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Ichnological Significance of Upper Disang Formation and Lower Barail Formation (Late Eocene to Early Oligocene) of Nagaland, Northeast India, in the Indo-Myanmar Ranges

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ABSTRACT

The Upper Disang-Lower Barail Transition Sequences of Nagaland in northeast India, Indo-Myanmar Ranges (IMR) are found to preserve reasonably diverse biological sedimentary structures. Three ichnofacies were observed, *Skolithos* ichnofacies consisting of *Bergaueria hemispherica*, *Gyrochorte comosa*, *Ophiomorpha nodosa*, *Skolithos linearis* and *Thalassinoides paradoxicus*; *Cruziana* ichnofacies – *Curvolithus simplex*, *Scolicia plana*, *Scolicia strozzii*, *Scolicia vertebralis*, *Treptichnus pedum*, *Taenidium diesingi* and *Palaeophycus tubularis*; and *Nereites* ichnofacies – *Chondrites targionii* and *Paleomeandron elegans*. Presence of *Skolithos* and *Cruziana* ichnofacies suggest well oxidising, substrate rich depositional environment in the fore-shoreface to offshore setting in general; and an overall possible fluctuation in the depositional bathymetry which is supported by the presence of *Nereites* ichnofacies in horizons alternating with *Skolithos* and *Cruziana* ichnofacies. The depositional system is proposed to be proximal to distal hyperpycnal-delta-fed turbidite system. Observation of sand spherules also suggests possibility of shoreline as one of the depositional environments.

INTRODUCTION

Nagaland is located in the northern extension of the Arakan Yoma Ranges representing orogenic upheavals during Cretaceous and Tertiary periods. The state is largely a hilly region and forms part of the northern continuation of the Disang-Barail Groups of sediments, which are mainly developed in the state of Manipur. The Naga Hill sediments, especially the Barail Group contain quite a lot of biogenic sedimentary structures, which are widely appraised as one of the most vital tools for evaluation of sedimentary environments in terms of hydrodynamic conditions during deposition, substrate stability, salinity variations, oxygenation levels, bathymetry, etc., (Seilacher, 1967; Bromley, 1996; Howard and Frey, 1984; Pemberton et al. 2001; Buatois and Mángano, 2011; Zhang and Zhao, 2015 and the references therein). In addition, the Upper Disang Formation is also found to contain fairly abundant trace fossils. So far, two research papers on trace fossils of the Naga hills have been published (Lokho et al. 2017; Khalo and Pandey 2018). The former studied the trace fossils of Yikhum and Sechu-Zubza section (Laisong Formation) and suggested a proximal hyperpycnal-delta-fed coarse grained turbidite in shallow marine setting based on three ichnofabrics, namely, *Ophiomorpha-Palaeophycus*, *Chondrites-Planolites*, and *Thalassinoides* and associated sedimentary structures. The later indicated a shallow nearshore to offshore marine environment with fluctuating energy conditions on the basis of two ichnofacies namely *Skolithos* and *Cruziana*, along the Pfutsero-Mesulumi road section in Phek district (the Disang-Barail Transition Sequences, Srivastava et al. 2004). However, the present research paper may certainly be able to make further addition to the palaeoenvironmental significance of trace fossils of the Naga hills, mainly the Disang-Barail Transition Sequences, since, the research outcomes discussed here were from locations which have not been reported earlier.

GEOLOGY

Based on the geo-tectonic and morpho-tectonic features, the Naga hills can be divided longitudinally into a number of belts. These are, from east to west; the Naga Metamorphics, the Ophiolite Belt, the Inner Fold Belt, the Kohima Synclinorium and the Schuppen Belt (Pandey, 2005). The Inner Fold Belt occupies the central part of Naga hills and consists of two major Synclinoria, namely the Kohima Synclinorium to the south and the Patkai Synclinorium to the north. It marks the margin of the Molásse basin which extends toward the Bengal basin indicating that the basin had been receding towards southwest as the uplift of the Indo-Myanmar Ranges (IMR) began gradually. A large spread of Disang Group of sediments with isolated covers of sediments of Barail Group and the Disang-Barail Transition Sequences characterize the geological setting of this belt and confined within two major tectonic zones, the Haflong-Disang Thrust in the west and the Ophiolite-Disang Thrust in the east. The Disang Group is characterised by thick succession of dark grey splintery shales. Carbonaceous materials are found in small lenses. Rao (1983) suggested brackish water, tidal flat environment of deposition for some of the members of the Disang Group. Its sedimentary record shows a continuity of shelf environment, where rapid subsidence favoured accumulation of a thick pile of Palaeogene rocks. On the other hand, the Barail Group is represented by hard, compact and well bedded sandstones which show different shades of colour and herringbone cross beddings indicating periodic variation of flow direction of the transporting medium (Gaur and Chakradhar, 1985). The Barails in the Zubza area is characterised by a thick argillaceous bluish grey shale, carbonaceous shale and a few centimetre scale coal seams.

