly lined burrow having afaint striations. The length of the burrow is 7 cm and diameter is 1.2 cm. The burrow is fill is identical to the host rock.

Remarks: This ichnospecies can differ from the other ichnospecies of *Palaeophycus* on the basis of having striations. Although striations are not clearly visible on the burrow due to erosion, the specimen is assigned to *P. striatus* considering the gross morphology.

Distribution: Kundal and Sanganwar (2000) described *P. striatus from* the Nimar Sandstone Formation, Bagh Group of Madhya Pradesh. Joseph *et al*. (2012) reported this ichnospecies from the Kaladongar Formation of Patcham Island, Kachchh.

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

(Plate 2, fig. M)

Material: Field photograph of sandstone bed with burrow.

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

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

Remarks: Pemberton and Frey (1982) and Keighley and Pickerill (1995) reviewed the controversies between *Planolites*, *Palaeophycus* and *Macaronichnus* and suggested *Palaeophycus* to be lined burrows. *Palaeophycus sulcatus* differs from *P. striatus* by anastomosing rather than longitudinal striations and from *P. alternatus* in having consistent rather than alternating striations (Crimes and McCall, 1995).

Ichnospecies: *Palaeophycus* isp.

(Plate 2, fig. N)

Material: Field photograph of buff coloured sandstone- shale alternation with a full relief burrow.

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

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

Remarks: The present burrow is identified as *Palaeophycus* because of its essentially horizontal, lined and unbranched character (Pemberton and Frey, 1982). The collapse nature of the burrow is restricting to species level identification. *Palaeophycus* is eurybenthic, facies-crossing form produced by poltchaetes or annelids (Pemberton and Frey, 1982).

Distribution: Patel and Shringarpure (1990) reported *Palaeophycus* from the Aquitanian, Burdigalian and Helvetian deposits of Gujarat and Parcha and Singh (2010) from the Cambrian rocks of Zanskar region of Ladakh Himalaya. From Northeastern region the ichnospecies has been reported by Mehrotra *et al*. (2002) and Lokho and Singh (2013) from Barail and Surma Group of Mizoram, respectively.

8. Ichnogenus: *Pholeus* Fiege (1944)

Ichnospecies: *Pholeus abomasoformis* Fiege (1944)

(Plate 3, fig. A)

Material: Field photograph of grey sandtone with burrow.

Occurrence: Grey colouredsandstone bed at S. HLimen quarry, Upper Bhuban unit, Aizawl, Mizoram.

Description: Endichnial, full relief, thinly lined, cylindrical burrow circular in cross-section. The burrow is consisting of gently curved, thick horizontal arm accompanied by a smaller upward oriented shaft at the opposite side of the burrow opening. The horizontal arm consists of faint scratch mark. The length of the burrow in horizontal arm is 13cm and diameter varies from 3cm to 6cm.

Remarks: *Pholeus abomasoformis* is the simplest and smallest form with no branching and is elliptical in cross-section (Knaust, 2007). The general structure of *Pholeus* in combination with the smaller vertical shaft burrow lining and scratch ornament are clear fingerprints indicating crustaceans as its producer (Knaust, 2002). The ichnospecies *Pholeus abomasoformis* is being reported for the first time from the Surma succession of Northeast India. It is horizontal burrow, morphologically tunnel and ethologically fodinichnia.

9. Ichnogenus*: Phycosiphon*

The ichnogenus *Phycosiphon* are small trace fossil that consist of a tube recurving as a series of lobes. The structure is filled with fne-grained material and surrounded by a mantle with coarser grain than the central fill. *Phycosiphon* isp. are deposit feeders, fully marine and possible tracemaker are vermiform organisms.

Ichnospecies: *Phycosiphon* isp.

(Plate 3, fig. B)

Material: Field photograph of sandstone bed with burrow.

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

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

Remarks: The size range of *Phycosiphon* and *Anconichnus* are virtually identical and their highly recurved shapes are similar (Fischer and Paulus, 1969; Goldring *et al*., 1991). Both have protrusive spreite lobes but the plane of these lobes is different. *Anconichnus* is supposed to be vertical to oblique (Kern, 1978) and less commonly horizontal (Goldring *et al*., 1991), whereas *Phycosiphon* is horizontal to oblique and seldom vertical.

10. Ichnogenus: *Planolites* Nicholson (1873)

The ichnogenus Planolites is unlined, rarely branched, straight or tortuous, smooth surface, irregular or annulated, circular or elliptical in cross-section, of variable dimensions and configuration; homogeneous, structure less in fillings of burrows, differing in lithology from the host rock (Pemberton and Frey, 1982; Stanley and Pickerill, 1998). Planolites Nicholson is morphologically very similar to Palaeophycus Hall, 1847. Differences between them were for which delineated by Pemberton and Frey (1982), Fillion and Pickerill (1990) and Keighley and Pickerill (1995). Planolites is a very common structure, produced by worm like deposit feeders in all facies (Pemberton and Frey, 1982; Fillion and Pickerill, 1984). It is horizontal burrow, morphologically tunnel and ethologically fodinichnia.

Ichnospecies: *Planolites annularis* Walcott (1890)

(Plate 3, fig. C)

Material: Field photograph of buff coloured silty-sandstone with burrow.

Occurrence: Grey coloured sandstone bed of Upper Bhuban unit, MZU Road section, Aizawl, Mizoram.

Description: Endichnial, full relief, horizontal, large, straight to gently curved, semicircular burrows exhibiting faint transverse annulations which are preserved on right side of the burrow. The burrow is exceptionally large and attains length more than 15 cm and diameter of 1 to 1.5 cm. Burrow lack lining and fill material is identical to the host rock.

Remarks: The distinct annulations distinguish this species from *P. beverleyensis*. Annulations possibly reflect the peristaltic movements of the trace maker.

Distribution: Kundal and Sanganwar, (1997, 2000) described this ichnospecies from various parts of Nimar Sandstone Formation of. Madhya Pradesh. Mude *et al*. (2012) also described it from the Mesozoic Jaisalmer Basin of Rajasthan.

Ichnospecies: *Planolites beverleyensis* Billings (1862)

(Plate 3, fig. E & F)

Material: Field photograph of Sandstone bed with burrow.

Occurrence: Grey coloured sandstone bed in Sakawrtuichhun and Tuivamit section of Upper Bhuban unit, Aizawl, Mizoram.

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

Remarks: Planolites is a broad ichnogenus ranging from Precambrian to Recent (Hantzschel, 1962; Crime and Anderson, 1985). *Planolites beverlyensis* is eurybenthic, extreamely facies crossing form, interpreted as Pascichnia and referred to polyphyletic vermiform deposit-feeders producing active backfilling (Rodriguez-Tovar and Uchman, 2004). As, the burrow fill is different from that of the host rock and burrows are straight to tortuous, they are identified as *Planolites beverleyensis* (Billings) (Pemberton and Frey, 1982). The genus *Planolites* is commonly recognized from shallow water marine environment (Seilacher, (1967).

Distribution: *Planolites beverlyensis* has been reported from various parts of Indian e.g. Patel *et al*. (2008) from the Jurssic rocks of Habo Dome, Kachchh; Mude *et al*. (2012) from Mesozoic Jaisalmer basin of Rajasthan; Malarkodi *et al*. (2009) from the Palaeocene sediments of Pondicherry; Joseph *et al*. (2012) from the Kaladongar Formation of Kachchh. Borkar and Kulkarni (1992) and Kundal and Sanganwar (1998, 2000) recorded *Planolites beverleyensis* (Billings) from the Wadhawan Formation of Gujarat and Bagh Group of Madhya Pradesh, respectively. Kundal *et al*., (2005) documented it from the Babaguru Formation at Bhilod village, Broach district, Gujarat. Kundal and Dharashivkar (2006) recorded this species from the Shankhodhar Sand-Clay Member of the Dwarka Formation. Recently, it has been recorded from the Ambalapuzha Formation (Warkalli Beds, Mio- Pliocene) at Papanasam, Varkala cliff Section (Mude *et al*., 2012). In Northeast India *P. beverlyensis* has been described by Singh *et al*. (2010) from Western Hill of Manipur.

Ichnospecies: *Planolites montanus* Richter

(Plate 3, fig. D)

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

Occurrence: Fine grained brown coloured shale of Upper Bhuban unit, Ropaiabawk section, Aizawl, Mizoram.

Description: Straight to slightly irregularly curved burrows, tubes approximately 4cm long and 0.5 mm to 4 mm wide circular tubes. These burrows, tubes are unbranched, curved, irregularly developed and slightly expanded at one end. Overall structures are parallel to bedding plane. The sediment filling of the tubes are made up of different material as of the host rock.

Remarks: Burrows are undulose, tortuous and isolated. They are disposed parallel to the bedding plane and preserved as positive epirelief. *P. montanus* is an unlined burrow infilled with sediments having textural and fabricational characters different from host rock. Present burrows are small in diameter and tortuous in nature. Hence, they are placed under *Planolites montanus* (Pemberton and Frey, 1982). They are interpreted morphologically as tunnel and ethologically as fodinichnia.

Distribution: Many researchers like Badve and Ghare (1978, 1980); Sanganwar and Kundal (1997); Kundal and Sanganwar (1998, 2000) reported this ichnospecies from Bagh Group of Madhya Pradesh while Chiplonkar and Ghare (1979) documented it from Trichinopoly Group, Tamil Nadu. Kundal *et al*., (2005) documented this from Babaguru Formation, Bhilod village, Broach district, Gujarat. Mude *et al*. (2012) described it from the Mesozoic Jaisalmer Basin of Rajathan. Kundal and Dharashivkar (2006) reported this ichnospecies from Shankhodhar Sand Clay Member (Dwarka Formation) at Dingeshwar Mahadev cliff. Singh *et al*. (2008) reported *P. montanus* from the Eocene-Lower Oligocene transition of Mainpur.
made by the suspension/deposit feeder polychaetes (Fursich, 1981).

Ichnospecies :*Planolites* isp.

(Plate 3, fig. G, H & I)

Material: Field photograph of sandstone with borrow.

Occurence: Fine to medium, grey colored sandstone bed at SAwkartuichhun Quarry and Brown sandstone bed of Ropaiabawk section, Upper Bhuban Unit, Aizawl, Mizoram.

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

Remarks : The morphological character of the present burrow resemble to t hat of *Planolites*Nicholson. Specis level identification is not attempt due to lack of more detail morphologic feature and hence is kept under open nomenclature.

Distribution: Many researchers like Badve and Ghare (1978, 1980); Sanganwar and Kundal (1997); Kundal and Sanganwar (1998, 2000) reported this ichnospecies from Bagh Group of Madhya Pradesh while Chiplonkar and Ghare (1979) documented it from Trichinopoly Group, Tamil Nadu. Kundal *et al*., (2005) documented this from Babaguru Formation, Bhilod village, Broach district, Gujarat. Mude *et al*. (2012) described it from the Mesozoic Jaisalmer Basin of Rajathan. Kundal and Dharashivkar (2006) reported this ichnospecies from Shankhodhar Sand Clay Member (Dwarka Formation) at Dingeshwar Mahadev cliff. Singh *et al*. (2008) reported *P. montanus* from the Eocene-Lower Oligocene transition of Mainpur.
made by the suspension/deposit feeder polychaetes (Fursich, 1981).

11. Ichnogenus: ***Rhizicorallium*** Zenker (1836)

Rhizocorallium traces are U-shaped burrows with spreiten that occur oblique to bedding. There is no consensus on the *Rhizocorallium* producers. Most authors agree that this tracemaker probably pertains to crustaceans. The lifestyle proposed for the Rhizocorallium producer varies according to the morphological features of the burrows. Bromley (1996) suggested *Rhizocorallium* is a dwelling and feeding trace and was formed by a suspension-feeder of unknown origins. *Rhizocorallium* occurs in greatly variable settings; usually related to unstable sedimentary environments, i.e. foreshore, high-energy regimes (Fursich 1975), it is also related to more intermediate shoreface depths (Worsley & Mork 2001), in the middle ramp setting (Knaust 1998), or in deep waters (Uchman 1992). This structure also occurs in fresh water environments (Fursich & Mayr 1981).

Ichnospecies: *Rhizocorallium jenense* Zenker (1836)

(Plate 3, fig. J)

Material: Field photograph of sandstone bed with burrow.

Occurrence: Fine to medium grained and grey colour sandstone Upper Bhuban Unit at S. Hlimen section, Aizawl, Mizoram.

Description: Full relief, slightly curved, horizontal to sub horizontal, unbranched U-shaped burrow containing spreiten. The limbs of the burrow filled with fine to medium grained sediments identical to the host rock. The distance between two limbs is 3.5 cm; maximum observed length of the burrow is about 7.2cm with a diameter of about 0.6cm.

Remarks: The present specimen exhibites similar morphological characters with the *Rhizocorallium jenense* described by Singh *et al*., (2008) from the Upper Eocene–Lower Oligocene succession of Manipur. It is interpreted as a burrow of suspension feeders (Fursich, 1974b) or scavenging organisms (Worsley and Mork, 2001). Singh *et al*. (2008) suggest that *R. jenense* occurs in greatly variable settings; usually related to unstable sedimentary environments, i.e. foreshore, high-energy regimes (Fursich, 1975), it is also related to more intermediate shoreface depths (Worsley and Mork, 2001), in the middle ramp setting (Knaust, 1998), or in deep waters (Uchman, 1992). Fursich and Mayr (1981) described this structure from the fresh water environments. *R. jenense* is generally related to transgressive surfaces, produced during a period of non-deposition, before and at the beginning of the subsequent deposition (Uchman *et al*., 2000; Rodriguez-Tovar *et al*., 2007). The ichnospecies is interpreted to indicate firmground (Desai, 2012).

Distribution: Desai (2012) and Joseph *et al*. (2012) described *R. jenense* from the Kaladongar Formation of Kachchh. Patel *et al*. (2008) described it from the Jurassic rocks of Habo Dome area, Kachchh. Recently, Khaidem *et al*. (2015) reported *R. jenense* from the flysch sediments of Laisong area of Manipur. `

12. Ichnogenus: *Rosselia* Dahmer (1937)

Ichnospecies: *Rosselia* isp.

(Plate 3, fig. K)

Material: Field photographs of grey coloured sandstone with burrows.

Occurrence: Fine grained and grey coloured sandstone bed of Upper Bhuban unit, S. Hlimen section, Aizawl, Mizoram.

Description: Vertical to oblique full relief burrows with concentric infill around an offcentered cylindrical shaft. Cocentric infill is form by an alternation of sandstone and mudstone laminae but sandstone laminae tend to be thicker producing a sand dominated infill. The thickness of the concentric laminae is 2 to 6 mm. Diameter of the burrow slightly or gradually varies along the axis resulting in a faint, bulbous morphology. The lining consists of nested concentric laminae. The sediment within the central shaft is lithologically similar to that of the host sediment.

Remarks: Several workers have compared *Rosselia* with the ichnogenera *Asterosoma* and *Cylindrichnus* (Chamberlain, 1971; Ha¨ntzschel, 1975; Frey and Howard, 1985; Desjardins *et al*., 2010). Frey and Howard (1985) noted that *Rosselia* has a similar concentric sand-mud infill to that of *Cylindrichnus concentricus*. 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 (Seilacher, 2007). *Rosselia* isp. represents a dwelling structure of detritus feeding organisms and terebellid polychaetes have been suggested as trace makers in younger examples (Hofmann *et al*. 2012). They resemble pillar-shaped burrows similar to those described as ‘‘stacked’’ variants by Nara (2002). *Rosselia* from the Bhuban Formation exhibit a sandstone-dominated infill and an offcenter inner tube. Howevof er, the presence of thin mudstone laminae reveals a concentric infill. Similar specimens of *Rosselia* have been described from the lower Cambrian Gog Group of the Canadian Rockies (Desjardins *et al*., 2010).

Distribution: Kundal and Sanganwar (1998) described *Rosselia* from the Nimar Sandstone of Bagh Beds, Madhya Pradesh.

13. Ichnogenus: *Skolithos* Haldemann (1840)

The genus *Skolithos* is widely recognized in near shore /shallow water marine environment (Seilacher, 7). Such types of burrows are resultant of suspension feeding of polychaetes like *Amphinome rostrata* and *Nereis costoe* (Patel and Desai, 2009). Straight tubes or pipes perpendicular to bedding plane, shafts parallel to each other, subcylindrical to cylindrical, unbranched. They are interpreted as domichnion activities of suspension feedin organisms.

Ichnospecies: *Skolithos verticalis* Hall (1843)

(Plate 4, fig. A & B)

Material: Field photograph of buff coloured sandstones and grey colored sandstone bed with a full relief burrow.

Occurrence: Fine to medium grained, buff colour sandstone bed along MZU Road section; Grey colored sandstone bed at S. Hlimen Quarry of Upper Bhuban unit, Aizawl, Mizoram.

Description: Burrows isolated, unbranched, cylindrical, lined and perpendicular to the bedding plane and widely spaced or as isolated form. The dimensions of the burrows vary in different burrow population; maximum observed depth is 8 cm and diameter varies from 08 to 1.3 cm. The burrows are emplaced in fine grained sandy sediments and filled fine grained muddy sediments which are dark in colour and structureless.

Remarks: *Skolithos verticalis* differs from the *Skolithos linearis* by the filled materials, later is filled with muddy sediments. *Skolithos verticalis* has rough, annulated burrow walls. It is widely recognized in the shallow water, intertidal deposits (Seilacher, 1967) and various shallow marine environments (Fillion and Pickerill, 1990; Alpert, 1974) and is probably thought to be produced by annelids or phoronids (Alpert, 1974).

Distribution: Patel *et al*. (2012) described this ichnospecies 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 this ichnospecies from the Palaeocene sediments of Pondecherry area while Reddy *et al*. (1992) recorded it for the first time from the Tipam succession of Assam.

Ichnospecies: *Skolithos* isp.

(Plate 4, fig. D & E)

Material: Field photograph of grey coloured grey sandstone and brown colored sandstone-shale with a full relief burrow.

Occurrence: Fine grained and grey colour sandstone bed Sakawrtuichhun 1 & 2 section, Brown colored sandstone-shale alternation at Ropaiabawk of Upper Bhuban Unit, Aizawl, Mizoram.

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

Remarks: Present specimens are placed under *Skolithos* as these exhibit isolated, unbranched, cylindrical tubes, perpendicular to bedding plane. *Skolithos* burrows widely recognized in the shallow water, intertidal deposits (Seilacher, 1967) and in various shallow marine environments (Fillion and Pickerill, 1990; Alpert, 1974) and the probable producers are annelids or phoronids (Alpert, 1974). Lokho and Singh (2013) reported *Skolithos* from the Bhuban Formation of Mizoram.

14. Ichnogenus: *Taenidium* Heer (1877)

The ichnogenus is variously oriented, unlined, straight, curved or sinuous, cylindrical trace fossil, containing a segmented fill, articulated by meniscus-shaped partings. Secondary branches may be present, but true branching is absent (D'Alessandro and Bromley, 1987; Keighley and Pickerill, 1994). *Taenidium* Heer, 1877 is a meniscate structure with a back fill, 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). The taxonomy of this ichnogenus and similar ichnotaxa has been discussed by D'Alessandro and Bromley (1987) and Keighley and Pickerill (1994).

Ichnospecies: *Taenidium* isp.

(Plate 4, fig. F)

Material: Field photograph of grey coloured shale bed with full relief burrow.

Occurrence: Fine grained sandstone bed of Upper Bhuban unit, S. Hlimen section, Aizawl, Mizoram.

Description: Concave and convex, hyporelief, endichnial burrows horizontal to to bedding, straight to gently curved backfilled burrows and the fills consisting of meniscate packets. The meniscates are symmetrical and equally spaced and shows prominent relief.

Remarks: *Taenidium* differs from other ichnospecies in its arcuate menisci more or less equally sized packets of alternating sediment types (D'Alessandro and Bromley, 1987). Few ichnospecies have also been encountered in marine settings (Keighley and Pickerill, 1994). It has been reported from the Mesozoic and Cenozoic flysch of Europe (Heer, 1877) and from the Ordovician deposits of the Ouachita Mountain

(Chamberlain, 1971). The cylindrical burrow exhibits typical periodic filling of tunnel in backward direction.

Distribution: Patel *et al*. (2012) reported *Taenidium* from the Jurassic rocks of Gangta Bet, Eastern Kachchh of Gujrat. It has also been reported by Joseph *et al*. (2012) from the Kaladongar Formation, Patcham Island of Kachchh.

15. Ichnogenera: ***Teichichnus*** Seilacher (1955)

The ichnogenus *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, as seen in transverse cross section. Bioglyphs may be present (Schlirf and Bromley, 2007). *Teichichnus* was introduced by Seilacher (1955) for describing horizontal, dwelling-feeding structures, in the form of walls with par al lellaminae, made by deposit-feeders, moving within the deposit.

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

(Plate 4, fig. G)

Material: Field photograph of grey coloured sandstone bed with a burrow.

Occurrence: Grey colour sandstone bed at S. Hlimen Quarry of Upper Bhuban unit, Aizawl, Mizoram.

Description: The Bhuban Formation specimen of *T. rectus* consist of straight to sinuous unbranched horizontal stacked circular U-shaped burrow. The stacked tubes are bend and shows oblong nature at its initial part and then after displays the uniform dimensions. The maximum observed length of the burrow is about 8cm and width is 0.7cm. Burrow filled is identical to host sediments.

Remark: Seilacher (1955) interpreted *Teichichnus* as the result of the vertical shift of horizontal burrow which might be U-shaped with pipe at the top. *T. rectus* has straight walled and generally having a higher width-depth ratio (approximately 1 to 1). Seilacher (1955) compared these forms to the modern structures made by the recent polycheate *Nereis diversicolor*.

Distribution: Patel and Shringarpure (1990) described this ichnofossil from Oligocene- Miocene stages of Western Kutch, Gujrat. Bandopadhyay *et al*. (2009) reported *Teichichnus* from the Andaman and Nicobar Islands and suggested that occurance of *Teichichnus* with *Thassinoides* and *Lorenziana* indicates a well oxygenated muddy bottom with a low sedimentation rate. Joseph *et al*. (2012) described *T. rectus* from the Kaladongar Formation of Kachchh area. Recently, Khaidem *et al*. (2015) described this ichnofossil from flysch sediments of Laisong, Manipur.

16. Ichnogenus: *Thalassinoides* Ehrenberg (1944)

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. Burrow walls are smooth and unlined and the burrow fill is passive. *Thalassinoides* is a facies crossing form and most typical of shallow marine environments. Thalassinoides is usually interpreted as a fodinichnial/domichnial structure, passively filled, but occasionally an agrichnial behaviour has been interpreted for the tracemaker (Myrow 1995; Bromley 1996; Ekdale and Bromley 2003); frequently related to oxygenated situations and soft but fairly cohesive substrates (Bromley and Frey 1974; Kern and Warme 1974; Ekdale *et al*. 1984; Bromley 1990). The recognized association between Thalassinoides and firm hardground substrates has been commonly used in sequence stratigraphy, especially in relation with the Glossifungites ichnofacies (Pemberton 1998; MacEachern *et al*. 1992; Pemberton and MacEachern 1995; Pemberton *et al*. 2001; Savrda *et al*. 2001).

Ichnospecies: *Thalassinoides horizontalis* Myrow (1995)

(Plate 4, fig. H)

Material: Field photograph of grey coloured sandstone-shale bed with burrow.

Occurrence: Grey colour sandstone - shale bed in MZU Road section section, Upper Bhuban unit, Aizawl, Mizoram.

Description: The fossil specimen is smooth, unlined, three dimensional, horizontal burrow system showing Y and T- shaped branching. The diagnostic features of this ichnospecies include bedding parallel oriented network, absence of vertical oriented offshoots from polygon framework and constant diameter of the individual tunnels. Tunnels are straight; length varies from 8.5 to 10cm and diameter varies from 2 to 2.6cm. Burrows chiefly consist of horizontal tunnels that bifurcate at an angle of 80 ˚- 170^{o}.

Remarks: The present burrow differs from the type material of Myrow (1995) only in diameter. *T. horizontalis* closely resembles *T. bacae* but differs from it in the absence of vertical shafts. *T. horizontalis* is robust trace and often occurs on the ripple marked siltysandstone. Though diameter is one of the prime factors in distinguishing the ichnospecies (Myrow 1995), overall morphological features of the present trace are identical to ichnospecies *T. horizontalis*. *Thalassinoides* has been considered as a facies-crossing form, most typical of shallow-marine environments. It is mainly produced by crustaceans (Frey *et al*. 1984; Bromley 1996) or other type of arthropods as deposit feeders (Ekdale 1992). It is usually interpreted as a fodinichnial/domichnial structure frequently related to oxygenated environment and soft but fairly cohesive substrates (Bromley and Frey 1974).

Distribution: Patel *et al*. (2008) described *T. horizontalis* from Jurassic rocks of Habo Dome, mainland Kachchh and Gangta Bet of Eastern Kachchh (Patel *et al*. 2012). Malarkodi *et al*. (2009) reported this ichnspecies from Palaeocene sediments of Pondicherry and Mude *et al*. (2012) from the Mesozoic Jaisalmere basin of Rajasthan.

Subsequently, Joseph *et al*. (2012) reported it from the Kaladongar Formation of Patcham Island.

Ichnospecies: *Thalassinoides paradoxicus* Rieth (1932)

(Plate 4, fig.I & J)

Material: Field photographs of grey coloured sandstone bed and one field with burrows.

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

Description: Endichnial, full relief, horizontal to slightly oblique, three-dimensional irregular burrow system spread on the bedding plane. The burrow system comprises of vertical to inclined shaft connected to surface; bifurcations are commonly T/Y shaped and also show swelling at junction. Length of branch varies from 15 to 42 cm and diameter from 2.5 to 5cm. The burrow fill is different than the surrounding.

Remarks: Present specimen resembles closely with the specimen of *Thalassinoides paradoxicus* described and figured by Rieth (1932). *T. paradoxicus* (Woodard) corresponds to branching, boxwork burrows highly irregular in size and geometry (Kennedy, 1967; Bromley and Ekdale 1984; Frey and Howard, 1985). *Thalassinoides paradoxicus* is different than the *T. horizontalis* consisting of vertical or inclined shaft and branch dichotomous (Howard and Frey, 1984).

Distribution: This ichnospecies has been reported by several workers from western India e.g. Kundal *et al*. (2005) from Babaguru Formation of Gujarat, Kundal and Dharashivkar (2006) 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. From central India it has been reported by Sanganwar and Kundal (1997). Kundal and Sanganwar (1998, 2000) reported it from the Nimar Sanstone Formation, Bagh Bed of Madhya

Pradesh. Sing *et al*. (2008) reported *T. paradoxicus* from the Disang and Barail Group of Manipur..

Ichnospecies: *Thalassinoides suevicus* Rieth (1932)

(Plate 4, figK)

Material: Field photographs of brown coloured sandstone-shale bed with specimen.

Occurrence: Fine grained brown colour sandstone-shale bed in Ropaiabawk section, Upper Bhuban unit, Aizawl, Mizoram.

Description: Profusely branched, Y-shaped, unornamented and irregular burrows passively filled and disposed; horizontal to oblique to the bedding plane. The burrows are spread over the bedding plane, whole system is ~10 cm in length but branches show variable length; diameter is also variable, main burrow is about 1.2 cm in diameter but branches appeared to be in smaller diameter as compared to main tunnel. Sediment fill is different than the host sediment.

Remarks: The present burrows are very densely branched and thereby placed under *Thalasinoides suevicus* Reith. *T. suevicus* is a predominantly horizontal structure that may contain enlargements at Y-shaped bifurcations (Kamola, 1984; Bromley and Ekdale 1984; Frey and Howard 1985, 1990).

Distribution: Patel *et al*. (2008) reported this ichnospecies from the Habo Dome area of mainland Kachchh. Kundal and Sanganwar (1998) and Kundal and Dharashivkar (2006) reported this ichnospecies from the Nimar Sandstone Formation, Bagh Group of M.P. and Neogene and Quaternary deposits of Dwarka- Okha area, Gujarat, respectively. Mude *et al*. (2012) documented *T. suevicus* from the Kand Formation of Gujarat and Mesozoic Jaisalmer basin of Rajasthan. From Southern India, Malarkodi *et al*. (2009) reported it from the Palaeocene sediments of Pondicherry area. Joseph *et al*. also reported this ichnospecies from the Kaladongar Formation of Kachchh region.

17. Ichnospecies Type-A

(Plate 4, fig. M)

Material: Field photograph of grey coloured sandstone with a full relief burrow.

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

Description: Burrows sub - horizontal to the bedding plane, unbranched and thinly lined. The burrow fill is different from the host rock. The maximum observed length of the burrow is about 30 cm and the diameter of the burrow ranges from 1.5 to 2.5 cm.

Remarks: The sub - horizontal unbranched pattern of the present burrow similar with ichnogenus *Ophiomorpha*, but its lining nature refuses the category. There is no previous record of burrow like Ichnospecies Type-A from the Cenozoic or other sedimentary successions of India. Specific identification has been kept under an open nomenclature.

18. Horizontal burrows

(Plate 4, fig. N)

Mterial: Field photograph of sandstone-shale bed with burrow.

Occurence: Grey coloured sandstone-shale bed at Tuivamit section, Upper Bhuban Unit, Aizawl, Mizoram.

Description: Horizontal, unbranched, unlined, unornamented burrow disposed parallel to the bedding plne. The burrow fill is identical to the host sediment and is swelling at one end. The maximum observed length of the burrow is approximately 4cm.

Remarks: The Horizontal, unbranched, unlined, unornamented nture of the burrow is similar with ichnospecies *Palaeophycus* its swelling nature refuses in this category. Due to lack of more detailed structure, the present specimen could not be identified.

3.2 ETHOLOGICAL DIVERSITY OF TRACE FOSSILS:

A total number of 32 ichnospecies have been described.from the three studied sections in the Upper Bhuban Unit of Surma succession of Mizoram.Ethologically, the ichnofossils show the dominance of domichnia and fodichnia group (Fig. 3.1).

Ethlogical Group	**Dwelling** **(Domichnia)**	**Feeding** **(Fodichnia)**

No. of Fossil	**20**	**12**

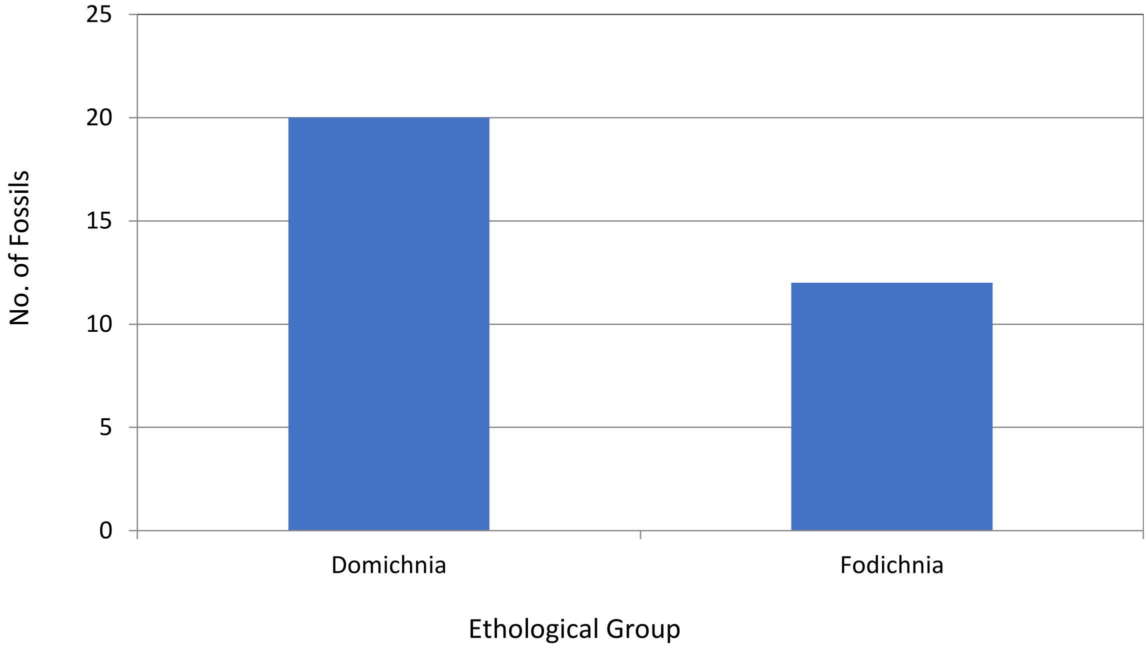


Figure 3.1: The diversity of domichnia and fodichnia traces.

3.3 ANALYSIS OF TRACE FOSSILS:

Overall, the preservation of ichnofossils is good. The burrows occur either branched or unbranched and parallel to bedding plane. However vertical lined burrows with 'U' and 'I' shape are equally common. The burrows range in dimensions from 0.5 cm to 40 cm.

A total of 32 ichnospecies belonging to 16 ichnogenera have been described from the collection, photographed, and described. Out of these 32 ichnospecies, two ichnospecies have been described for the first time in the Bhuban succession of Mizoram. Two ichnospecies cannot be identified and are kept under an open nomenclature. The remaining 28 ichnospecies were already described by previous workers. The new ichnospecies described are *Ancorichnus* isp and *Phycosiphon* isp. from the Upper Bhuban unit of Bhuban Formation of Kulikawn to S.Hlimen section and Ramrikawn – Sakawrtuichhun section, Aizawl, Mizoram. Out of 32 ichnospecies, 13 are found in two or more sections.

Trace fossils collected from the three sections belong to *Skolithos, Cruziana,* and mixed *Skolithos- Cruziana* ichnofacies. The occurrence and relative frequency of the trace fossils from the study are shown in table 3.1.

Table 3.1: Occurrence and relative frequency (R= Rare, F= Frequent, A= Abundant) of trace fossils in different localities.

Trace Fossils	Localities		
	Kulikawn – S.Hlimen	Temple -MZU	Ramrikawn - Sakawrtuichhun
Ancorichnus isp	R	-	-
Cochlichnus anguineus	R	-	-
Diplocraterion helmerseni	R	R	-

Diplocraterion parallelum	R	F	F
Funalichnus bhubani	-	R	F
Laevicyclus mongraensis	R	R	-
Ophiomorpha annulata	-	R	-
Ophiomorpha borneensis	-	-	R
O. irregulariae	-	R	-
Ophiomorpha nodosa	-	F	F
Palaeophycus tubularis	-	R	R
Palaeophycus striatus	-	R	-
Palaeeophycus sulcatus	-	R	-
Palaeophycus isp.	-	R	R
Pholeus abomasoformis	R	-	-
Phycosiphon isp.	R	-	-
Planolites annularis	-	R	-
Planolites monatus	-	-	R
Planolites beverleyensis	-	R	R
Planolites isp	-	R	R
Rhizocorallium jenense	R	-	-
Rosellia isp	R	-	-
Skolithos verticalis	R	R	-
Skolithos isp.	-	R	F
Taenidium isp.	R	-	-
Teichichnus rectus	R	-	-

T. horizontalis	-	R	-
T. paradoxicus	-	F	R
Thalassinoides suevicus	-	-	R
Thalassinoides isp	-	R	R
Ichnospecies Type A	-	-	R
Horizontal burrow	-	R	-

CHAPTER 4

DEPOSITIONAL ENVIRONMENT

4. DEPOSITIONAL ENVIRONMENT AND PALAEOECOLOGY

4.1 GENERAL REMARKS

The study of trace fossils also called ichnology is concerned with understanding the disturbance of the sediments by living organisms, i.e. biogenic sedimentary structures. Apart from the consistent recognition of vertebrate (e.g. dinosaur) footprints from 1828 onwards, trace fossils were at first grouped as ‘fucoids’ (fossil seaweeds), and their algal origin was hotly debated. Until quite recently, trace fossils have been ignored in most geology courses. At outcrop they have commonly been dismissed as ‘burrows’ or ‘worm traces’, suggesting that they have little to contribute to the elucidation of geological history. The reverse is often true. Trace fossils, in contrast to many body fossils which are rolled and derived, are records of life and events that took place in situ during or soon after the deposition of the sediment. They often occur where no body fossils have been preserved, for example in non-marine red beds, or where organisms were entirely soft-bodied. Trace fossils record behavioral, ecological, and sedimentological events which body fossils and other sedimentary structures cannot highlight directly (Sailacher, 1967; Pemberton *et al*., 1990; Bromley, 1996).

Trace fossils have been very well documented from flysch and turbidite sequences from many parts of the world wherein affinities of certain types of burrows towards particular sedimentary facies have been established. For example- Graphuglyptid burrows occur characteristically in flysch sediments (Crimes, 1977; Ksiazkiewicz, 1977; Leszczynski, 1992).

Studies on the modern ichnozonations from the Mandvi area show that biogenic structures occur in distinct patterns concerning the micro-geomorphic intertidal zonation (Patel *et al*. 2001; Desai, 2003). They distinguished three zones concerning biogenic structures and the bioturbation index. These are supratidal, intertidal and subtidal. These modern ichnozonations may be correlated with the studied rock records. The supratidal zone is rarely submerged and comprises a low bioturbation index (Taylor and Goldring, 1995). The 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 (Patel, 2002). A subtidal zone is characterized by a higher degree of bioturbation index (6), obliterated physical sedimentary structures, and feeding dwelling structures. *Thalassinoides* association is a characteristic of the subtidal environment (Desai and Patel, 2008).

Crimes (1975) suggested that ichnofossils reflect the behavioral response of animals and these responses are controlled by energy conditions at the depositional interface, substrate types and availability of food and ichnofossils are more sensitive environmental indicators. He further mentioned that sandy shore is a very exacting environment and relatively few benthic animals can fill this niche. The animal must be able to endure current and wave action, desiccation, and rapid fluctuations in temperature and salinity. Animals that can tolerate such extreme conditions often do a show by escaping from the surface into permanent or semi-permanent burrows. This response is reflected in ichnofossils which show a preponderance of vertical burrows, U-shaped burrows, and burrows with pellets (Kundal and Dharashivkar, 2006).

4.2 DEPOSITIONAL ENVIRONMENT AND PALAEOECOLOGY

4.2.1 Kulikawn – S. Hlmen section:

Rocks of the Upper Bhuban Formation of the Surma Group are studied in Kulikawn – S. Hlimen section, Aizawl (Fig.4.1) for their ichnofossils content. The section shows an intercalated sequence of shale and sandstone, sandstone bed, and their admixture in various proportions. The sandstone bed consists of an ethologically diverse group of trace fossils. These trace fossils largely constitute domichnia and fodichnia associations (Table 4.1). Domichnia are cylindrical dwelling burrows having strong wall lining of suspension feeders (Simpson, 1975). The domichnia signatures are tangibly manifested in the recorded forms like *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Laevicyclus mongraensis*, *Rhizocorallium jenense*, *Rosselia* isp. and *Skolithos verticalis*. Fodichnia features are evident in *Pholeus* *abomasoformis, Taenidium i*sp. and *Teichichnus rectus.* The clastic sediments are characterized by the vertical 'U' and 'I' shaped lined burrows like *Laevicyclus, Diplocraterion*, *Rhizocorallium,* and *Skolithos. Skolithos* are also dwelling burrows of suspension-feeding organisms (Patel and Desai, 2009). These four suspension-feeder structures comprise a pioneer community of opportunists commonly displaying low diversity and high density of trace fossils. These burrows were produced over a short period of time and the depositional environment was inhospitable to most life forms. This may be attributed to oxygen depletion, variable salinity, uneven rates of sediment accumulation, or merely a newly-deposited biologically unconditioned substrate.

The trace fossils from this section represent the *Diplocraterion* assemblage and *Skolithos* assemblage. *Diplocraterion* assemblage occurs in the wavy grey color sandstone unit of the middle part of the section. This assemblage is characterized by suspension-feeding burrows of *Laevicyclus mongraensis*, *Ancorichnus* isp., and *Pholeus abomasoformis* showing feeding and dwelling activities of crustaceans and polychaete-like organisms which are known to occur in shallow marine set-up. The *Skolithos* assemblage is present in sandstone beds associated with *Rosselia, Taenidium,* and *Teichichnus rectus,* suggesting relatively moderate to high energy conditions and shifting substrate.

The trace fossils associated with these assemblages belong to *Skolithos* ichnofacies, *Cruziana* ichnofacies, and at places mixing of both *Skoliths-Cruziana* ichnofacies. *Skolithos* ichnofacies indicates sandy shifting substrate and high energy conditions in the foreshore zone while the *Cruziana* ichnofacies indicate unconsolidated, poorly sorted soft substrate and low energy condition in the shoreface/offshore zone. Together these ichnofacies indicate sandy shifting substrate and high energy conditions in foreshore to an unconsolidated, poorly sorted soft substrate and low energy conditions in the shoreface/offshore zone of the shallow marine environment for the deposition of the ichnoferous horizons of this section.

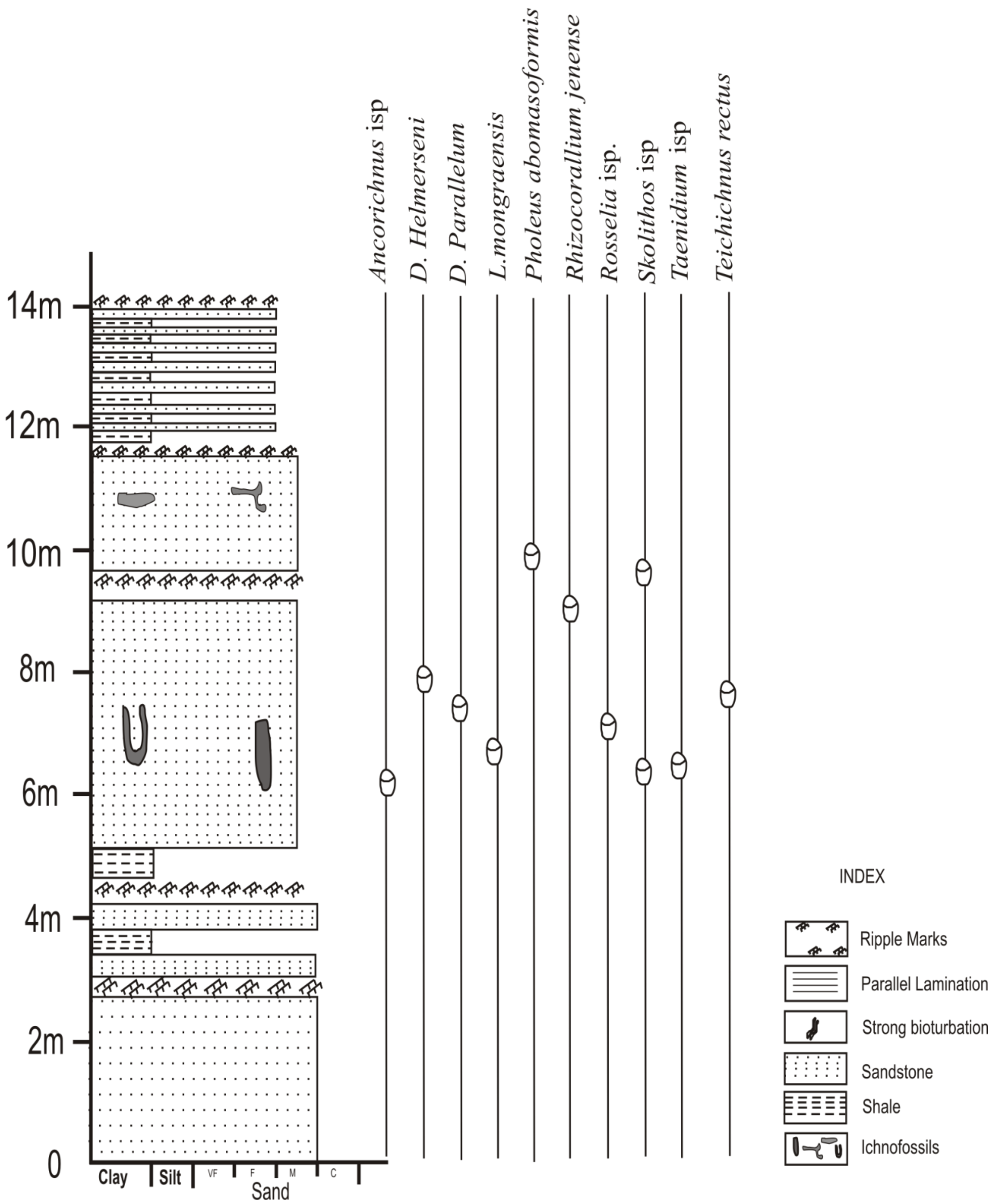


Figure 4.1: Lithocolumn of Upper Bhuban Formation along Kulikawn – S.Hlimen section.