The Disang-Barail Transition Sequences in Nagaland is characterized by 80–100 m thick heterogeneous succession of sand-mud lithology that overlies gradationally the repetitious argillaceous Disang sediments and passes upward into dominantly arenaceous Barail Group of rocks. The sand-silt units in the succession exhibit numerous alternations of thin, flaggy, well cemented siltstone, fine-grained, occasionally medium-grained sandstones and sandy or silty shales. Separation of the Disang Group from the Barail Group is presently based on the first appearance of multi-storeyed sandstones

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which define the base of the Barail Group. This approach is convenient for lithostratigraphic sub-division, but it has certain practical limitations (Devdas and Gandhi, 1986). Evans (1932) has also recorded the aspect of similarity between the lower units of Laisong shales and the underlying Disang shales. The rapid alternation of 3–4 m of sandstones and shales in basal part of the Laisong Formation further prevents precise delineation of the contact.

Of the four sections of trace fossils study in the Nagaland, the section marked as ‘C’ in the geological map (Fig.1) near the RCC bridge on the Dzü-ü River (25°39'19.78"N and 94°11' 12.61"E; 919 m a.s.l.) in the proximity of Chakabhama village is closer to the upper Disang Formation, though in the Disang-Barail Transition Sequences, as indicated by the presence of thick succession of dark grey splintery shales and various other features characteristic of the Upper Disang Formation such as sandstone bodies in between shales and current ripples at places. On the other hand, the Kigwema, Kiruphema and Peducha sections although in the Disang-Barail Transition Sequences are closer towards the Barail Group (Fig. 1). The Kigwema section (Fig.2) (25°36'09ºN and 94°06'43ºE; 1635 m a.s.l.) is characterized by intercalations of shales, silty shales, fine sandstones and medium sandstones and important sedimentary features namely ripple marks, planar cross beddings and pot casts. Further, it may be noted that the thickness of the Laisong Formation (Lower Barail Formation) and the Jenam Formation (Middle Barail Formation) as observed at the Kigwema section is approximately 600 m and 500 m respectively. From this it may be inferred that the thickness of the Barail succession wedges toward Nagaland as compared those in Manipur and this fact supports the view that the Barail Group successions in Nagaland represent a more marginal setting in comparison with the other Barail Group successions in parts of Manipur. The Kiruphema section (25°43'40"N and 94°01'42"E; 1103 m a.s.l.) has very remarkable sedimentary successions with coarsening upward sequence consisting predominantly of arenaceous sediments representing a prograding sequence. In the Peducha section (25°44'02"N and 94°00'07"E; 954 m a.s.l.) the nature of sediments is intercalation of shales, silty shales and fine sandstones (Fig.3). Typical sedimentary structures include cross beddings, ripple marks, rhythmic beddings, graded beddings, load casts, flute casts, groove marks and pebbly/cobbly horizons. Moreover, other structures are the huge load casts that remarkably represent the base of the turbidite deposits. Such feature can be correlated with similar occurrence in the Gelmon section (24°07'39.74"N and 93°53'56.95"E) of Manipur, which also marked the Disang-Barail Transition Sequences.