Table 4.1: Morphological, Post-Pre, Ethological and Facies classification of ichnospecies from Surma Group of Kulikawn – S. Hlimen section, Aizawl, Mizoram.

Name of Ichnospecies	**Morphological Simpson, (1975)**	**Pre-Post Origin(Tovar et al., 2010)**	**Ethological (Seilacher, 1964)**	**Ichnofacies (Seilacher, 1964, 1967)**
Ancorichnus isp.				
Diplocraterion helmerseni	Shaft	Pre	Domichnia	*Skolithos*
Diplocraterion parallelum	Shaft	Pre	Domichnia	*Skolithos*
Laevicyclus mongraensis	Shaft	Pre	Domichnia	*Skolithos*
Pholeus abomasoformis	Tunnel	Pre	Fodichnia	*Skolithos*
Rhizocorallium Jenense	Tunnel	Post	Domichnia	*Skolithos/ Cruziana*
Rosselia isp.	Tunnel	Post	Domichnia	*Cruziana*
Skolithos verticalis	Shaft	Pre	Domichnia	*Skolithos*
Teanidium isp.	Tunnel	Post	Fodichnia	*Cruziania*
Teichichnus rectus	Tunnel	Post	Fodichnia	*Cruziania*

4.2.2 Temple - MZU section:

The Upper Bhuban succession of Temple - MZU road section, Aizawl shows a good exposure of rocks approximately 70.2 m thick sequence of shale, sandstone, sandstone-shale alternation and their admixtures. Sedimentary structures typical of tidal environment *viz*., festoon cross-stratified sandstone-shale and upward transition from slightly wavy parallel laminae to trough coset developed in sandstone-shale intercalation facies are common This succession has yielded a total of 20 ichnospecies of 10 ichnogenera. Since this section is an area of settlement, a study has been carried out in three localities along Temple – MZU road where the rocks are well exposed i.e. Ropaipabawk, Tuivamit, and MZU road near 6 miles sections. The occurrence and overall distribution of the trace fossil assemblages found in the Bhuban Formation of Temple – MZU section are shown in Figure 4.2 and facies and ethology in Table 4.2. The occurrence and distribution of trace fossils are controlled by various environmental parameters such as energy level, substrate, light, salinity, oxygen level, and bathymetry (Pemberton, 2001). These parameters have controlled the distribution and activities of trace producers during the deposition of the Upper Bhuban succession of this section. The succession is mainly dominated by lined vertical 'I', 'Y'and'U' shaped dwelling burrows. *Diplocraterion, Ophiomorpha,* and *Skolithos* are endichnial burrows of chiefly suspension-feeding organisms. The ichnofossil assemblage recorded from this section shows a wide range of behavioral patterns but is dominated by dwelling burrows. The domichnian signatures are preserved in ichnospecies like *Diplocraterion helmerseni, Diplocraterion parallelum, Funalichnus bhubani, Laevicyclus mongraensis, Ophiomorpha annulata, Ophiomorpha borneensis, Ophiomorpha irregulaire, Ophiomorpha nodosa, Palaeophycus annulatus, Palaeophucus striatus, Palaeophycus sulcatus, Palaeophycus tubularis, Skolithos* *verticalis,* and *Skolithos isp* while the fodichnian features are evident in *Cochlichnus anguineus, Planolites beverleyensis, Thalassinoides suevicus, Thalassionoides horizontalis, Thalassionoides paradoxicus,* and *Thalassionoides* isp. *Funalichnus bhubani* isp. nov. occur in association with *Diplocraterion* and *Skolithos* which are endichnial burrows of chiefly suspension-feeding organisms and are typical members of the *Skolithos* ichnofacies (Seilacher, 1967; MacEachern and Pemberton, 1992). The sandstone-shale units are dominated by the cylindrical, branched, large-sized three-dimensional horizontal burrows of *Thalassinoides* with *Planolites and Palaeophycus.* These horizontal biogenic structures indicate low wave and current energy conditions in the subtidal environment. The crustacean burrows of *Thalassinoides* are preserved as positive hyporelief, occurring in nearshore environments and often forming large networks. *Thalassinoides* is a typical member of the *Cruziana* ichnofacies (Seilecher, 1967) colonizing in reduced energy conditions in shallow marine environments. *Planolites* and *Palaeophycus* are horizontal structures that occur below the sediment-sediment interface, suggesting unconsolidated substrates experiencing relatively moderate to low energy subtidal conditions.

The ichnospecies of the Temple – MZU road section belongs to *Skolithos* and *Cruziana* ichnofacies but a mixed association of *Skolithos-Cruziana* ichnofacies is also observed. The presence of *Skolithos* ichnofacies indicates the unconsolidated shifting substrate, high energy conditions, and drastic changes in the sedimentation rate (Walker and James, 1992; Singh *et al*., 2008) and *Cruziana* ichnofacies indicate deposition under low to moderate energy conditions, unstable and unconsolidated substrate in offshore to transition shoreface environment. Therefore, the behavioral nature and distribution pattern of the ichnofossils as well as sedimentological attributes suggests that Upper Bhuban succession exposed in the Temple-MZU section was deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of the shallow marine environment.

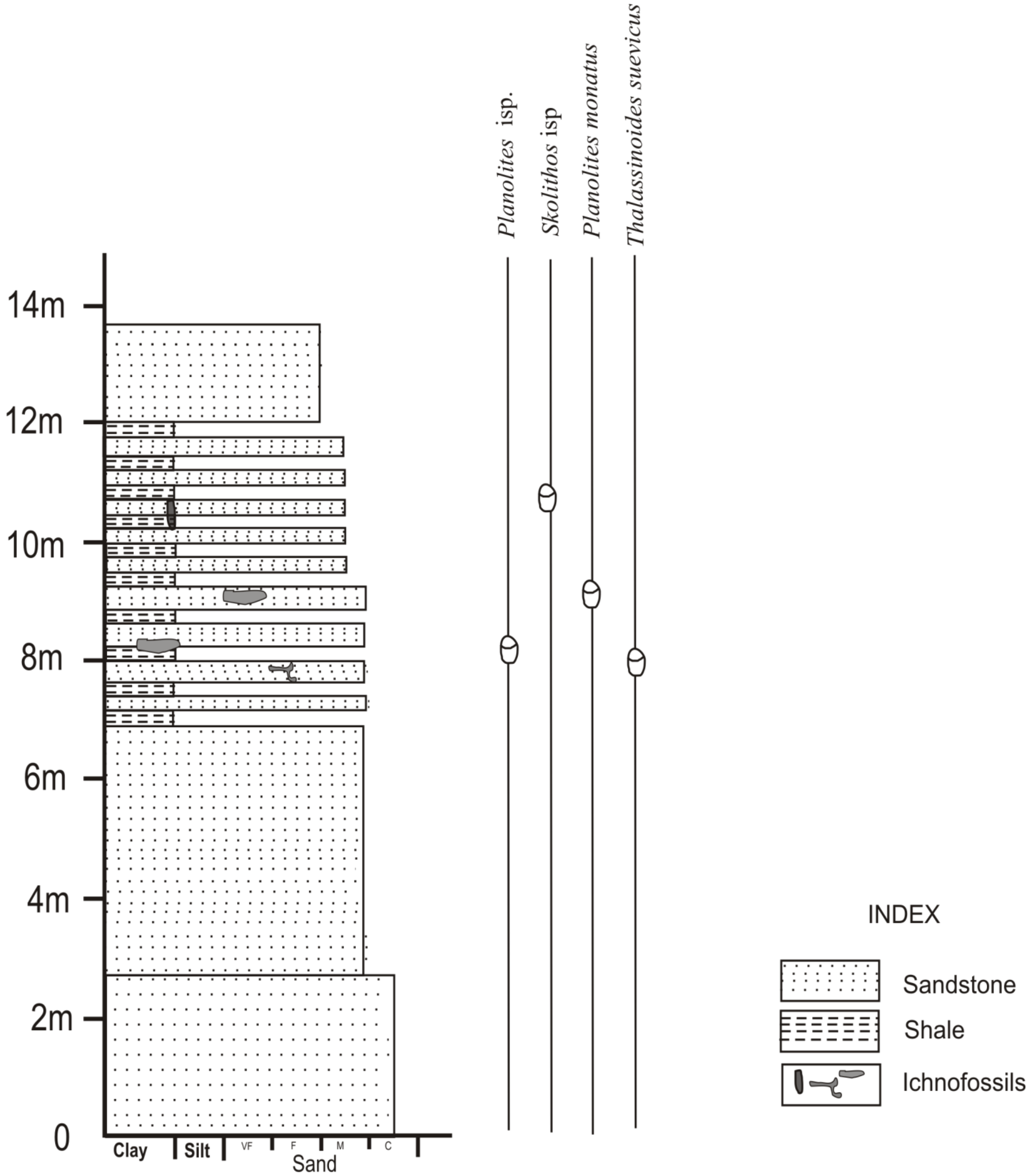


Figure 4.2: Lithocolumn of Upper Bhuban Formation along Temple- MZU section (Ropaiabawk area)

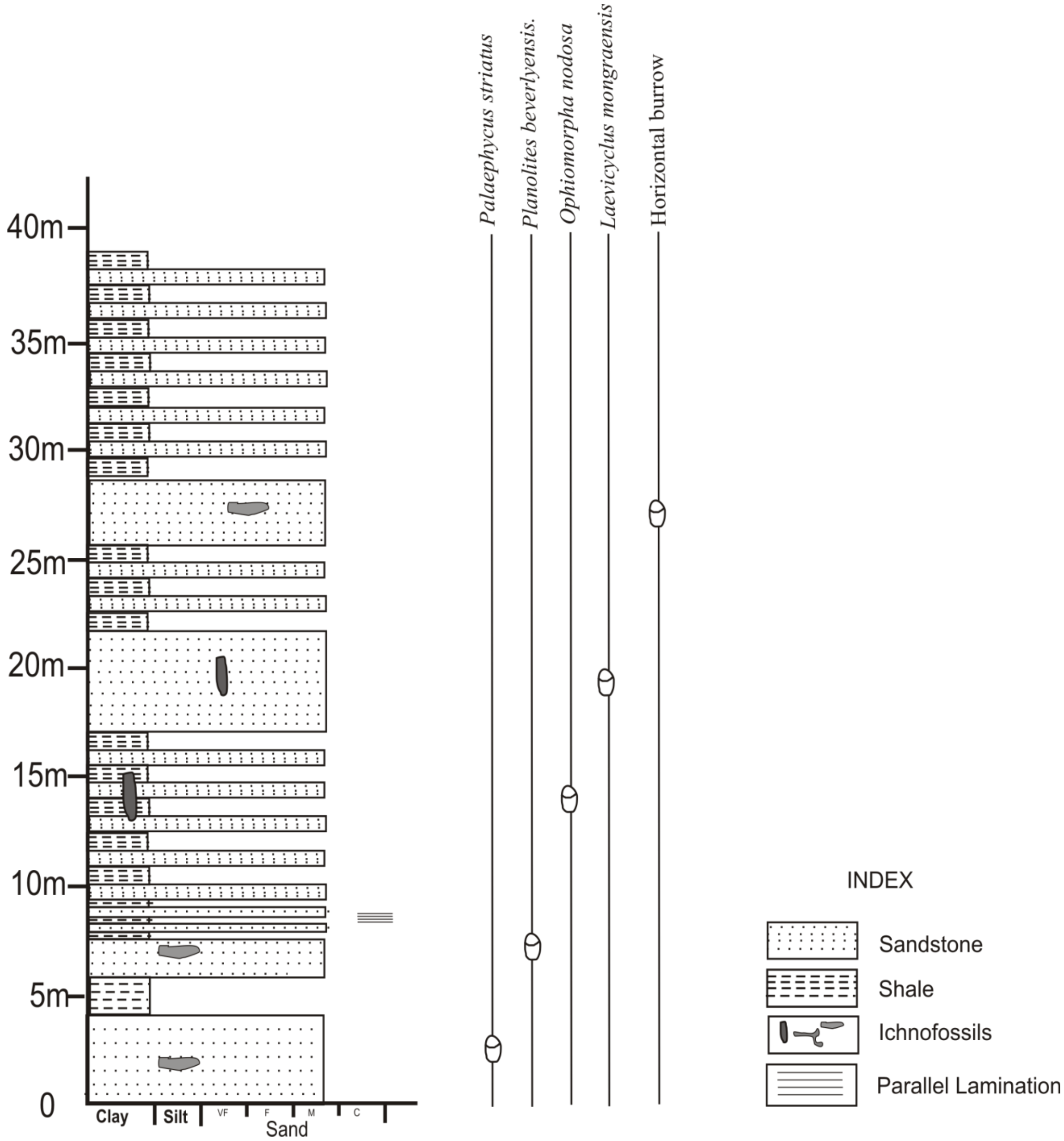


Figure 4.3: Lithocolumn of Upper Bhuban Formation along Temple- MZU section (Tuivamit area)

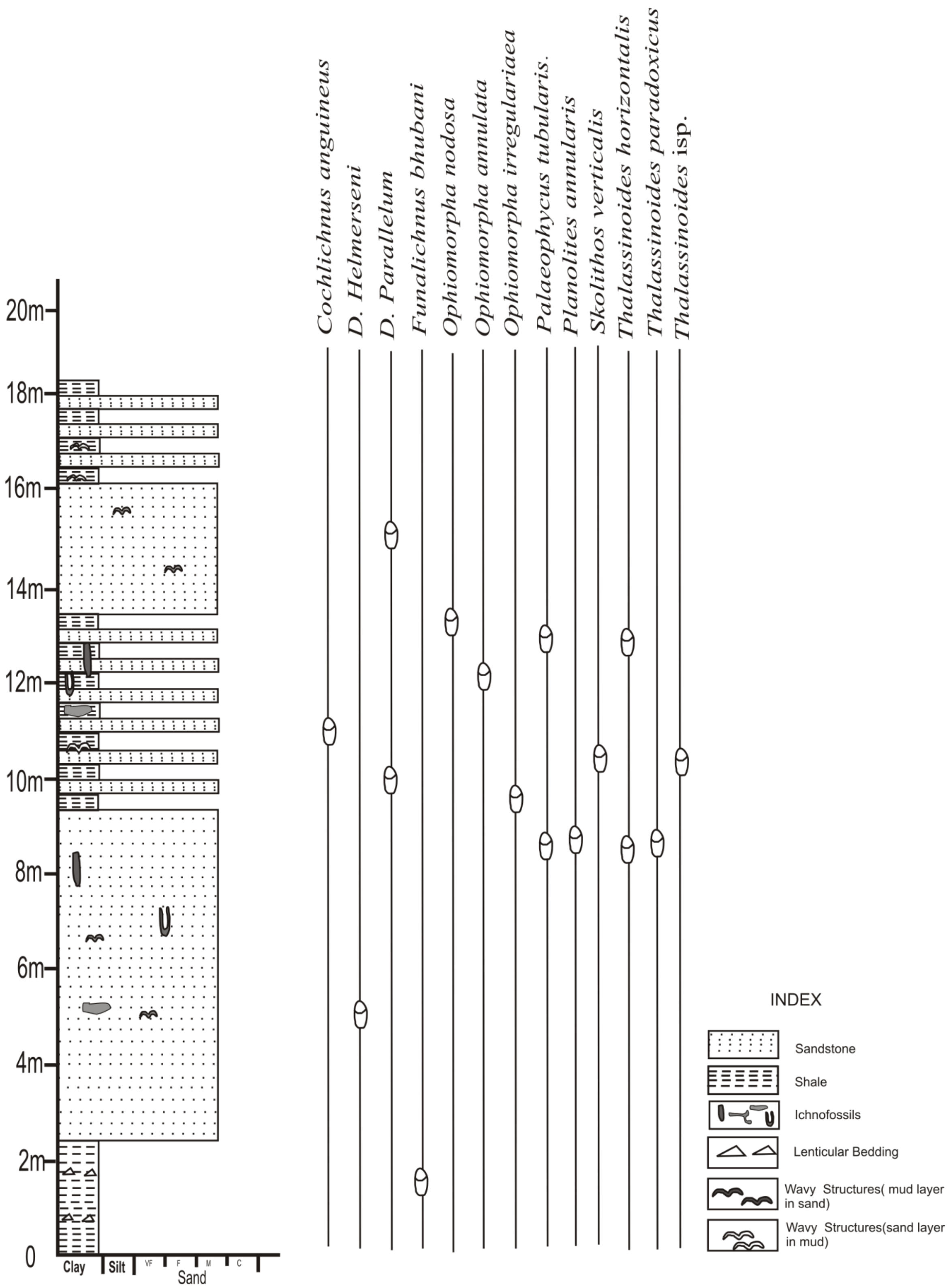


Figure 4.4: Lithocolumn of Upper Bhuban Formation along Temple - MZU section (near 6 miles)

Table 4.2: Morphological, Post-Pre, Ethological, and Facies Classification of ichnospecies from Surma Group of Temple - MZU section, Aizawl, Mizoram.

Name of Ichnospecies	**Morphological Simpson, (1975)**	**Pre-Post Origin(Tovar et al., 2010)**	**Ethological (Seilacher, 1964)**	**Ichnofacies (Seilacher, 1964, 1967)**
Cochlichnus anguineus	Tunnel	Post	Fodichnia	*Cruziana*
Diplocraterion helmerseni	Shaft	Pre	Domichnia	*Skolithos*
Diplocraterion paralellum	Shaft	Pre	Domichnia	*Skolithos*
Funalichnus bhubani	Shaft	Post	Domichnia	*Skolithos*
Laevicyclus mongraensis	Shaft	Pre	Domichnia	*Skolithos*
Ophiomopha annulata	Shaft	Pre	Domichnia	*Skolithos*
Ophiomorpha irregulariae	Shaft	Pre	Domichnia	*Skolithos*
Ophiomorpha nodosa	Shaft	Pre	Domichnia	*Skolithos*
Palaeophycus striatus	Tunnel	Post	Domichnia	*Cruziana*

Palaeophycus sulcatus	Tunnel	Post	Domichnia	*Cruziana*
Palaeophycus tubularis	Tunnel	Post	Domichnia	*Cruziana*
Planoites annularis	Tunnel	Post	Domichnia	*Cruiana*
Planolites beverleyensis	Tunnel	Post	Domichnia	*Cruziana*
Planolites monatus	Tunnel	Post	Domichnia	*Cruziania*
Planolites isp.	Tunnel	Post	Domichnia	*Cruziania*
Skolithos verticalis	Shaft	Pre	Domichnia	*Skolithos*
Skolithos isp.	Shaft	Pre	Domichnia	*Skolithos*
Thalssinoides horizontalis	Tunnel	Pre	Fodichnia	*Skolithos*/ *Cruziana*
Thalassinoides paradoxicus	Tunnel	Pre	Fodichnia	*Skolithos*/ *Cruziana*
Thalassinoides suevicus	Tunnel	Pre	Fodichnia	*Skolithos*/ *Cruziana*
Thalassinoides isp.	Tunnel	Pre	Fodichnia	*Skolithos*/ *Cruziana*
Horizontal burrows	Tunnel	Post	Domichnia	*Cruziana*

4.2.3 Ramrikawn to Sakawrtuichhun Section:

Biogenic structures preserved in rock succession along Ramrikawn to Sakawrtuichhun section have been described in detail in the present study and are characterized taxonomically at the ichnospecies level. A total of 14 ichnospecies of 8 ichnogenera have been identified which include *Diplocraterion parallelum, Funalichnus bhubani, Ophiomorpha borneensis, Ophiomorpha nodosa*, *Palaeophycus tubularis*, *Palaeophycus sulcatus*, *Palaeophycus* isp., *Phycosiphon* isp., *Planolites beverleyensis*, *Planolites isp., Skolithos linearis, Thalassinoides paradoxicus* and Ichnospecies Type A. The lithology and the distribution of trace fossils are shown in Figure 4.3.

As shown in Table 4.3, the ichnofossil assemblages of the Bhuban rocks of Ramrikawn - Sakawrtuichhun section is ethologically mainly of Fodichnia and Domichnia association. Simpson (1975) mentioned the existence of close affinity between fodichnia and domichnia and observed that fodichnia are feeding burrows of deposit feeders, excavated while in search of food within the sediments or at the sediment surface. Regarding domichnia, Simpson (1975) mentioned that these are cylindrical dwelling burrows having a strong wall of suspension feeder. These fodichnian and domichnian signatures are tangibly manifested in the present ichnoassemblage record. Domichnian signature is reflected in ichnospecies of *Diplocraterion parallelum*, *Funalichnus bhubani*, *Ophiomorpha borneensis*, *Ophiomorpha nodosa*, and *Skolithos* isp. Fodichnian signature reflected by *Palaeophycus sulcatus*, *Palaeophycus tubularis*, *Palaeophycus* isp., *Planolites beverleyensis, Planolites* isp., *Thalassinoides paradoxicus* and *Thalassinoides* isp.

The ichnotaxa reported from this succession are typical of the *Skolithos* and the *Cruziana* ichnofacies. The *Skolithos* ichnofacies are related to relatively high levels of wave or current energy and are typically developed in clean, well-sorted, loose, or shifting particulate substrates. Such conditions commonly occur on the shoreface and sheltered foreshores, but similar conditions occur also in a wide range of high-energy shallow-water environments (MacEachern *et al*., 2007). The *Cruziana* ichnofacies are most characteristic of permanently subtidal, poorly sorted, and unconsolidated (muddy) substrates in shallow marine settings typified by uniform salinity. Conditions typically range from moderate energy levels lying below fair-weather (minimum) wave base but above storm wave base, to lower energy levels in deeper, quieter waters. The most common settings correspond to the offshore extending to the very distal fringes of the lower shoreface (MacEachern *et al.*, 2007). *Skolithos* ichnofacies ordinarily grade seaward into the *Cruziana* ichnofacies, as was presented in some idealized shoreface models for ichnofacies (Frey *et al.*, 1990; Pemberton and MacEachern, 1995). Moreover, in a shallow environmental context, increased energy and allied parameters thus represent a temporary excursion of *Skolithos*-type conditions into an otherwise *Cruziana*-type setting. Therefore the ichnological data collected from the Ramrikawn-Sakawrtuichhun section suggest that the Upper Bhuban rocks in this section were deposited under foreshore to shoreface/offshore zone of shallow-marine environment, with occasional high-energy conditions.