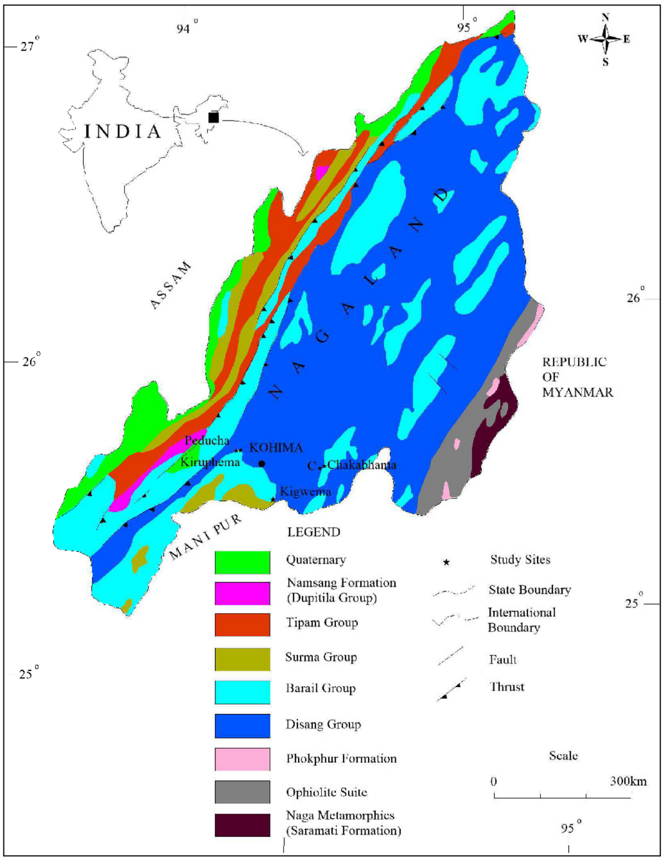

Fig.1. Geological map of Nagaland showing the studied sections (modified after Kenye and Lhoupenyi, 2008).

SYSTEMATIC ICHNOLOGY

The ichnospecies described below are the outcome of ichnological research in parts of Nagaland state. The collected specimens are housed in Mantrimayum Ichnological Museum (MIM), Sagolband Bijoy Govind Leikai, Imphal, Manipur, India.

Ichnogenus: *Bergaueria* Prantl 1945
Ichnospecies: *Bergaueria hemispherica* Crimes, Legg, Marcos and Arboleya 1977 (Fig. 4a)

Diagnosis: Unlined or thinly lined *Bergaueria*, diameter slightly less than, equal to, or more typically greater than height; rounded lower end rarely exhibits faint radial ridges emanating from a central depression and a peripheral ridge; surface may be smooth but concentric ornamentation typically present (after Prantl, 1945; Crimes et al. 1977; Pemberton et al. 1988; Fillion and Pickerill, 1990).

Materials: Three specimens and more field observations at Kigwema. Specimen Nos. MIM/TF/B/01, 02, 03.

Description: Typically knob-shaped, hypichnial mound preserved on surface of fine sandstone beds, with hemispherical terminations, vertically arranged, oval to circular in outline with 14–20 mm diameter and 4–7 mm height; the sandy fill is essentially structureless.

Remarks: *Bergaueria hemispherica* is either domichnia or cubichnia of shallow burrows or casts of upper part of deeper vertical burrows (Leszczyñski, 2004). Probably produced by suspension-feeders such as sea-anemones; indicative of normal marine conditions on a wave or tide dominated shoreface and in flysch deposits (Knaust, 2017); common element of the *Skolithos* ichnofacies in brackish water environments, but greatly reduced in size (Uchman, 1995). The name plug-shaped has also been introduced (Pemberton et al. 1988) and ranges from Lower Cambrian (Pemberton and Magwood, 1990) to Oligocene (Ksiazkiewicz, 1977).

Ichnogenus: *Chondrites* Sternberg 1833.
Ichnospecies: *Chondrites targionii* (Brongniart 1828) (Fig. 4b).

Diagnosis: Dendritic branching tunnel systems oriented parallel to bedding plane with no evidence of vertical expression. Branches straight or slightly curved, with the angle of branching frequently sharp. Branch diameters constant throughout each individual burrow, few millimeters wide (Gong, 1999; Uchman, 1999).

Materials: Six specimens analysed from Kigwema, two have been collected. Specimen Nos. MIM/TF/CT/01, 02.

Description: The structures consist of a tangle of regularly branched burrows which are overlapping with one another. First order branches dominate. The angle of branching is usually sharp. Most of the tunnels are more or less straight, radiating with average width of 3 mm and lengths ranging from about 20–60 mm; longest tunnel is about 100 mm.

Remarks: The size and shape of the specimens are in the range of *Chondrites targionii* described by Uchman (1999). Tracemaker is able to live at the oxic/anoxic interface, in dysaerobic conditions, as a chemosymbiont (Fu, 1991). In the studied section *Chondrites* appear