Table 4.3: Morphological, Post-Pre, Ethological, and Facies Classification of ichnospecies from Surma Group of Ramrikawn- Sakawrtuichhun section, Aizawl, Mizoram.

Name of Ichnospecies	**Morphological Simpson, (1975)**	**Pre-Post Origin(Tovar et al., 2010)**	**Ethological (Seilacher, 1964)**	**Ichnofacies (Seilacher, 1964, 1967)**
Diplocraterion parallelum	Shaft	Pre	Domichnia	*Skolithos*
Funalichnus bhubani	Shaft	Post	Domichnia	*Skolithos*
Ophiomorpha borneensis	Shaft	Pre	Domichnia	*Skolithos/ Cruziana*
Ophiomorpha nodosa	Shaft	Pre	Domichnia	*Skolithos*
Palaeophycus tubularis	Tunnel	Post	Domichnia	*Cruziana*
Palaeophycus Sulcatus	Tunnel	Post	Domichnia	*Cruziana*

Planolites beverleyensis	Tunnel	Post	Domichnia	*Cruziana*
Planolites isp.	Tunnel	Post	Domichnia	*Cruziana*
Skolithos isp.	Shaft	Pre	Domichnia	*Skolithos*
Thalassinoides paradoxicus	Tunnel	Post	Fodichnia	*Skolithos/ Cruziana*
Thalassinoides isp.	Tunnel	Post	Fodichnia	*Skolithos/ Cruziana*
Ichnospecies Type A	Tunnel	Post	Domichnia	*Skolithos*

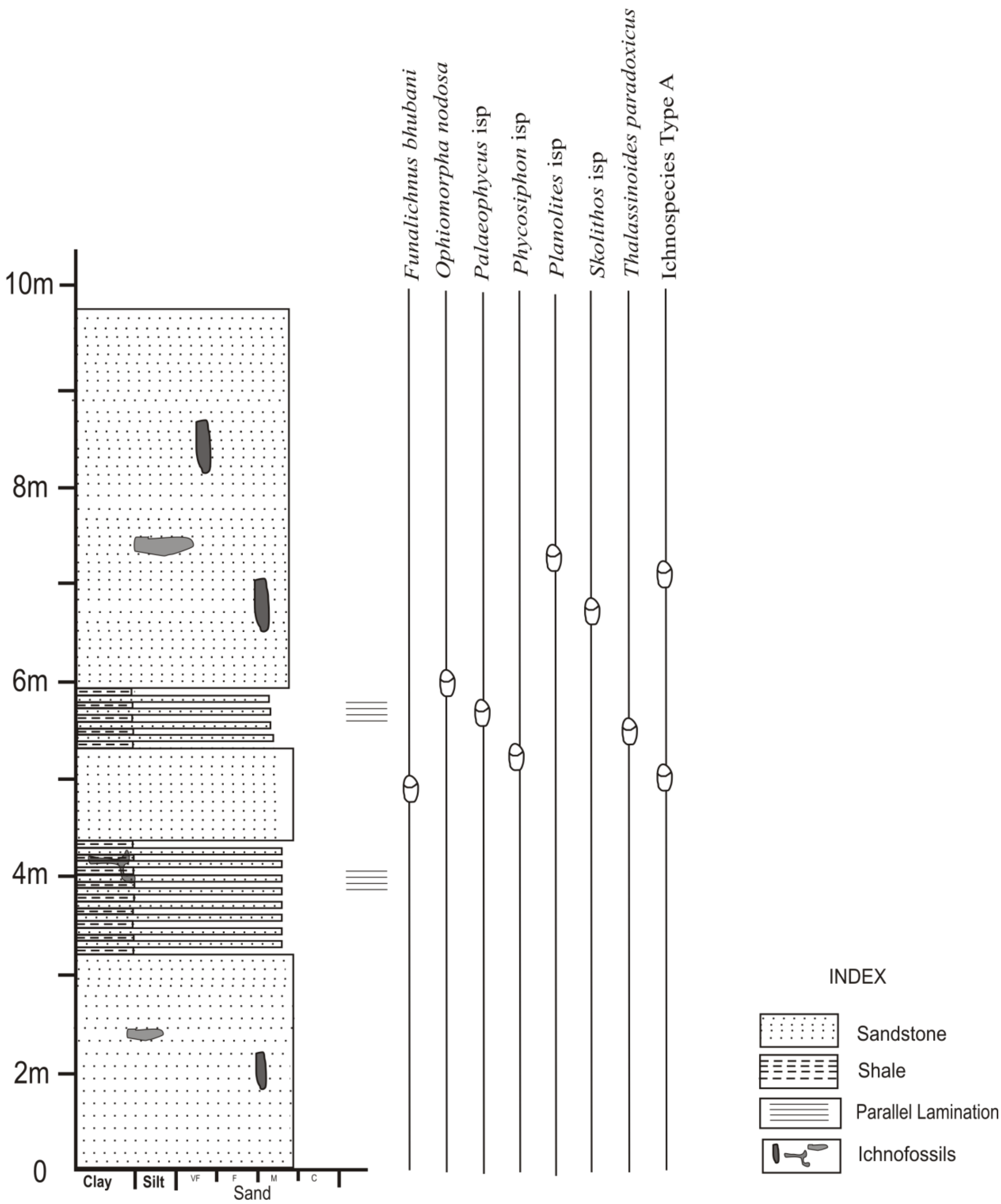


Figure 4.5.1: Lithocolumns of Upper Bhuban Formation exposed along Ramrikawn - Sakawrtuichhun section, Aizawl (Quarry 1).

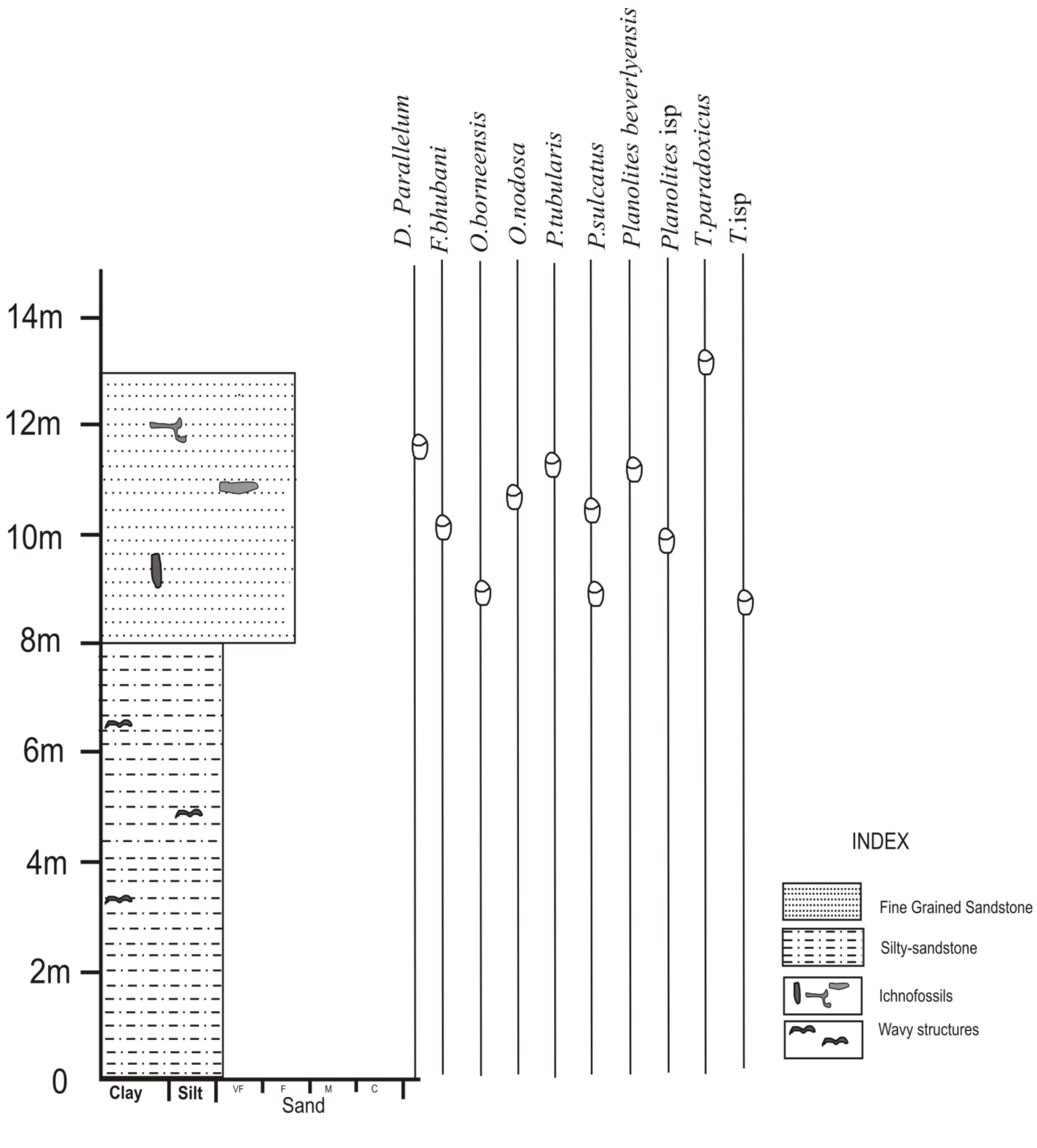


Figure 4.5.2: Lithocolumns of Upper Bhuban Formation exposed along Ramrikawn - Sakawrtuichhun section, Aizawl (Quarry 2).

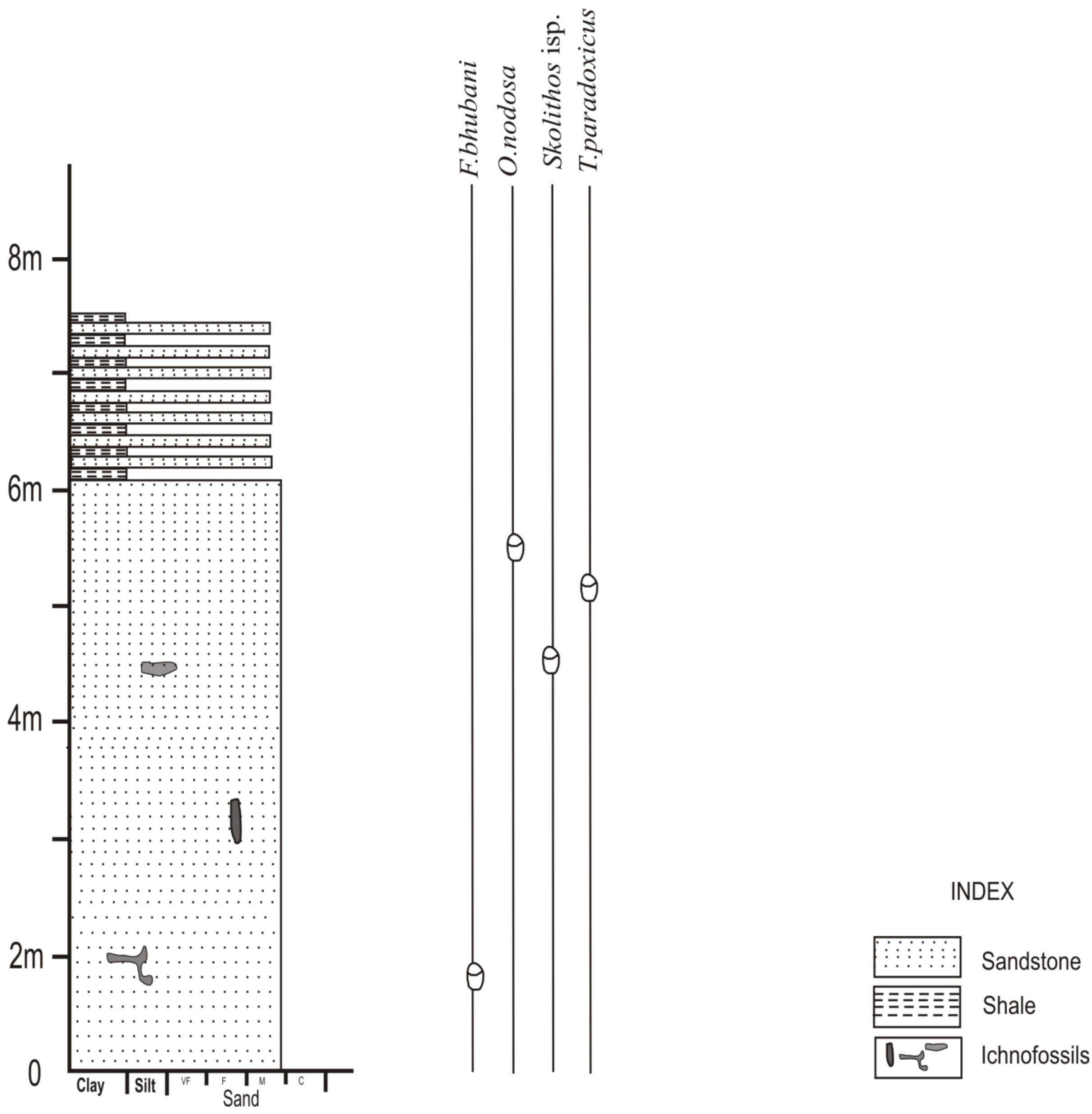
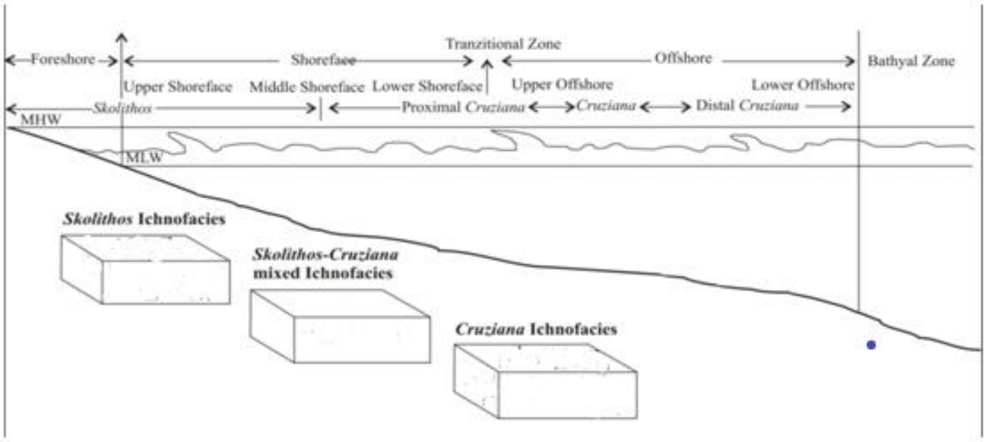


Figure 4.5.3: Lithocolumns of Upper Bhuban Formation exposed along Ramrikawn - Sakawrtuichhun section, Aizawl (Quarry 3).

4.3 CONCLUSION

The trace fossils of the Upper Bhuban Formation are abundant and ubiquitous in nature. A total 32 ichnospecies belonging to19 ichnogenera are identified and classified according to their morphological characters. The recurring pattern of the trace fossils assemblages reflect the presence of suspension and deposit feeding animals throughout the sequences. Isolated occurrence of crawling and resting trace reflect change in depositional regime. Overall, the trace fossil assemblages of the Upper Bhuban Formation belongs to the *Skolithos, Cruziana* and mixed *Skolithos/Cruziana* ichnofacies (Fig. 4.5) and indicates variable hydrodynamic conditions as low wave and current energy conditions with intervening periods of high wave and current energy conditions (*Skolithos* ichnofacies) and an intermediate period of stressful environment. The *Cruziana* ichnofacies is most characteristic of permanently subtidal, poorly sorted, and unconsolidated (muddy) substrates in shallow marine settings typified by uniform salinity. Conditions typically range from moderate energy levels lying below fair-weather (minimum) wave base but above storm wave base, to lower energy levels in deeper, quieter waters. Thus it can be inferred that the studied successions of Upper Bhuban Formation, Surma Group of Mizoram were deposited under sandy shifting substrate and high energy conditions in foreshore to unconsolidated, poorly sorted soft substrate and low energy condition in shoreface/offshore zone of shallow marine environment with occasion storm events.

Schematic representation of ichnofacies and their depositional environment is shown in Fig. 4.1.



***Skolithos* Ichnofacies**

1. *Ancorichnus* isp.
2. D.helmerseni
3. *D. parallelum*
4. *F. bhubani* isp. nov
5. *Laevicyclus mongraensis*
6. *Ophiomorpha irregulaire*
7.O.nodosa
8. Pholeus abomasoformis
9. *Rosselia* isp.
10.*Skolithos verticalis*
11. *Skolithos* isp.

***Skolithos-Cruziana* mixed Ichnofacies**

11. *Ophiomorpha annulata*
12.*Ophiomorpha borneensis*
13. *Rhizocorallium jenense*
14. T.horizontalis
15. T.suevicus
16. T.horizontalis
17. *Thalassinoides* isp.
18. *Phycosiphon isp.*

***Cruziana* Ichnofacies**

1.*Cochlichnus anguineus*
2. *Palaeophycus* isp.
3.Planolites beverleyensis
4.*Planolites annularis*
5. *Planolites montanus*
6.*P. tubularis*
7.*P.sulcatus*
8.*P. annulatus*
9 *P. striatus*
10.Taenidium isp.
11.Teichichnus rectus
12.Ichnospecies Type A

Figure 4.1: Schematic representation of Ichnofacies and their depositional environment

CHAPTER 5

CORRELATION

5. CORRELATION

5.1 GENERAL REMARKS

The lithostratigraphic units together with entombed trace fossils have been extensively used for local as well as regional correlation of rock successions. The principle of fossil correlation states that the strata containing a similar group of fossils may correspond in age. In context of trace fossils, correlation is used to relate the depositional environment of different horizons. Correlation of the present sequence is attempted in two ways. Firstly, attempt has been made to establish relationship in terms of depositional settings among various ichnoferous successions of different sections of the study area and secondly, correlation of the studied sections with the Miocene successions of other areas of India has been attempted.

A detailed ichnological study of the Upper Bhuban Formation has been performed in three sections around Aizawl, Mizoram i.e. Kulikawn to S. Hlimen section, Temple to MZU section and Ramrikawn to Sakawrtuichhun section. The litho-units which contain these ichnospecies are mainly sandstone, shale and their admixtures. Lithological variations and temporal and spatial distribution of trace fossils have been discussed in chapter-2.

A total of 32 ichnospecies belonging to 16ichnogenera have been collected and described. Among these ichnospecies, 13 are found in two or more sections. Two ichnospecies, namely *Skolithos* isp. and *Diplocraterion parallelum* have been reported from all the three sections. Owing to this correlation of depositional environment among these sections has been attempted to a fare degree of accuracy. Distribution of the described ichnospecies in the four studied sections is given in table 5.1.

Table 5.1: Correlation of the Upper Bhuban rocks of the studied sections (P=Present).

Name of the ichnospecies	Kulikawn– S. Hlimen	Temple -MZU	Ramrikawn-Sakawrtuichhun
Ancorichnus isp.	P	-	-
Cochlichnus anguineus	-	P	-
Diplocraterion helmerseni	P	-	-
Diplocraterion parallelum	P	P	P
Funalichnus bhubani	-	P	P
Laevicyclus mongraensis	P	P	-
Ophiomorpha annulata	-	P	-
Ophiomorpha bornensis	-	-	P
Ophiomorpha irregulariae	-	P	-
Ophiomorpha nodosa	-	P	P
Pkaeophycus sulcatus	-	-	P
Palaeophycus striatus	-	P	P
Palaeophycus tubularis	-	P	P
Palaeophycus isp.	-	P	P
Pholeus abomasoformis	P	-	-
Phycosihons isp.	-	-	P
Planolites anularis	-	P	-
Planolites beverleyensis	-	P	P
Planolites monatus	-	P	-

Planolites isp.	-	P	P
Rhizocorallium jenense	P	-	-
Rosselia isp.	P	-	-
Skolithos verticalis	P	P	-
Skolithos isp.	P	P	P
Taenidium isp.	P	-	-
Teichichnus rectus	P	-	-
Thalassinoides horizontalis	-	P	-
Thalassinoides parodoxicus	-	P	P
Thalassinoides suevicus	-	P	-
Thalassinoides isp.	-	P	P
Ichnospecies Type A	-	-	P
Horizontal Burrow	-	P	-

5.2. LOCAL CORRELATION

Correlatoin of depositional environment of the three studied sections has been attempted based on the recovered ichnospecies. Ten ichnospecies belonging to nine ichnogenera have been described from Upper Bhuban units of Bhuban Formation Kulikawn – S. Hlimen section. These include *Ancorichnus* isp., *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Laevicyclus mongraensis*,*Pholeus abomasoformis*, *Rhizocorallium jenense*, *Rosselia* isp., *Skolithos* isp., *Taenidiium* isp. and *Teichichnus rectus*. These ichnoassemblages represent *Skolithos* ichnofacies, *Cruziana* ichnofacies and at places mixed *Skoliths*-*Cruziana* ichnofacies. The

Skolithos ichnofacies is related to relatively high levels of wave or current energy, and is typically developed in well-sorted, loose or shifting substrates. Such conditions commonly occur in the foreshore zones. The *Cruziana* ichnofacies is most characteristic of poorly sorted, unconsolidated (muddy) substrates, uniform salinity and low energy conditions in the shore-face/off-shore zones. Together these two ichnofacies indicate sandy shifting substrate and high energy conditions in foreshore to unconsolidated, poorly sorted soft substrate and low energy condition in shoreface/offshore zone of shallow marine environment for the deposition of the succession in this section.

A total of 22 ichnospecies belonging to 10 ichnogenera have been described from the Upper Bhuban unit of Bhuban Formation in Temple to MZU section, which include *Cochlichnus anguineus, Diplocraterion helmerseni, D. parallelum, Funalichnus bhubani* isp. nov, *Laevicyclus mongraensis, Ophiomorpha annulata, Ophiomorpha irregulaire, O. nodosa, Palaeophycus sriatus, P. Sulcatus, P. tubularis, Palaeophycus* isp., *Planolits annularis, Planolites beverleyensis, Planolites Monatus, Planolites isp., Skolithos verticalis, Skolithos* isp.,*Thalassinoides horizontalis, T. Suevicus, T. Paradoxicus* and *Thalassinoides* isp. The ichnofossil assemblages characteristically display the development of *Skolithos*, *Cruziana* and mixed *Skolithos-Cruziana* ichnofacies typical of shallow marine settings which indicates that the Upper Bhuban Formation of Temple - MZU section was deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine environment.

The Upper Bhuban unit of Bhuban Formation of Ramrikawn to Sakawrtuichhun section yielded trace fossil assemblage of 14 ichnospecies belonging to 8 ichnogenera. These include *Diplocraterion parallelum*, Funalichnus bhubani, Ophiomorpha borneensis, *Ophiomorpha nodosa, Palaeophycus sulcatus, Palaeophycus tubularis, Phycosiphon isp., Planolites beverleyensis, Planolites* isp., *Skolithos* isp., *Thalassinoides paradoxicus, Thalassinoides* isp. and Ichnospecies Type A. The ichnotaxa described from the studied succession are typical for the *Skolithos* and the *Cruziana* ichnofacies which indicates a foreshore to shoreface/offshore shallow-marine environment, with occasional high-energy depositional conditions for the Bhuban Formation of Ramrikawn to Sakawrtuichhun section.

5.3 CORRELATION WITH MIOCENE SUCCESSIONS OF INDIA

Trace fossils from the Miocene successions are well reported from various parts of Northeastern (Reddy *et al*., 1992; Mehrotra *et al*., 2001; Lokho and Singh, 2013; Singh *et al*., 2010; Chakraborty *et al*., 2013), and Western India (Patel and Shringarpure, 1990, 1992, 1998; Kundal *et al*., 2005; Kundal and Mude, 2008; Mude, 2012; Kundal and Dharsivakar, 2006). Only few researches have been done in North (Agrawal and Singh, 1983 and Sudan *et al*., 2002) and South India (Mude *et al*., 2012). Therefore, correlation of depositional environment of the studied sections has been attempted with the rock successions of these four areas.

5.3.1 Northern India

Agrawal and Singh (1983) described dwelling and feeding burrows mostly of insects and worms from the fluvial Middle Siwalik successions of Uttar Pradesh. In the state of Jammu and Kashmir, trace fossils of the Murree Group (late Eocene-early Miocene) have been described by Sudan *et al*. (2002). Ichnofossils described are *Chondrites* isp., *Cosmorhaphe fuchsi*, *Dendrotichnium* cf. *llarenai*, *Imbrichnus* cf. *wattonensis*, *Ophiomorpha* isp., *Planolites* isp., *Skolithos* isp., *Thalassinoides* isp. which mainly correspond to feeding-dwelling forms, are facies-related, allowing for differentiation of four ichnofacies. These ichnofacies broadly suggest that the sediments of the Murree Group were deposited in coastal environment under brackish to fresh water conditions (Sudan *et al*., 2002). In the present study the ichnospecies of *Ophiomorpha*, *Planolites*, *Skolithos* and *Thalassinoides* are reported from Temple to MZU and Ramrikawn to Sakawrtuichhun sections suggesting that the depositional environment of Upper Bhuban Formation, Surma Group of Mizoram may be broadly correlatable with the Murree Group of Jammu and Kashmir. Detailed correlation is however not possible owing to limited ichnological data set from the Murree Group.

5.3.2 Southern India

Mude *et al*. (2012), for the first time reported ichnofossils from the Ambalapuzha Formation of Mio-Pliocene age. Only *Skolithos linearis* and *Planolites beverleyensis* were identified and respectively belonging to *Skolithos* and *Cruziana* ichnofacies, allowing interpretation of deposition of the succession in shallow water, near-shore marine environment with moderate to high energy conditions (Mude *et al*., 2012). In the present study *Skolithos* are reported from all the three studied sections and *Planolites beverleyensis* are reported from Temple to MZU and Ramrikawn to Sakawrtuichhun sections of the study area. Therefore, in terms of broad depositional environment all the four sections of the study area are correlatable with the Ambalapuzha Formation (Mio-Pliocene). Detailed correlation is however not possible owing to lack of detail data from the Ambalapuzha Formation.

5.3.3 Northeast India

5.3.3.1 Tipam succession of Assam

Reddy *et al*. (1992) described several ichnogenera from the Tipam succession of Mio-Pliocene age of Assam and classified into *Skolithos* ichnofacies. This occurrence, together with that of trace fossils from the Kopili and Barail Groups (Palaeocene to Oligocene) has been interpreted as high energy shallow marine palaeoenvironmental settings for the Upper Assam Shelf. In the study area, the typical members of *Skolithos* ichnofacies *Skolithos* isp. occur in All the three studied sections and *Thalassinoides paradoxicus* are found to occur in Temple to MZU section and Ramrikawn to Sakawrtuichhun section. Therefore, the depositional environment of the Upper Assam shelf can be broadly correlated with the Bhuban Formation of the study area.

5.3.3.2 Oligocene-Miocene deposits of Bhuban and Boka Bil Formations, Manipur

Singh *et al*. (2010) reported 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. They inferred that the overall distribution pattern and behavioural nature of the ichnoassemblage and sedimentological attributes suggests that the sediments of Bhuban and Boka Bil Formations were deposited under frequent fluctuating sea level, moderate to strong energy condition, subtidal to lower intertidal environment rich in organic nutrients.Temple to MZU section and Ramrikawn to Sakawrtuichhun Section comprises of four ichnospecies which were described by Singh *et al*. (2010) e.g. *Diplocreterion* isp., *Ophiomorpha nodosa, P. Tubularis* and *Planolites beverleyensis*. These ichnofossils are typical members of the *Skolithos* and *Cruziana* ichnofacies. Therefore, Bhuban Formation of Manipur is broadly correlatable with the Upper Bhuban Formation of the study area. Spatial distribution of the ichnospecies from the study area in the Miocene successions of Northeastern India is given in table 5.2.

Table 5.2: Section wise correlation of trace fossils of the present study with the Miocene successions of other Northeast India (P=Present).

Kulikawn – S. HLImen	**Tipam Group, Assam. Reddy *et al*. (1992)**	**Bhuban Formation of Mizoram. Mehrotra *et al*. (2001), Lokho & Singh (2013)**	**Bhuban and Boka Bil Formation of Manipur. Singh *et al*. (2010)**	**Siwalik succession of Sikkim. Chakraborty *et al*. (2013)**
Ancorichnus isp,			p	
Diplocraterion helmerseni			P	
D. parallelum			p	

Laevicyclus mongraensis			p	
Pholeus abomasoformis			P	
Rhizocorallium jenense				
Rosselia isp.				
Skolithos isp.				
Tenidium isp.				
Teichichnus rectus		P	P	
Temple – MZU Section				
Cochlichnus anguineus			P	
Diplocraterion helmerseni			P	
D.parallelum			P	
Funalichnus bhubani				
Laevicyclus mongraensis			P	
Ophiomorpha annulata				

Oborneensis		P	P	
O.irregulariae				
Palaeophycus tubularis		P	P	
P. striatus				
Palaeophycus isp.				
Planolites annularis				
P. beverleyensis			P	
P. monatus				
Planolites isp.				
Skolithos verticalis	P			
Skolithos isp.			P	
Thalassinoides horizontalis				
T. paradoxicus				
T. suevicus				
Thalassinoides isp.				
Horizantal burrow				

Sakawrtuichhun – Ramrikawn section				
Funalichnus bhubani				
Ophiomorpha borneensis				
O.nodosa			P	
Palaeophycus tubularis		P	P	
P. sulcatus				
Palaeophycus isp.				
Phycosiphon isp.				
Planolites beverleyensis			P	
Planolites isp.				
Skolithos isp.				
Thalassinoides paradoxicus				
Thalassinoides isp.				

Ichnospecies Type A				

5.3.4 Correlation with the Miocene Successions of Western India

The Miocene ichnological researches are comparatively extensive in Western India. Many workers have contributed a significant amount of research works in this field e.g. Patel and Shringarpure (1990, 1998), Kundal *et al*. (2005), Kundal and Dharashivkar (2006), Kundal and Mude (2008), Mude (2012) and Patel (2014).

5.3.4.1 Aquitanian, Burdigalian and Helvetian rocks of Kutch

Early ichnological research in Western India was conducted by Patel and Shringarpure (1990) in Aquitanian, Burdigalian and Helvetian rocks of Kutch region. They briefly described ichnogenera *Skolithos, Arenicolites, Planolites, Palaeophycus, Chondrites, Cylindricum, Ophiomorpha, Scolicia, Spongliomorpha, Teichichnus, Macanopsis, Monocraterion* and *Thalassinoides.* These ichnofacies most likely indicate intertidal to sub-tidal depositional environment (Patel and Shringarpure, 1990). The Kulikawn – S. Hlimen, Temple – MZU and Ramrikawn – Sakawrtuichhun section comprises trace fossils of *Skolithos, Planolites, Palaeophycus, Ophiomorpha, Teichichnus* and *Thalassinoides* which are typical members of *Skolithos* and *Cruziana* ichnofacies. The ichnofacies developed in these sections indicates a foreshore to shoreface-offshore zone of shallow marine environment. Therefore, the Aquitanian, Burdigalian and Helvetian rocks of Kutch region (Patel and Shringarpure, 1990) can be broadly correlatable with the Upper Bhuban Formation of Kulikawn – S. Hlimen, Temple - MZU and Ramrikawn - Sakawrtuichhun sections in terms of depositional environment. are also found to occur in Temple – MZU and Ramrikawn - Sakawrtuichhun sections.

5.3.4.2 Babaguru Formation of the Cambay basin, Gujarat

Ichnofossils from the late Eocene to early Miocene of the Cambay Basin were studied by Kundal *et al*. (2005) with the reporting of six ichnospecies from the Babaguru Formation (early Miocene). This ichnoassemblage has been further subdivided in to *Skolithos* and *Cruziana* ichnofacies. Mude (2012) suggested that the Miocene succession of Babaguru Formation was deposited under moderate to high energy conditions in the near shore, littoral to shallow sublittoral environment and the predominance of vertical burrows and less density was interpreted as a paucity of nutrients. In the study area from Upper Bhuban Formation all the three studied sections at contain ichnospecies of *Laevicyclus* and *Skolithos,* Temple to MZU section and Ramrikawn to Sakawrtuichhun section contain ichnospecies *Ophiomorpha, Palaeophycus*, *Planolites*, and *Thalassinoides*. These burrows show typical characteristics of *Skolithos* and *Cruziana* ichnofacies described by Kundal *et al*. (2005) and Mude (2012). The depositional environment of Kulikawn to S. Hlimen, Temple to MZU and Ramrikawn to Sakawrtuichhun sections are inferred as foreshore to shoreface-offshore zone of shallow marine environment, therefore the depositional condition of Babaguru Formation of Gujarat can be broadly corelatable with the Upper Bhuban Formation of these sections.

5.3.4.3 Neogene-Quarternary deposits of Dwarka-Okha area, Gujarat

Kundal and Dharsivakar (2006) described a rich and diversified assemblage comprising 17 ichnospecies belong to 10 ichnogenera namely, *Cylindrichnus concentricus, Keckia annulata, Laevicyclus mongraensis, Ophiomorpha borneensis, O. irregulaire, O. nodosa, Palaeophycus heberti, P. tubularis, Planolites annularis, Pl. beverleyensis, Pl. montanus, Psilonichnus upsilon, Rhizocorallium karaiensis, R. yelmensis, Skolithos* isp., *Thalassinoides paradoxicus* and *T. suevicus* from Neogene-Quarternary deposits of Dwarka-Okha area, Jamnagar district, Gujarat. These ichnospecies belong to *Skolithos-Cruziana* mixed ichnofacies which indicates littoral to shallow sublittoral sandy shore with very high energy conditions of depositions (Kundal and Dharashivkar, 2006). In the study area, Temple to MZU, Kulikawn to S.Hlimen and Ramrikawn to Sakawrtuichhun section comprises inchnospecies of

Laevicyclus, Ophiomorpha, Palaeophycus, Planolites, Rhizocorallium, Skolithos and *Thalassinoides,* which are typical members of *Skolithos* and *Cruziana* ichnofacies. Temple to MZU, Kulikawn to S.Hlimen and Ramrikawn to Sakawrtuichhun successions were deposited under foreshore to shoreface-offshore zone of shallow marine environment. Therefore, the depositional environment of the Neogene-Quarternary deposits of Dwarka-Okha area can be broadly correlatable to all the studied sections of the study area.

5.3.4.4 Dwarka Formation of Porbandar area, Saurashtra, Gujarat

Kundal and Mude (2008) reported *Granularia isp., Ophiomorpha irregulaire, O. nodosa, Palaeophycus heberti, P. tubularis* and *Planolites beverleyensis* from the Dwarka Formation exposed in and around Porbandar area, Saurashtra, Gujarat and further subdivided into *Skolithos, Cruziana, Skolithos/Cruzina* and *Cruziana/Nereites* ichnofacies. It has been suggested by them that the Neogene-Quarternary succession of Porbandar area was deposited under nearshore environment. The sections of the study area comprise ichnospecies of *Ophiomorpha, Palaeophycus* and *Planolites*, which are also classified into *Skolithos*, *Cruziana* and *Skolithos/Cruziana* ichnofacies. Therefore, the depositional environment of the Upper Bhuban Formation in Temple to MZU, Kulikawn to S.Hlimen and Ramrikawn to Sakawrtuichhun sections can be broadly correlatable with the shallow marine depositional environment of the Neogene-Quarternary sediments of Porbandar area.

5.3.4.5 Kand Formation of Cambay basin, Gujarat

Mude (2012) documented *Laevicyclus mongraensis, Planolites beverleyensis, P. montanus, Thalassinoides paradoxicus* and *T. suevicus* from the ferruginous sandstone of Kand Formation of the Cambay basin. The trace fossils are associated with soft grounds, in a shallow marine environment, with moderate to low energy conditions, and nutrient availability (Mude, 2012). In the study area Upper Bhuban rocks of Temple to MZU, Kulikawn to S.Hlimen and Ramrikawn to Sakawrtuichhun were deposited under foreshore to shoreface-offshore zone of shallow marine environment .Therefore, the depositional environment of the Kand Formation of Cambay basin can be broadly related to all the studied sections of the study area.

5.3.4.6 Argillaceous limestone, Western Kachchh, Gujarat

Miocene sequence of the northwestern part of the Kachchh has been studied for their trace fossils by Patel (2014). This sequence comprises of highly fossiliferous and bioturbated argillaceous limestone and shales. Total 46 ichnospecies of 32 ichnogenera were identified which shows highly diversified behavioral activities and displayed abundance of dwelling and feeding structures of the infaunal organisms. The whole sequence is mainly dominated by *Arenicolites, Ophiomorpha, Palaeophycus, Planolites, Polykladichnus, Skolithos, Rhizocorallium* and *Thalassinoides*. The ichnofossils were further subdivided into *Skolithos* ichnofacies and *Cruziana* ichnofacies. The intensely bored rocks indicate semi-consolidated substrate for development of *Glossifungites* ichnofacies type conditions. The presence of *Skolithos-Cruziana* ichnofacies indicates unconsolidated, shifting, poorly sorted, soft substrate in moderate to low wave and current energy conditions while

Glossifungites ichnofacies indicate firm but unlithified sediments. Sedimentological and ichnological evidences indicate that the Miocene argillaceous limestones were deposited in foreshore-shoreface environments. The depositional environment of the Upper Bhuban succession exposed along Temple to MZU, Kulikawn to S.Hlimen and Ramrikawn to Sakawrtuichhun sections of the study area are inferred as foreshore to shoreface-offshore zone of shallow marine environment. As such the depositional condition of argillaceous limestone of Western Kachchh can be correlatable with the Bhuban Formation of these sections.

Table 5.3: Section wise correlation of trace fossils of the present study with the Miocene successions of Western India (P=Present).

Kulikawn – S. Hlimen	Aquitanian, Burdigalian and Helvetian rocks of Kutch. Patel & Shringarpure (1990, 1998)	Babaguru Formation, Gujrat. Kundal et al. (2005), Mude (2012)	NeogeneQuaternary deposits, Gujrat. Kundal & Dharshivkar (2006)	Dwarka Formation, Gujrat. Kundal & Mude (2008)	Kand Formation, Gujrat. Mude (2012)	Argillaceous limestone, Western Kachchh. Patel (2014)
Ancorichnus isp,						
Diplocraterion helmerseni						P
D. parallelum						
Laevicyclus mongraensis			p			
Pholeus abomasoformis			P			
Rhizocorallium jenense						
Rosselia isp.						
Skolithos isp.						
Tenidium isp.		P				
Teichichnus rectus						
Temple – MZU Section						

Cochlichnus anguineus						
Diplocraterion helmerseni						P
D.parallelum						
Funalichnus bhubani						
Laevicyclus mongraensis			P			
Ophiomorpha annulata						
O. borneensis						
O.irregulariae						
O.nodosa						P
Palaeophycus tubularis						P
P. striatus						P
Palaeophycus isp.						
Planolites annularis						
P. beverleyensis		P	P	P	P	P
P. monatus						
Planolites isp.						
Skolithos verticalis						
Skolithos isp.						P

Thalassinoides horizontalis						
T. paradoxicus		P	P	P	P	P
T. suevicus			P			
Thalassinoides isp.						
Horizantal burrow						
Sakawrtuichhun – Ramrikawn section						
Funalichnus bhubani						
Ophiomorpha borneensis			P			
O.nodosa		P	P	P		P
Palaeophycus tubularis			P			
P. sulcatus			P			
Palaeophycus isp.						
Phycosiphon isp.			P			
Planolites beverleyensis						
Planolites isp.						

Skolithos isp.	P					
Thalassinoides paradoxicus			P			
Thalassinoides isp.						
Ichnospecies Type A						

CHAPTER 6

CONCLUSIONS

6. SUMMARY AND CONCLUSIONS

1. The Upper Bhuban Formation of Surma Group (Lower to Middle Miocene) is well exposed in Aizawl district of Mizoram, India. This formation has been further divided into lower, middle and upper Bhuban units (Ganju, 1975; Tiwari and Kachhara, 2003). The present study has been conducted in Upper Bhuban units of Bhuban Formation exposed along three sections namely, Kulikawn – Hlimen, Temple – Mizoram University and Ramrikawn to Sakawrtuichhun section.

2. Extensive field study performed along these sections enabled to measure rock successions along these sections. A 14 m thick succession of Upper units of Bhuban Formation along Kulikawn – Hlimen section; 70.2m and 30m successions of Upper unit of Bhuban Formation along Temple - MZU and Ramrikawn - Sakawrtuichhun sections respectively. The dominant lithologies are sandstone, shale, silty-sandstone and their admixtures in various proportions along with a few pockets of calcareous sandstone and intraformational conglomerates.

3. A litholog showing the distribution of trace fossil is recorded. The collection has yielded a rich association of trace fossils. Ichnofossils mainly occur in sandstone, sandstone-shale alternation and shale lithologies.

4. A total of 32 ichnospecies belonging to 16 ichogenera have been identified from the collection, photographed and described. Out of these 32 ichnospecies, two ichnospecies could not be identified up to species level owing to poor preservation and less numbers of specimens. The remaining 28 ichnospecies were already described by previous workers. The ichnospecies *Phycosiphon* isp. and *Ancorichnus* isp. are being reported for the first time from Miocene succession of Mizoram

5. All the trace fossils in the study area belong to *Skolithos*, *Cruziana* and mixed *Skolithos*- *Cruziana* ichnofacies. Ethologically, the assemblage is dominated by domichnia and fodichnia .

6. 10 ichnospecies belonging to 9 ichnogenera have been described from Kulikawn – Hlimen section. These include *Ancorichnus* isp., *Diplocraterion helmerseni*, *Diplocraterion parallelum, Laevicyclus mongraensis, Pholeus abomasoformis*, *Rhizocorallium jenense*, *Rosselia* isp., *Skolithos* isp., *Taenidium* isp. and *Teichichnus rectus.*These ichnoassemblages represent *Skolithos* ichnofacies, *Cruziana* ichnofacies and at places mixed *Skolithos-Cruziana* ichnofacies. The members of the *Skolithos* ichnofacies are *Diplocraterion helmerseni*,*Diplocraterion parallelum*, *Laevicyclus mongraensis, O. nodosa, O. borneensis, Laevicyclus mongraensis*, *Pholeus abomasoformis*, *Skolithos* isp. and. *Cruziana* ichnofacies is represented by *Rosselia* isp., *Taenidium* isp. and *Teichichnus rectus*, whereas mixed *Skolithos-Cruziana* ichnofacies is represented by *Rhizocorallium jenense* and *Rosselia* isp..Ethologically, the association belongs to domichnia and fodichnia.. Domichnian signature is present in *Diplocraterion helmerseni*, *Diplocraterion parallelum*, *Laevicyclus mongraensis, Rhizocorallium jenense, Skolithos* isp., *Pholeus abomasoformis* and fodichnian in *Rhizocorallium* isp., *Taenidium* isp. and *Teichichnus rectus*.The *Skolithos* ichnofacies is related to relatively high levels of wave or current energy and is typically developed in well-sorted, loose or shifting substrates. Such conditions commonly occur in the foreshore zones. The *Cruziana* ichnofacies is most characteristic of poorly sorted, unconsolidated (muddy) substrates, uniform salinity and low energy conditions in the shoreface/offshore zones. Together these two ichnofacies indicate sandy shifting substrate and high energy conditions in foreshore to unconsolidated, poorly sorted soft substrate and low energy condition in shore-face/offshore zone of shallow marine environment for the deposition of the succession exposed in Kulikawn to Hlimen section.

7. A total of 20 ichnospecies belonging to 10 ichnogenera have been described from Temple to MZU section, which include the ichnofossil assemblages of *Skolithos*,*Cruziana* and mixed *Skolithos-Cruziana* ichnofacies. The domichnian signatures are preserved in ichnospecies like *Diplocraterion helmerseni, Diplocraterion parallelum*, *Funalichnus bhubani, Laevicyclus mongranesis, Ophiomorpha annulata, Ophiomorpha borneensis,Ophiomorpha irregulaire, Ophiomorpha nodosa, Palaeophycus annulatus, Palaeophucus striatus*, *Palaeophycus*

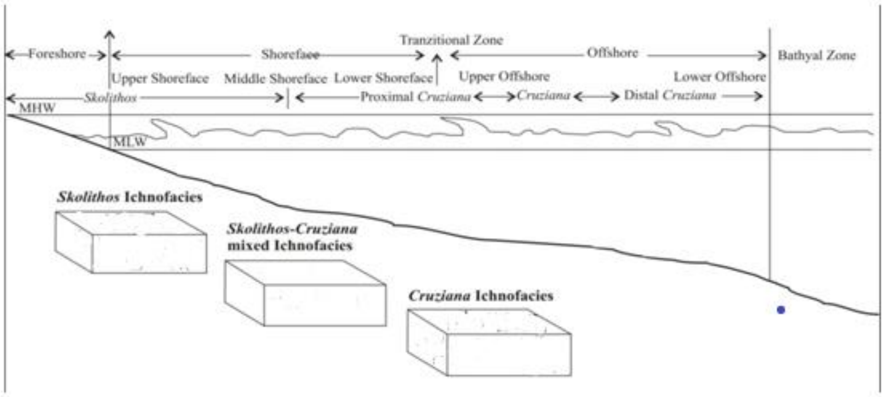
sulcatus, Palaeophycus tubularis, Skolithos verticalis and *Skolithos isp* while the fodichnian features are clearly evident in *Cochlichnus anguineus, Planolites beverleyensis, Thalassinoides suevicus, Thalassionoides horizontalis, Thalassionoides paradoxicus* and *Thalassionoides* isp. *Funalichnus bhubani* isp. nov. occur in association with *Diplocraterion* and *Skolithos* which are endichnial burrows of chiefly suspension feeding organisms and are typical members of the *Skolithos* ichnofacies (Seilacher, 1967; MacEachern and Pemberton, 1992). The members of the *Skolithos* ichnofacies are, *Diplocraterion helmerseni, D. parallelum, Funalichnus bhubani* isp. nov., *Laevicyclus mongraensis, Ophiomorpha irregulaire, O. nodosa, O.annulata* and *Skolithos verticalis*. *Cruziana* ichnofacies is represented by *Palaeophycus sulcatus, P.tubularis, P. striatus, Planolites beverleyensis,Planolites monatus* and *Thalassinoides Paradoxicus* whereas mixed *Skolithos*- *Cruziana* ichnofacies is represented by *Thalassinoides horizontalis* and *Thalassinoides suevicus*. The development of *Skolithos, Cruziana* and mixed *Skolithos-Cruziana* ichnofacies, indicates that the Upper Bhuban Formation of Temple-MZU section was deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine environment.

8. The Upper Bhuban unit of Bhuban Formation of Ramrikawn - Sakawrtuichhun section yielded trace fossil assemblage of 15 ichnospecies belonging to 7 ichnogenera. These include *Diplocraterion parallelum, Funalichnus bhubani, Ophiomorpha borneensis, Ophiomorpha nodosa, Palaeophycus tubularis, Palaeophycus sulcatus, Palaeophycus* isp., *Phycosiphon* isp., *Planolites beverleyensis, Planolites isp., Skolithos* isp., *Thalassinoides paradoxicus, Thalassinoides* isp. and Ichnospecies Type A. The ichnotaxa described from the studied succession are typical for the *Skolithos* and the *Cruziana* ichnofacies. The members of *Skolithos* ichnofacies are *Diplocraterion parallelum, Funalichnus bhubani, Ophiomorpha borneensis, Ophiomorpha nodosa* and *Skolithos* isp.*Cruziana* ichnofacies is represented by *Palaeophycus tubularis, Palaeophycus sulcatus, Palaeophycus* isp., *Phycosiphon* isp., *Planolites beverleyensis, Planolites isp., Skolithos* isp., *Thalassinoides paradoxicus, Thalassinoides* isp. and Ichnospecies Type A.. Etholoically, the assemblage belongs to domichnia and fodichnia groups. Domichnian signature is reflected in ichnospecies

of *Diplocraterion parallelum, Funalichnus bhubani, Ophiomorpha borneensis, Ophiomorpha nodosa* and *Skolithos* isp. Fodichnian signature reflected by *Palaeophycus sulcatus, Palaeophycus tubularis, Palaeophycus* isp., *Planolites beverleyensis, Planolites* isp., *Thalassinoides paradoxicus* and *Thalassinoides* isp. The *Skolithos* and *Cruziana* ichnofacies indicates a foreshore to shore-face/offshore shallow-marine environment, with occasional high-energy depositional conditions.

9. The recurring pattern of the trace fossils assemblages reflect the presence of suspension and deposit feeding animals throughout the sequences. Isolated occurrence of crawling trace reflect change in depositional regime. Overall, *Skolithos, Cruziana* and mixed *Skolithos/Cruziana* ichnofacies indicate variable hydrodynamic conditions as low wave and current energy conditions with intervening periods of high wave and current energy conditions and an intermediate period of stressful environment. The *Cruziana* ichnofacies is most characteristic of permanently subtidal, poorly sorted, and unconsolidated (muddy) substrates in shallow marine settings typified by uniform salinity. Conditions typically range from moderate energy levels lying below fair-weather (minimum) wave base but above storm wave base, to lower energy levels in deeper, quieter waters. Thus it can be inferred that the studied successions of Upper Bhuban Formation, Surma Group of Mizoram were deposited under sandy shifting substrate and high energy conditions in foreshore to unconsolidated, poorly sorted soft substrate and low energy condition in shore-face/offshore zone of shallow marine environment with occasion storm events. Schematic representation of ichnofacies and their depositional environment is shown in the figure 6.1.

10. Out of 32 ichnospecies, twelve ichnospecies are found in two or more sections. Two ichnospecies, namely *Diplocraterion parallelum* and *Skolithos* isp. have been reported from all the three sections. Owing to this correlation of depositional environment among these sections has been attempted to a fare degree of accuracy.



***Skolithos* Ichnofacies**

1. *Ancorichnus* isp.
2.D.helmerseni
2..*D. parallelum*
3..*F. bhubani* isp. nov
4..*Laevicyclus mongraensis*
6.*Ophiomorpha irregulaire*
7.O.nodosa
8.Pholeus abomasoformis
9. *Rosselia* isp.
10.. *Skolithos verticalis*
11. *Skolithos* isp.

***Skolithos-Cruziana* mixed Ichnofacies**

11.*Ophiomorpha annulata*
12.*Ophiomorpha borneensis*
13.*Rhizocorallium jenense*
14.T.horizontalis
15.T.suevicus
16.T.horizontalis
17. *Thalassinoides* isp.
Phycosiphon isp.

***Cruziana* Ichnofacies**

1.*Cochlichnus anguineus*
2. *Palaeophycus* isp.
3.Planolites beverleyensis
4.*Planolites annularis*
5. *Planolites montanus*
6.*P. tubularis*
7.*P.sulcatus*
8.*P. annulatus*
9 *P. striatus*
10.Taenidium isp.
11.Teichichnus rectus
12.IchnospeciesmType A

Figure 6.1: Schematic representation of Ichnofacies and their depositional environment.

11. As discussed earlier, sandy shifting substrate and high energy conditions in foreshore to unconsolidated, poorly sorted soft substrate and low energy condition in shoreface/offshore zone of shallow marine environment for the deposition has been inferred for the succession of Upper units of Bhuban Formation in Temple – MZU section. Upper Bhuban unit of Bhuban Formation along Kulikawn – S. Hlimen section was inferred to have been deposited under fluctuating energy conditions in foreshore to shoreface/offshore zones of shallow marine environment. UpperBhuban unit of Bhuban Formation in Ramrikawn – Sakawrtuichhun section has been assigned to foreshore to shoreface/offshore shallow-marine environment with occasional high-energy depositional conditions Therefore, the rock successions of Upper Bhuban Formation of Kulikawn – S. Hlimen , Temple – MZU and Ramrikawn – Sakawrtuichhun sections were deposited under similar depositional set-up and as such these rock succession are correlatable.

12. Correlation of depositional environment of the studied sections has been attempted with the Miocene successions of other parts of India. Sudan *et al*. (2002) suggested that the Murree Group of Jammu and Kashmir was deposited in coastal environment under brackish to fresh water conditions. The Upper Bhuban successions in the studied sections may be broadly correlatable with the Murree Group of Jammu and Kashmir. The Ambalapuzha Formation in Kerela was deposited under shallow water near-shore marine environment with moderate to high energy conditions (Mude *et al*.,2012). All the three sections of the stud y area are broadly correlatable with the Ambalapuzha Formation (Mio-Pliocene) in terms of broad depositional environment. A high energy shallow marine depositional environment of the Tipam succession of upper Assam shelf inferred by Reddy *et al*. (1992) is broadly correlatable with theUpper Bhuban Formation of the study area. 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. Thus these formations are also broadly correlatable with the Upper Bhuabn Formation of the studied sections in terms of depositional environment.

13. Correlation of depositional environment has also been attempted with the Miocene successions of western India. The depositional environment of Aquitanian, Burdigalian and Helvetian rocks of Kutch region (Patel and Shringarpure, 1990) can be broadly correlatable with the Upper Bhuban Formation of Kulikawn – S. Hlimen, Temple – Mzu and Ramrikawn – Sakawrtuichhun sections. Kundal *et al*. (2005) and Mude (2012) suggested that the Babaguru Formation of Cambay basin was deposited under moderate to high energy conditions in the near shore, littoral to shallow sublittoral environment and the predominance of vertical burrows and less density was interpreted as a paucity of nutrients. Thus, the depositional condition of the Upper Bhuban Formation from the studied sections also, can be broadly correlatable with this formation. The Neogene-Quarternery deposits of Dwarka-Okha area of Gujarat was deposited under littoral to shallow sublittoral sandy shore with very high energy conditions of depositions (Kundal and Dharashivkar, 2006), which can be broadly correlatable to all the studied sections of the study area. Kundal and Mude (2008) suggested a nearshore environment of deposition for the Dwarka Formation of Porbandar area, which is also broadly correlatable with the study area. Mude (2012) inferred that the Kand Formation of the Cambay basin was deposited under shallow marine environment, with moderate to low energy conditions, and nutrient availability. The Upper Bhuabn successions in the studied sections are also inferred to be deposited in a similar depositional set-up and therefore broadly correlatable with the Kand Formation of Cambay basin. Patel (2014) suggested that the deposition of argillaceous limestones of western Kachchh took place in foreshore-shoreface environments. Thus, it can also be correlatable with the deposition of Upper Bhuban Formation in the studied sections.

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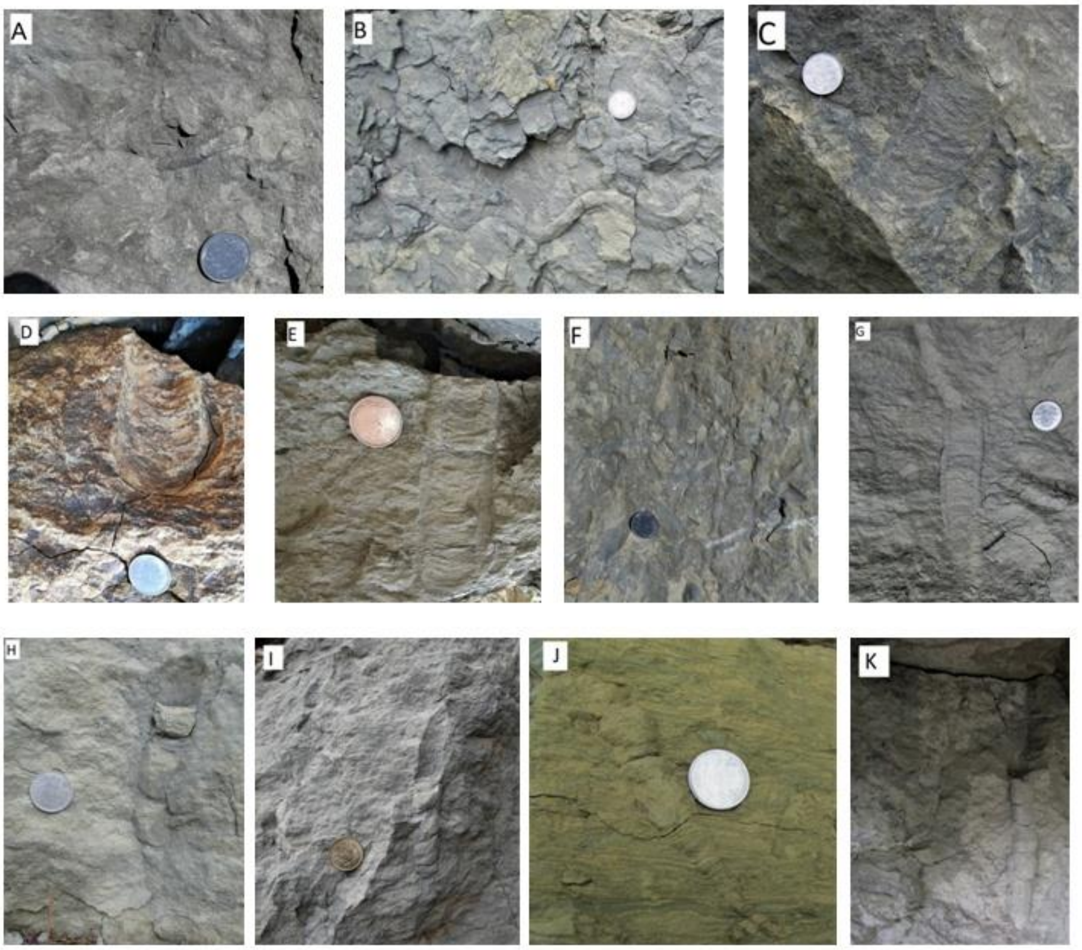
PLATES

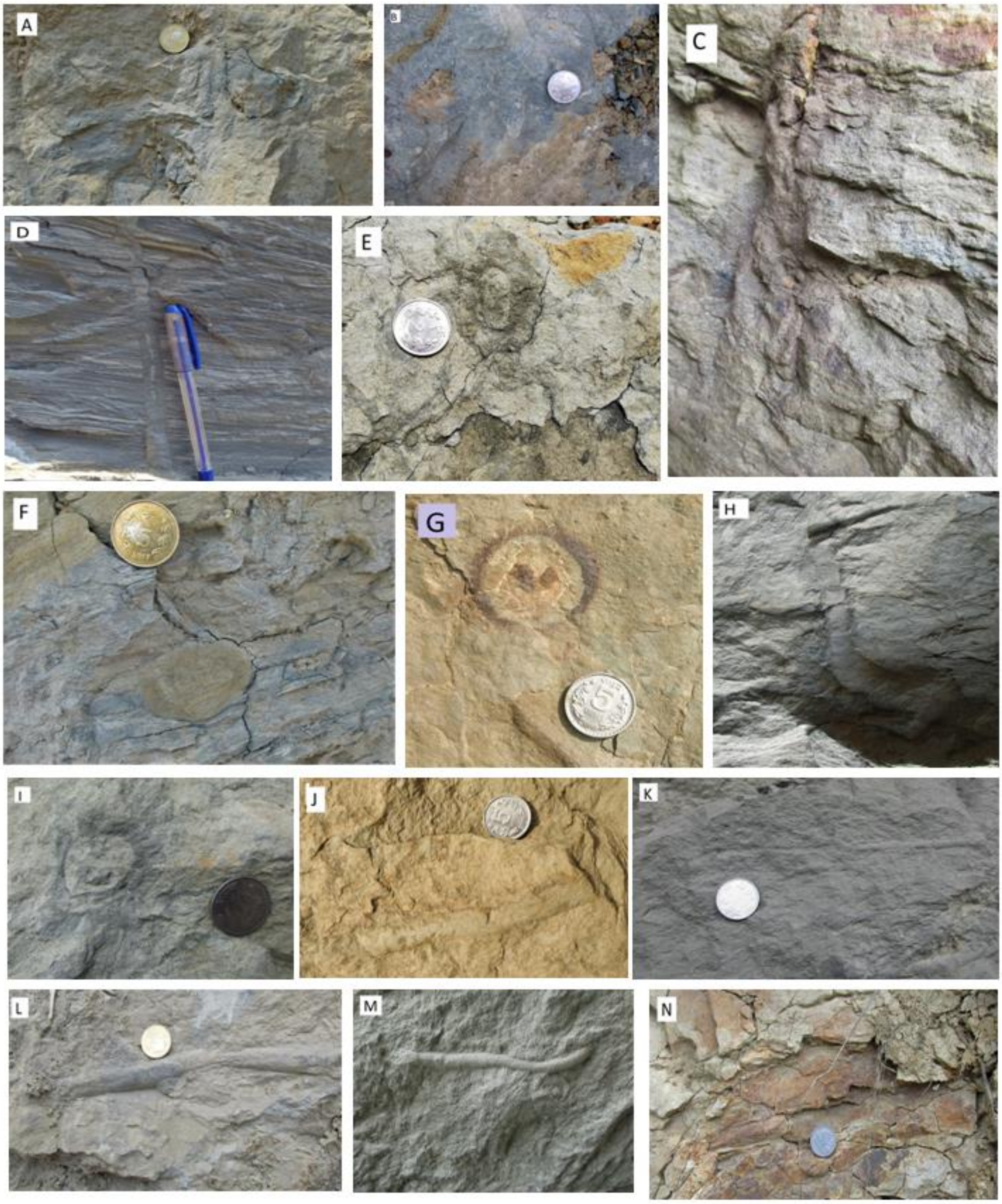
PLATE 1



EXPLANATION OF PLATE 1

Fig.No.	**Explanation**	**Pg.no**
A	*Ancorichnus* isp. from sandstone bed at Kulikawn-S.Hlimen section .	27-28
B	*Cochlichnus anguineus* from sandstone bed at Temple – MZU section .	28-29
C&D	*Diplocraterion helmerseni* from sandstone bed at Kulikawn – S. Hlimen and Temple -MZU section .	29
E,F&G	*Diplocraterion parallelum* sandstone bed at Klikawn-S.Hlimen and Ramrikawn-Sakawrtuichhun section.	30
H, I, J & K	*Funalichnus bhubani* from sandstone bed at Kulikawn -S.Hlimen, Temple – MZU and Ramrikawn-Sakawrtuichhun section.	31-33

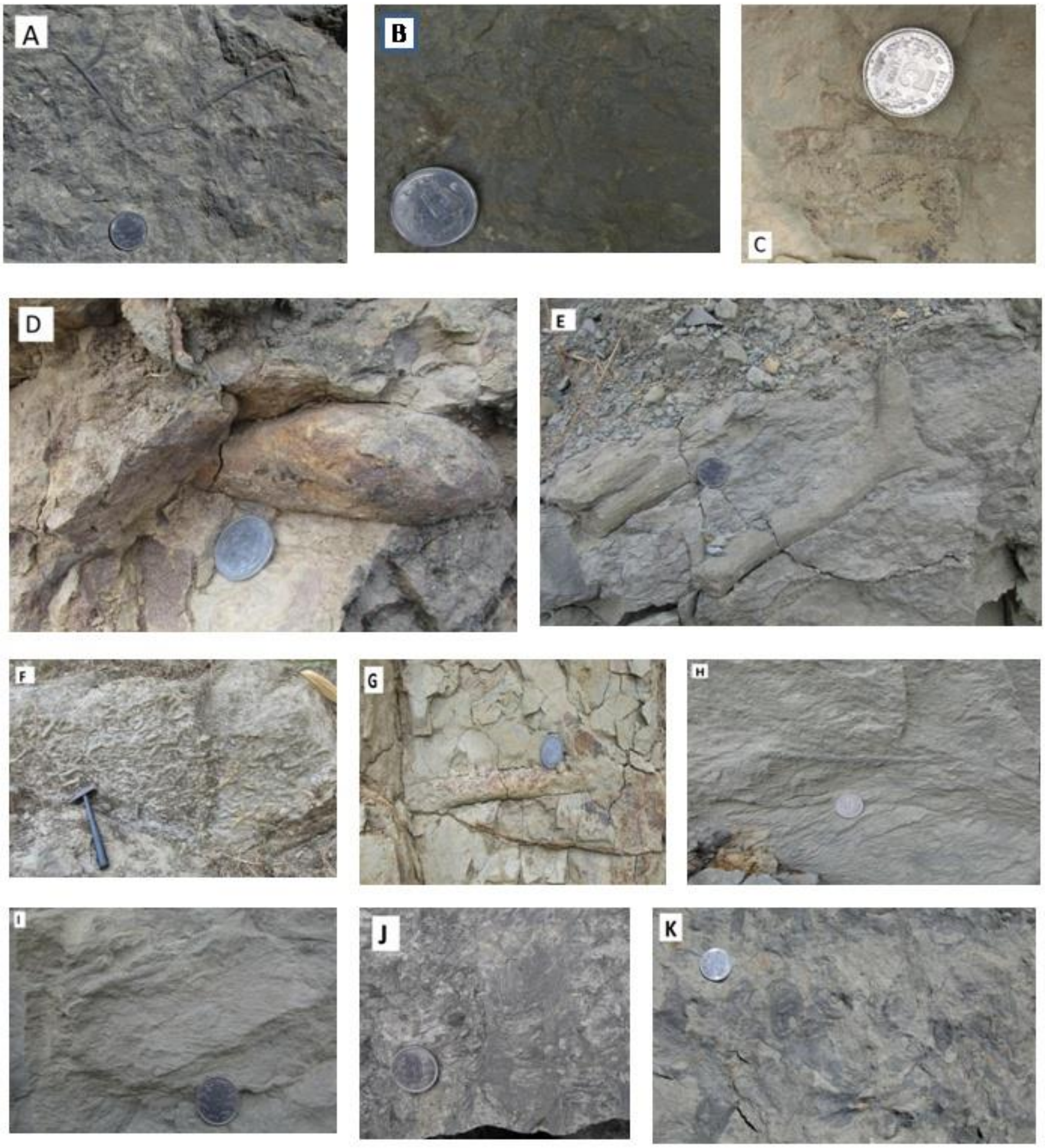
PLATE 2



EXPLANATION OF PLATE 2

Fig.No.	Explanation	Pg.no
A&B	*Laevicyclus mongraensis* from sandstone bed at Kulikawn-S.Hlimen section .	33-34
C	*Ophiomorpha annulata* from sandstone bed at Temple – MZU section .	34
D	*Ophiomorpha borneensis* from sandstone bed at Temple -MZU section .	34-35
E	*Ophiomorpha irregulariae from* sandstone bed at Ramrikawn-Sakawrtuichhun section.	36-37
F,G,H&I	*Ophiomorpha nodosa* from sandstone bed at , Temple – MZU and Ramrikawn- Sakawrtuichhun section.	35-36
J&K	*Palaeophycus tubularis* from sandstone bed at Temple-MZU and Ramrikawn-Sakawrtuichhun section.	37-38
L	*Palaeophycus striatus* from sandstone bed at Temple-MZU and Ramrikawn-Sakawrtuichhun section.	38-39
M&N	*Palaeophycus sulcatus*from sandstone bed at Temple – Mzu and Ramrikawn-Sakawrtuichhun section.	39

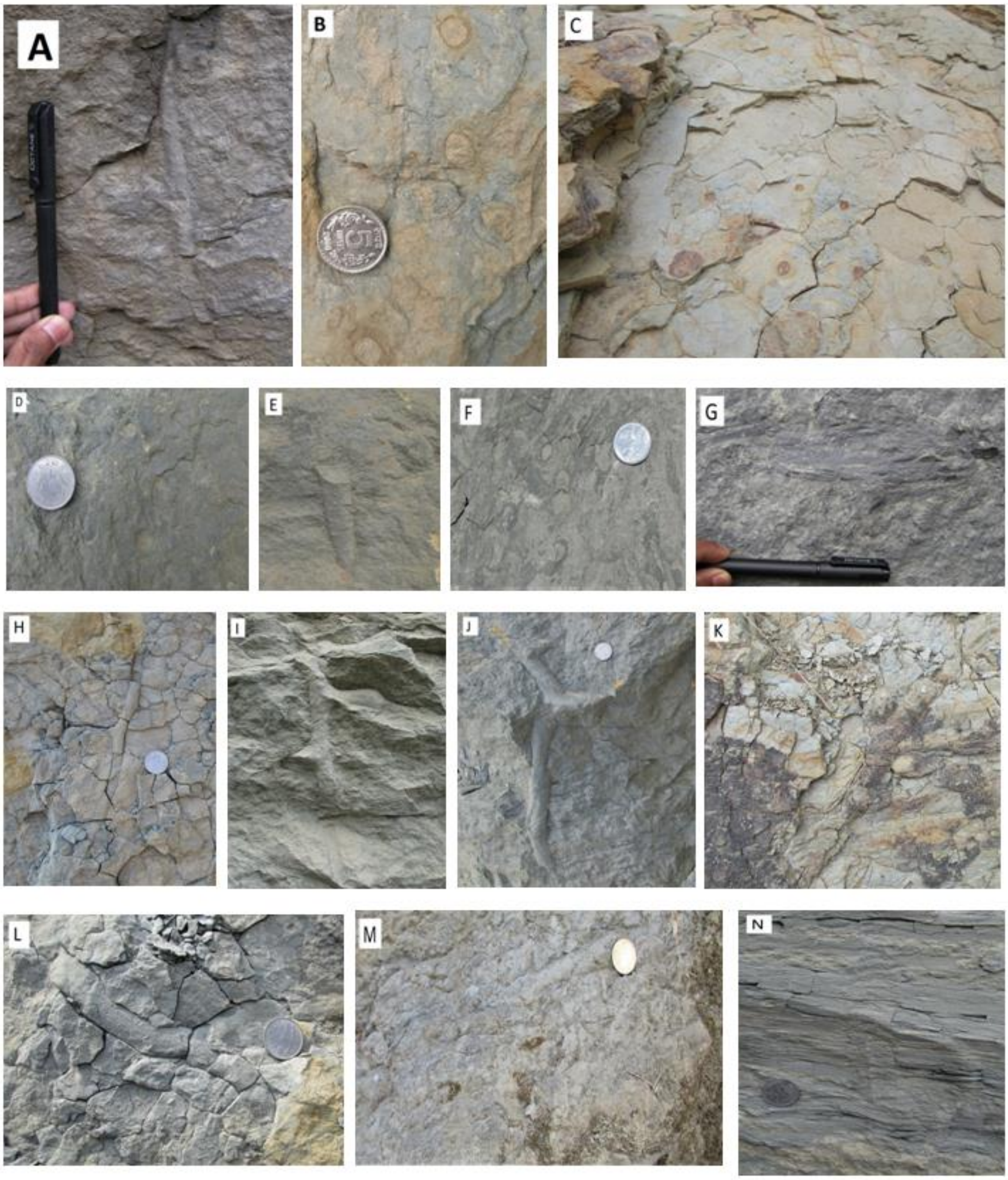
PLATE 3



EXPLANATION OF PLATE 3

Fig.No.	Explanation	Pg.no
A	*Pholeusanabomasoformis* from sandstone bed at Kulikawn-S.Hlimen section .	40
B	*Phycosiphon* isp. from sandstone bed at Ramrikawn – Sakawrtuichhun section .	40-41
C	*Planlites annularis* from sandstone bed at Temple -MZU section .	41-42
D	*Planolite monatus from* sandstone bed at Temple – MZU section.	43-44
E & F	*Planolites beverleyensis* from sandstone bed at , Temple – MZU and Ramrikawn- Sakawrtuichhun section.	42-43
G,H&I	*Planolites* isp. from sandstone bed at Temple-MZU and Ramrikawn-Sakawrtuichhun section.	44
J	*Rhizocorallium jenense* from sandstone bed at Kulikawn-S.Hlimen section.	44-46
K	*Rosselia* isp. from sandstone bed at Kulikawn-S.Hlimen section.	39

PLATE 4



EXPLANATION OF PLATE 4

Fig.No.	**Explanation**	**Pg.no**
A&B	*Skolithos verticalis* from sandstone bed at Kulikawn-S.Hlimen and Temple - MZUsection .	47-48
C,D&E	*Skolithos* isp. from sandstone bed at Ramrikawn – Sakawrtuichhun and sandstone-shale bed at Temple - MZusection .	48
F	*Taenidium* isp. from sandstone bed at Kulikawn -S.Hlimen section .	49
G	*Teichichnus rectus.* from sandstone bed at Kulikaw S.Hlimen section.	50
H	*Thalassinoides horizontalis* from sandstone-shale bed at Temple – MZU section.	51-52
I &J 52	*Thalassinoides paradoxicus* from sandstone bed at Temple-MZU and Ramrikawn-Sakawrtuichhun section.	52-
K,L	*Thalassinoides suevicus* from sandstone bed at Temple-MZU section.	53
M	Horizontal burrow . from sandstone bed at Temple -MZU section.	54
N.	Ichnospecies Type A from sandstone bed at Ramri-Kawn to Sakawrtuichhun section.	54

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I, the undersigned certify that to the best of knowledge and belief, the Resume correctly describes my qualification and myself.

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Ichnofossil assemblage of Bhuban Formation (Surma Group) from Zuangtui area, Aizawl, Mizoram

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Abstract

Bhuban succession of Surma Group (early to middle Miocene) is well exposed in Zuangtui section of Aizawl district of Mizoram and comprises ~40 m thick sequence of alternating sandstone, siltstone and shale and their admixtures in various proportion. Highly bioturbated rocks of this section show behaviorally diverse groups of trace fossils. A total of 17 ichnospecies have been identified from this section. 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.* These trace fossils represent the record of *Skolithos, Cruziana* and *Teredolites* ichnofacies and at places the mixed *Skolithos-Cruziana* ichnofacies. *Teredolites* infested log-grounds and the other ichnological evidences indicates that the rocks of Bhuban Formation exposed in Zuangtui area, Aizawl district of Mizoram were deposited under near shore high energy conditions.

Key words: Ichnofossils; depositional environment; Bhuban Formation; Surma Group; Aizawl.

Introduction

The Surma Group of rocks in Mizoram exhibit a rich and diversified assemblage of body fossils[9,53,54,58-60,62-69] and trace fossils.[37,41,42,50-52,70,71] Trace fossils can be used as a useful tool for interpretation of palaeoenvironmental and stratigraphic framework in the absence of body fossils.[40,44,57]

The Miocene rocks of Bhuban Formation are well exposed in the Zuangtui area of Aizawl district. A ~40 m thick sequence of the Bhuban rocks consisting of sandstone, siltstone, shale and their admixtures in various proportions has been measured in this section. The succession contains well-preserved, diverse trace fossil assemblages which are useful indicators of the environmental conditions prevailing during the time of deposition. Therefore, the main purpose of the present paper is to describe the trace fos-

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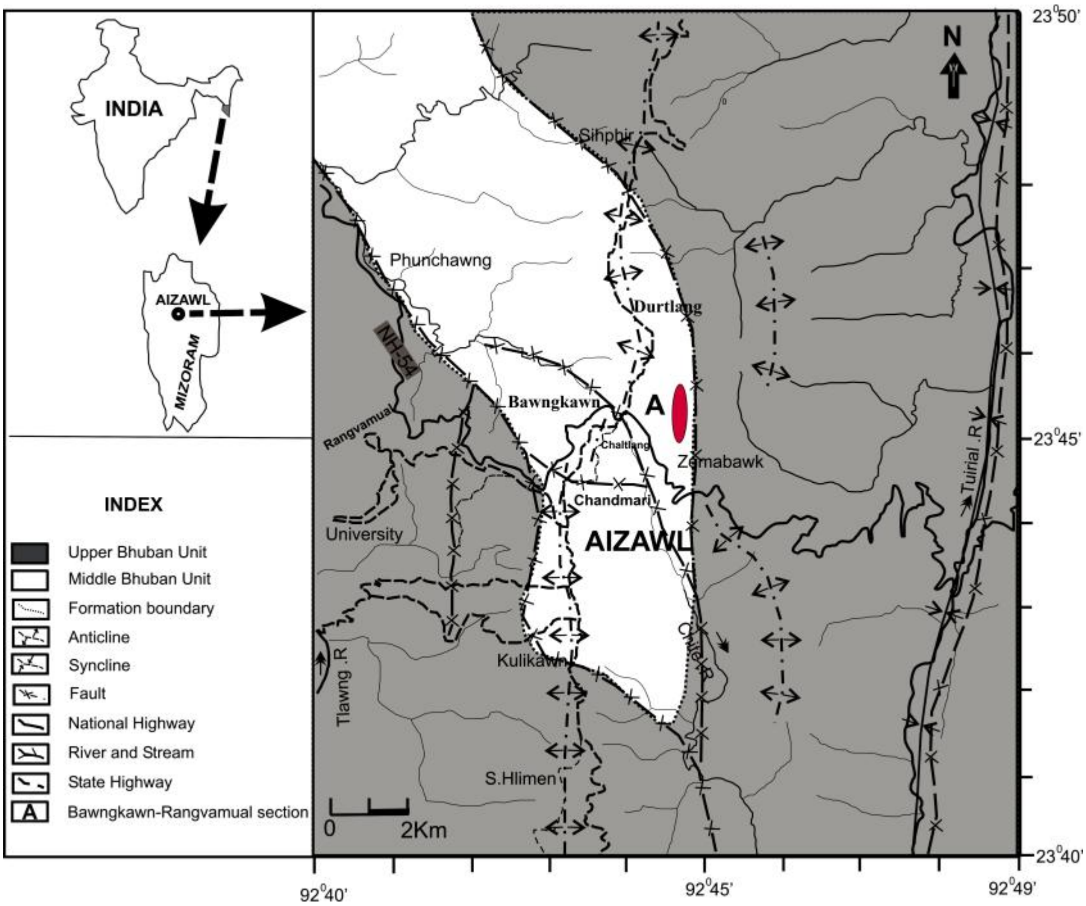

Figure 1. Location map of the study area (after Malsawma *et al.* 2010).

sils assemblage from this section and their palaeoenvironmental significance.

Location and geological setting

The study area is located in the northern part of Aizawl city, and falls under the Survey of India Topo-Sheet no. 84A/9 and between latitude 23°46'18.9" to 23°46'21.36" N and longitude 92°44'53.15" to 92°44'53.43" E (Fig. 1). At the study site, the Middle Bhuban Unit of Bhuban Formation is well exposed, along a small road cut section which provides well developed exposed sequence. The Tertiary sedimentary succession of Mizoram has been grouped into the Barail (Oligocene), the Surma (Lower to Middle Miocene) and the Tipam Groups (Upper Miocene to early Pliocene) in the ascending order. The Lower-Middle Miocene rocks of Mizoram are represented by Surma Group of rocks which has been subdivided into Bhuban and Bokabil Formation. Bhuban Formation is the best and thickest developed lithostratigraphic unit in Mizoram, it attains a thickness about 5000 m. This Formation is further subdivided into Lower, Middle and Upper Bhuban units. The entire sedimentary column of the formation is a repetitive succession of arenaceous and argillaceous rocks. The main lithologies exposed are sandstone, siltstone, shale, mudstone and their admixtures in various proportions and few pockets of shell limestone, calcareous sandstone and intraformational conglomerate (Fig. 2).[64] The stratigraphic succession with the lithological

Table 1. Stratigraphic succession of Mizoram (modified after Karunakaran 1974 and Ganju 1975).

Age	***Group***	***Formation***	***Unit***	***Generalized Lithology***
Recent	Alluvium			Silt, clay and gravel
------Unconformity------				
Early Pliocene to Late Miocene	Tipam (+900 m)			Friable sandstone with occasional clay bands
------Conformable and transitional contact------				
Miocene to Upper Oligocene	S U R M A (+5950 m)	Bokabil (+950 m)		Shale, siltstone and sandstone
		------Conformable and transitional contact------		
		B H U B A N (5000 m)	Upper Bhuban (1100m)	Arenaceous predominating with sandstone, shale and siltstone
			-------Conformable and transitional contact--	
			Middle Bhuban (3000m)	Argillaceous predominating with shale, siltstone-shale alternations ans sandstone
			-------Conformable and transitional contact--	
			Lower Bhuban (900m)	Arenaceous predominating with sandstone and silty-shale
------Unconformity obliterated by faults------				
Oligocene	Barail (+3000 m)			Shale, siltstone and sandstone
------Lower contact not seen------				

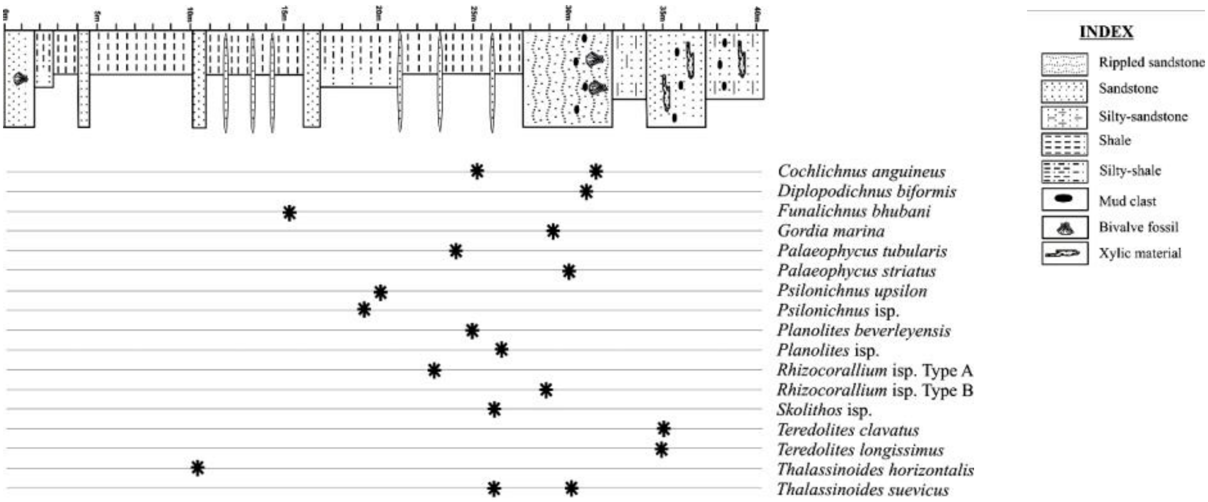

Figure 2. Generalized lithocolumn of the study area showing the distribution of the trace fossils.

characteristics of each unit is given in Table 1.[19,27]

Materials and Methods

The trace fossils collected from the Bhuban Formation (Surma Group) are thoroughly studied group wise up to species level for their systematic paleontological description with the help of type material and available literature in the laboratory. The data regarding the distribution pattern of fossils in the sediments such as orientation, density and state of preservation, their association, relationship with the enclosing sediments are also collected in order to decipher the depositional environment of the associated sediments.

Systematic Description

All the ichnospecies described and illustrated in this thesis are archived in the Palaeontology Laboratory of the Department of Geology, Mizoram University, Aizawl, Mizoram. These include *Cochlichnus angnineus, 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*. In the present study, ichnogenera and ichnospecies are named using the binomial system of nomenclature and described alphabetically.

Ichnogenus *Cochlichnus* Hitchcock, 1858
Ichnospecies *Cochlichnus anguineus* Hitchcock, 1858 (Figure 3a)
Material: Specimen no Geol/ZTF/1.

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

Remarks: The present specimen shows regular sinousity in structures which is similar to *C. anguineus* Hitchcock. Eager *et al.*[11] suggested that *Cochlichnus* are the crawling traces and probably are the feeding structures of small worms or worm like animals. Hakes[20] reported *Cochlichnus* in sediments of supposedly low salinity palaeoenvironment. In the context of Mizoram, Tiwari *et al.*[70] and Rajkonwar *et al.*[51] reported and described *Cochlichnus anguineus* from the Middle Bhuban Unit of Bhuban Formation, Surma Group of Aizawl.

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

Ichnogenus *Diplopodichnus* Brady, 1947
Ichnospecies *Diplopodichnus biformis* Brady, 1947 (Figure 3d)
Material: Specimen no Geol/ZTF/3.

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

Remarks: The general morphology and orientation of the ichnogenera represents crawling trails of molluscan origin.[24] The present traces are similar with *Diplopodichnus biformis* described by Keighley & Pickerill[28] and Buatois *et al.*[8] Buatois *et al.*[8] considered *Diplopodichnus* as a marine and non-marine Paleozoic trace fossil with possible range into the Late Proterozoic. It was also reported in Lower Triassic playa sediments of Germany, Middle Triassic carbonates of Poland and in Late Triassic deep lacustrine sediments of Argentina.[31,32,43] The present specimen is the first record of *Diplopodichnus* from the Surma rocks of Mizoram as well as other Miocene succession in India.

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

Ichnnogenus *Funalichnus* Pokorny, 2008
Ichnospecies *Funalichnus bhubani* Tiwari *et al.* 2013 (Figure 3c)
Material: Specimen no Geol/ZTF/2.

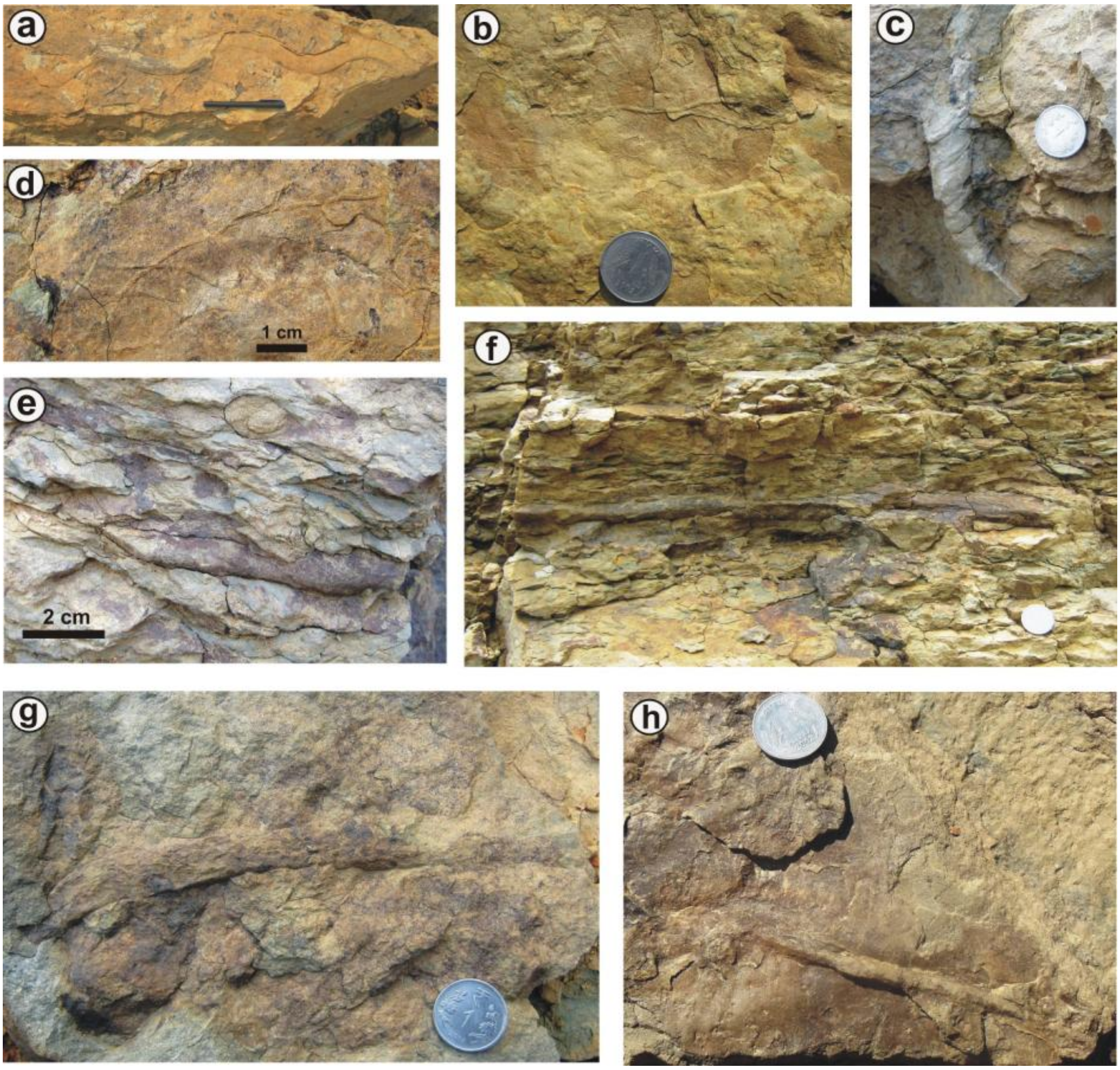

Figure 3. a. *Cochlichnus anguineus*, b. *Gordia marina*, c. *Funalichnus bhubani*, d. *Diplopodichnus biformis*, e. *Planolites* isp., f. *Planolites beverleyensis*, g. *Palaeophycus striatus*, h. *Palaeophycus tubularis*.

Description: The burrow is long, isolated, unbranched, vertical, straight to gently curved, endichnial and unlined burrow. The cylindrical body of the burrow shows slightly tapering at the bottom part. The burrow consists of a number of small cylindrical segments. The individual segments are smooth and slightly higher as compared to the interspaces, which are usually parallel to the bedding plane and are inclined to right or left sides. The burrow is circular to subcircular in cross section. Maximum length of the burrow is 12 cm and diameter ranges from 1.2 to 2 cm.

Remarks: Pokorny[49] described *Funalichnus* from the Upper Cretaceous of the Bohemian Basin, Czech Republic and include the type ichnospecies *Funalichnus strangulatus*. The present burrow of *Funalichnus* is similar with *Funalichnus bhubani* described by Tiwari *et al.*[71] from the Bhuban Formation of Surma Group of Aizawl. Tiwari *et al.*[71] suggested that the vertical nature and cylindrical segment form of *Funalichnus bhubani* indicates that the animal excavated the surrounding compact sediments to its body length and pushed the sediments periodically downward to maintain its position. Periodically filled structures are interpreted as a dwelling structure that may have had some combined feeding habits.

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

Ichnogenus *Gordia* Emmons, 1844
Ichnospecies *Gordia marina* Emmons, 1844 (Figure 3b)

Material: Specimen no Geol/ZTF/12.

Description: Straight to gently curved, long, smooth, slender trail. The trail is unbranched and uniform in thickness, which is 7 cm long and 0.3 cm wide. The sediments in the trail is similar with the surrounding rocks.

Remarks: The present specimen does not possess the regular sinuous of *Cochlichnus*, the loose meanders of *Helminthopsis* and regular meanders of *Cosmorhaphe*, therefore it is placed under *Gordia marina*. Hantzschel[24] considered *G. marina* as a scavenging or grazing trails of vermiform organisms. Rajkonwar *et al.*[50] reported *G. marina* for the first time from the Bhuban Formation of Aizawl district of Mizoram.

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

Ichnogenus *Paleophycus* Hall, 1847
Ichnospecies *Paleophycus striatus* Hall, 1852 (Figure 3g)

Material: Specimen no Geol/ZTF/7.

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

Remarks: The gross morphology of the ichnospecies resembles with *Palaeophycus striatus* described by Tiwari *et al.*[70] and Rajkonwar *et al.*[50] from the Surma succession of Northeast India. *P. striatus* differs from the rest of the ichnospecies of *Paleophycus* in having striations.

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

Ichnospecies *Palaeophycus tubularis* Hall, 1847 (Figure 3h)

Material: Specimen no Geol/ZTF/6.

Description: The burrow is cylindrical, full relief, long, smooth, unbranched, straight to slightly curved and preserved parallel to the bedding plane. The burrow fill is structureless and similar to the host rock. The maximum observed length of the burrow is 12 cm and diameter is 0.8 to 1 cm.

Remarks: The present specimen is identified as *Palaeophycus tubularis* on account of its horizontal smooth, straight, long and unbrached burrows with distinct lining. *Palaeophycus* is a eury-benthic facies-crossing form produced probably by polychaetes or annelids.[48] It can reasonably be compared with the form described by Patel *et al.*[47], Badve[1] and Kundal & Sanganwar[34] from the Bagh Group of Madhya Pradesh. Singh *et al.*[57] documented this species from Boka -Bil Formation (late Oligocene to Miocene) of Manipur. Tiwari *et al.*[70] and Rajkonwar *et al.*[50] described this species from the Bhuban Formation of Aizawl, Mizoram.

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

Ichnogenus *Planolites* Nicholson, 1873
Ichnospecies *Planolites beverleyensis* Billings, 1862 (Figure 3f)

Material: Specimen no Geol/ZTF/13.

Description: The burrow is simple, straight to slightly curved, unbranched, semicircular in cross section and horizontal to the bedding plane. The colour of the sediments in the burrow is different from the host rock. The maximum observed length of the burrow is 32 cm and diameter ranging from 1.8 to 2.5 cm.

Remarks: The present specimen shows the typical morphological characters of *Planolites beverleyensis*.[48] The ichnospecies has been reported by various workers from different parts of India.[3,33-35,57] *P. beverleyensis* has been described by Tiwari *et al.*[70] and Rajkonwar *et al.*[50,52] from the Bhuban Formation of Aizawl, Mizoram.

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

Ichnospecies *Planolites* isp. (Figure 3e)

Material: Specimen no Geol/ZTF/14.

Description: Simple, horizontal, endichnial, long, cylindrical, smooth-walled, unlined, straight to gently curved, unbranched burrow and oriented parallel to bedding plane. The sediment fill in the burrow is different from the host sediment.

Remarks: Since the observed burrows are unbranched, unlined, preserved parallel to the bedding and the burrow fill is different from the host rock, hence placed under the ichnogenus *Planolites* Nicholson. Due to lack of more detail morphologic feature, they are described as *Planolites* isp. and kept under open nomenclature.

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

Ichnogenus *Psilonichnus* Fursich, 1981

Ichnospecies *Psilonichnus upsilon* Frey *et al.* 1984 (Figure 4a & b)

Material: Field photograph of silty-sandstone with a full relief burrow.

Description: Burrows inclined, I-shaped, some are branched at the lower part, the branches are different from each other in terms of size and shape. Dimensions of the burrows vary in different burrow population but are constant in a given burrow. Maximum observed length is 32 cm and diameter ranges from 1.8 to 2.2 cm. The burrow fill is identical to the surrounding rocks.

Remarks: Present ichnospecies resembles very well with *Psilonichnus upsilon* reported by Singh *et al.*[57] from the Bokabil Formation of Manipur and Rajkonwar *et al.*[50] from Bhuban Formation of Mizoram. This ichnospecies has also been reported by Frey *et al.*[16] and Kundal & Dharashivkar.[33]

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

Ichnospecies *Psilonichnus* isp. (Figure 4c)

Material: Specimen no Geol/ZTF/8 and 9.

Description: The burrow is simple, isolated, I-shape, unbranched, unlined and vertical to incline to the bedding planes. The burrow material is almost similar with the host rock. The maximum observed length of the burrow is 8.5 cm and diameter is 1.8 to 2 cm.

Remarks: The overall morphological character of the present burrow is resembles with the ichnogenus *Psilonichnus*.[17] The species level identification has not been attempted due to lack of enough significant characters.

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

Ichnogenus *Rhizocorallium* Zenker, 1836

Ichnospecies *Rhizocorallium* isp. Type A (Figure 5d)

Material: Field photograph of silty-sandstone with a full relief burrow.

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

Remarks: The present specimen is partly weathered due to exposure to the environment.

Due to presence of spreiten and horizontal to the bedding plane, it is placed under the ichnogenus *Rhizocorallium* Zenker.

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

Ichnospecies *Rhizocorallium* isp. Type B (Figure 3e)

Material: Field photograph of grey sandstone with a full relief burrow.

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

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

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

Ichnogenus *Skolithos* Haldemann, 1840

Ichnospecies *Skolithos* isp. (Figure 4d & e)

Material: Specimen no Geol/ZTF/15.

Description: Burrows occur as solitary cylindrical, unbranched tubes disposed perpendicular to the bedding plane. Surface annulations are not seen. The lengths of the burrows are 4cm and diameter 8 to 10mm.

Remarks: Present specimens are placed under *Skolithos* isp. as these exhibit uniform diameter throughout the cylindrical tubes, perpendicular to bedding plane and surface annulations are not visible. Since the burrows are perpendicular to the bedding plane, the surface annulations are not seen, therefore the present burrows are described as *Skolithos* isp. and kept in open nomenclature.[24] They are interpreted morphologically as shaft and ethologically as domichnia.

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

Ichnogenus *Teredolites* Leymerie, 1842

Ichnospecies *Teredolites clavatus* Leymerie, 1842 (Figure 4g, h & i)

Material: Specimen no Geol/ZTF/10 and 11.

Description: Borings are clavate shaped, densely crowded, predominantly perpendicular to the grain in woody substrates, varying length between 2-10 mm and width between 3-5 mm. The bores are appearing round to oval, occasionally club shaped, having length-width ratio usually less than 5.

Remarks: Present ichnofossils exhibit similar morphological characteristics described by Leymerie.[36] *Teredolites* is restricted to borings in xylic material whereas *Gastrochaenolites* for equivalent borings in lithic material.[29] *T. clavatus* was reported by several workers from various Cretaceous and Tertiary sediments of the world.[10,29,36] It was reported by Mehrotra *et al.*[41] for the first time from the Bhuban Formation of Mizoram. Recently, Rajkonwar *et al.*[52] reported T. clavatus from Upper Bhuban Unit of the Bhuban Formation in Aizawl.

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

Ichnospecies *Teredolites longissimus* Kelly and Bromley, 1984 (Figure 4f, g & h)

Material: Specimen no Geol/ZTF/5.

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

Remarks: The present specimens are similar

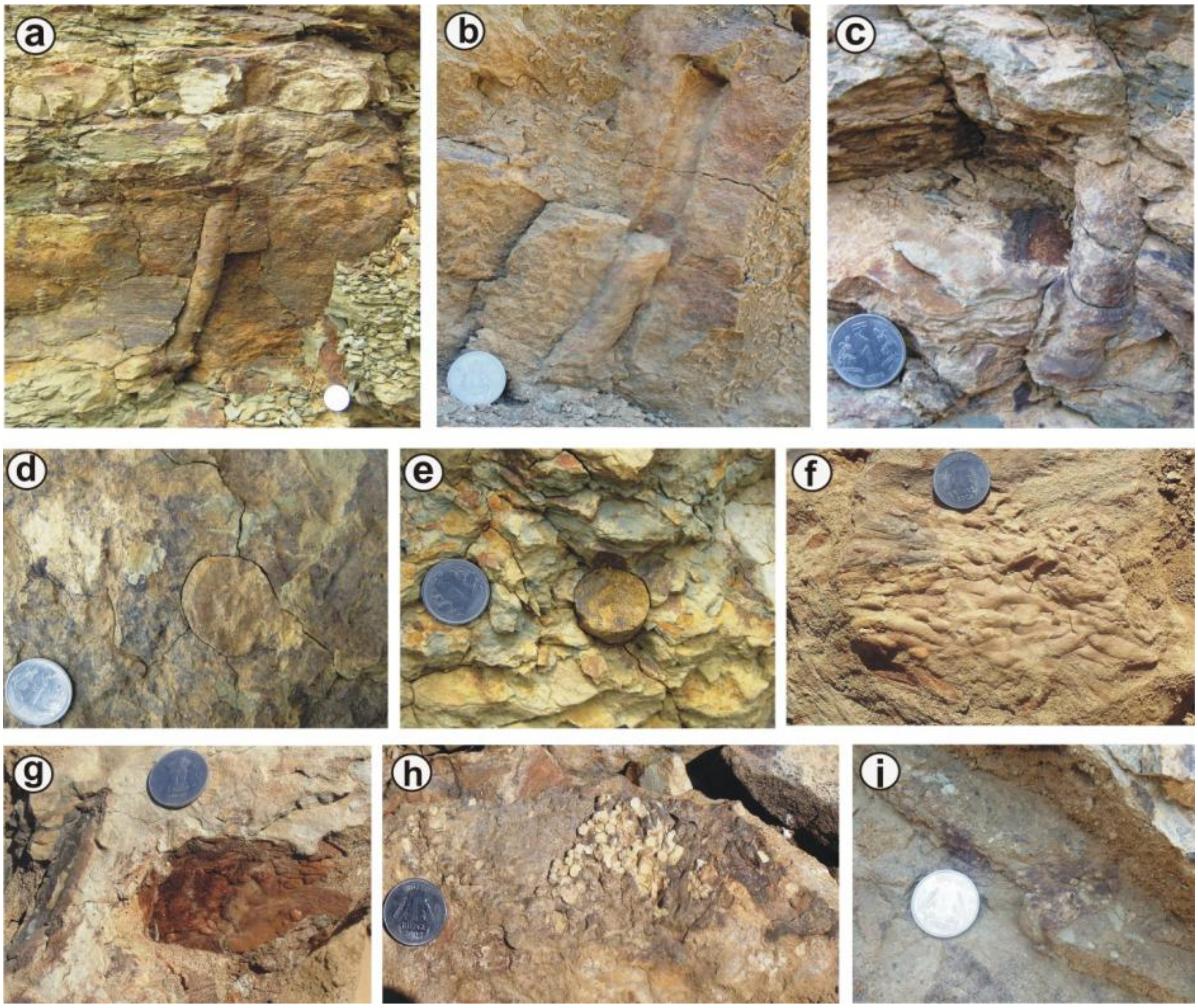

Figure 4. a. *Psilonichnus upsilon*, b. *Psilonichnus upsilon*, c. *Psilonichnus* isp., d. *Skolithos* isp., e. *Skolithos* isp., f. *Teredolites longissimus*, g. *Teredolites clavatus* and *T. longissimus*, h. *Teredolites clavatus* and *T. longissimus*, i. *Teredolites clavatus*.

with *Teredolites longissimus* described by Kelly and Bromley[29]. This ichnospecies predominantly develops parallel to the wood grain, having length-width ratio-usually greater than 5. For the first time Rajkonwar *et al*.[52] reported *Teredolites longissimus* from Upper Bhuban Unit of the Bhuban Formation in Aizawl.

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

Ichnogenus *Thalassinoides* Ehrenberg, 1944

Ichnospecies *Thalassinoides horizontalis* Myrow, 1995 (Figure 5a)

Material: Field photograph of grey sandstone with a full relief burrow.

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

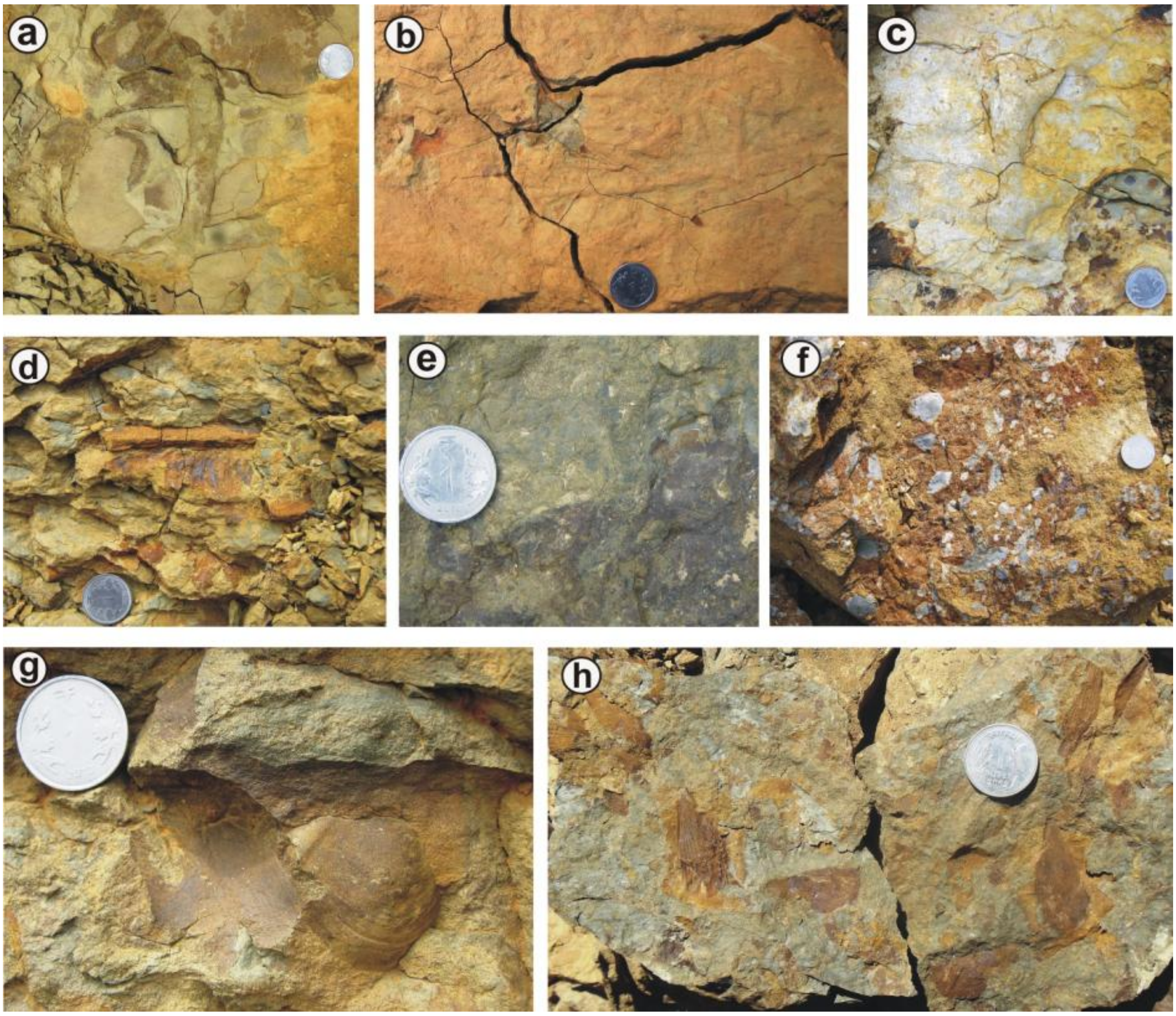

Figure 5. a. *Thalassinoides horizontalis*, b. *Thalassinoides suevicus*, c. *Thalassinoides suevicus*, d. *Rhizocorallium* isp. Type-A, e. *Rhizocorallium* isp. Type-B, f. Mud clast in brown coloured, medium grained sandstone, g. Bivalve cast (*Apolymetis* sp.) preserved in the bottom most medium grained sandstone, h. Bivalve *Pinna* preserved in grey sandstone.

3.5 cm.

Remarks: *Thalassinoides horizontalis* can be differentiated from the other ichnospecies of *Thalassinoides* in lack of the vertical component[45] and as occurring underneath the bedding plane. The morphological features of the present specimen resembles very well with the form described as *T. horizontalis* by Tiwari *et al.*[70] and Rajkonwar *et al.*[50] from the Bhuban Formation of Mizoram.

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

Ichnospecies *Thalassinoides suevicus* Rieth, 1932 (Figure 5b & c)

Material: Specimen no Geol/ZTF/4.

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

Remarks: The present burrows are very densely branched and thereby placed under *Thalassinoides suevicus*. Kundal & Sanganwar[34] and Kundal & Dharashivkar[33] also reported this ichnospecies from the Nimar sandstone Formation, Bagh Group of M.P and Neogene and Quaternary deposits of Dwarka-Okha area, Gujarat respectively.

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

Discussion and Conclusion

Vertical endichnial burrows of *Funalichnus bhubani*, *Psilonichnus upsilon* and *Skolithos* occur in silty-shale and shale beds exposed in the middle part of the succession are typical member of *Skolithos* ichnofacies.[38,56] Frey *et al.*[16] defined *Psilonichnus upsilon* based on unlined, sparsely branched, sub-vertical burrows that occur in back-beach and lower costal dune facies. The trace maker of *Psilonichnus upsilon* as the extant ghost crab *Ocypode quadrata*, elucidated by polyester casts of J-shaped burrows from the lower backshore areas. The *Skolithos* ichnofacies indicates the unconsolidated and shifting nature of the substrate, high energy conditions and a rapid change in the sedimentation rate and erosion of surface sediments.[57,72] *Funalichnus bhubani* indicates the changes in the colonization pattern of the benthic community.[71] Abundance of these biogenic structures and sedimentary characteristics may be attributed to a relatively moderate to high wave and current energy conditions and shifting of substrate exploited by the opportunistic animals in the foreshore/shoreface environments. Moreover, associated genera are intimately related to high energy shoreface environment indicating that the producer of the *Funalichnus* also occupied similar type of environmental set-up. The high abundance of horizontal deposit feeding traces namely, *Cochlichnus*, *Planolites*, *Palaeophycus*, *Rhizocorallium* and *Thalassinoides suevicus* are indicative of extremely quiet water conditions with less reworking where organic matter was being deposited along with the sediments.[26] This assemblage represents transitional zone to lower shoreface environment, somewhat quieter offshore conditions; most probably the lowest energy levels.[18] Bromley (1990) considered it as semi vagile and vagile, middle level deposit feeder structures, present in oxygenated situations. Because of lower energy level, less abrupt shifting of sediments and less change in temperature and salinity, *Planolites-Palaeophycus* assemblage characterized by feeding and grazing traces of most probably originators like polychaetes. The *Thalassinoides* are frequently related to the oxygenated situations and soft but fairly cohesive substrates.[5,7,13,30] This assemblage shows predominance of the deposit as well as the suspension feeder crustaceans and polychaetes. Overall this assemblage consists of dominant horizontal feeding structures suggests the low to moderate energy conditions, unstable, soft, unconsolidated substrate of the shoreface environment. *Cochlichnus* is a crawling trace and probably the feeding structures of small worms or worm-like animals[11] and reported in sediments of low salinity palaeoenvironment. The xylic material which hosts the *Teredolites* is interpreted to have either been carried down shallow distributary channels and trapped on flanking sand flats or was stranded on flats during the transgressive episodes that generated the flooding surfaces.[10,61] During the Lower Miocene time the rocks formed in Mizoram area were deposited in shallow marine setup, whereas this area has now turned into a positive land mass as a result of the withdrawal of the sea.

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