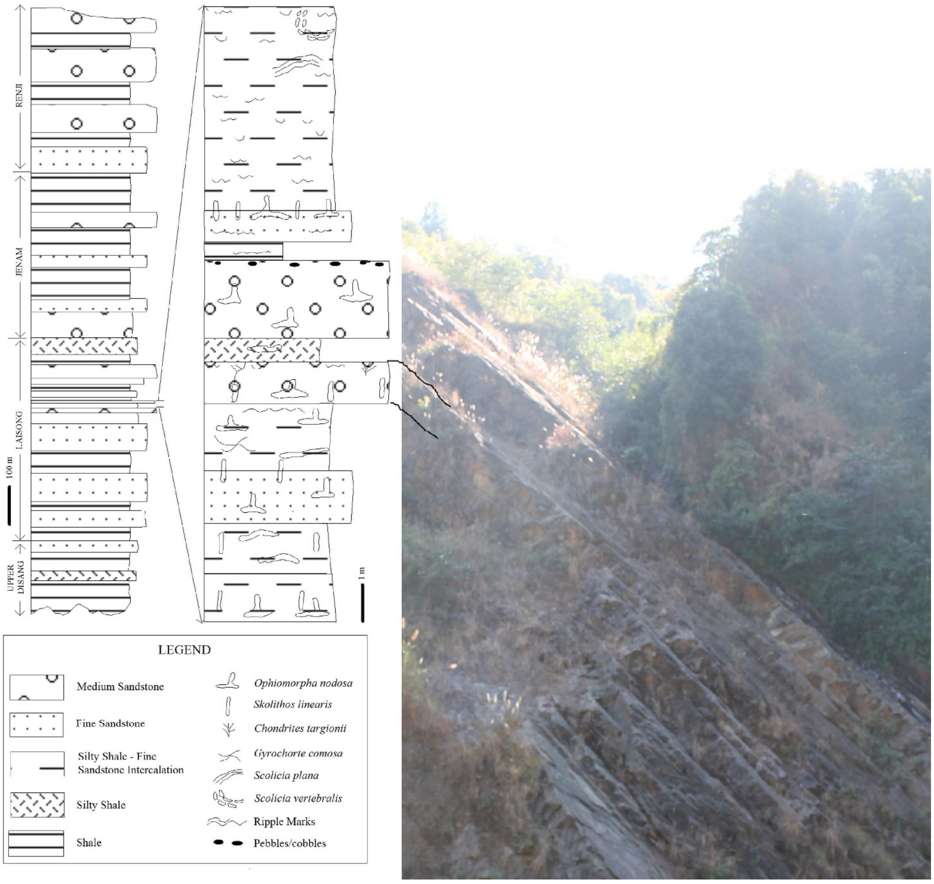

Fig.2. Lithocolumn and field photograph of the Kigwema section.

sparsely together with *Skolithos* and *Thalassinoides* that allow the interpretation of oxygenated bottom waters; high degree of branching suggests construction by endobenthic deposit feeders. Simpson (1957) presumed siphunculids as the producers; Schäfer (1972) relates *Chondrites* to recent polychaetes forms. Age ranges from Cambrian (Crimes, 1987) to Holocene (Werner and Wetzel, 1981).

Ichnogenus: *Curvolithus* Fritch 1908.
Ichnospecies: *Curvolithus simplex*
Buatois, Mángano, Mikuláš and Maple
1998 (Fig. 4c).

Diagnosis: Straight to curve, horizontal, sub-horizontal to rarely oblique, ribbon-like or tongue-like, flattened, unbranched, essentially endostratal traces with three rounded lobes on upper surface and upto four lobes on concave or convex lower surface. Central lobe on upper surface wider than outer lobes and separated from them by shallow, angular furrows (Buatois et al. 1998).

Materials: Five samples from the silty fine sandstone at Kiruphema. Collected Specimen No. MIM/TF/CUR/01.

Descriptions: Straight to slightly winding, horizontal, trilobate ribbon-like trace fossils. From a hypichnial view, they are composed of central, flat or slightly convex rounded side lobes with all parts smooth. The width of the entire burrow is 8–10 mm while those of side lobes are 2–3 mm.

Remarks: According to the revision by Buatois et al. (1998), *Curvolithus* has only two ichnospecies: *C. multiplex*, and *C. Simplex*. *C. multiplex* is easily recognizable by the quadralobe lower surface. *Curvolithus* is interpreted as a locomotion trace (repichnion), produced most probably by carnivorous gastropods (Heinberg, 1973) similar to recent representatives of the *Cephalasidae* family (Heinberg and Birkelund, 1984). *Curvolithus* occurs from the Proterozoic (Webby, 1970) to the Miocene (Keij, 1965) in various shallow marine or even brackish environments, including distal fan deltas, tidal flats and offshore settings (Buatois et al., 1998). Lockley et al. (1987) proposed a subset of *Cruziana* ichnofacies - *Curvolithus* ichnofacies - corresponding to deltaic-influenced near shore environments subject to rapid deposition exceeding physical reworking.

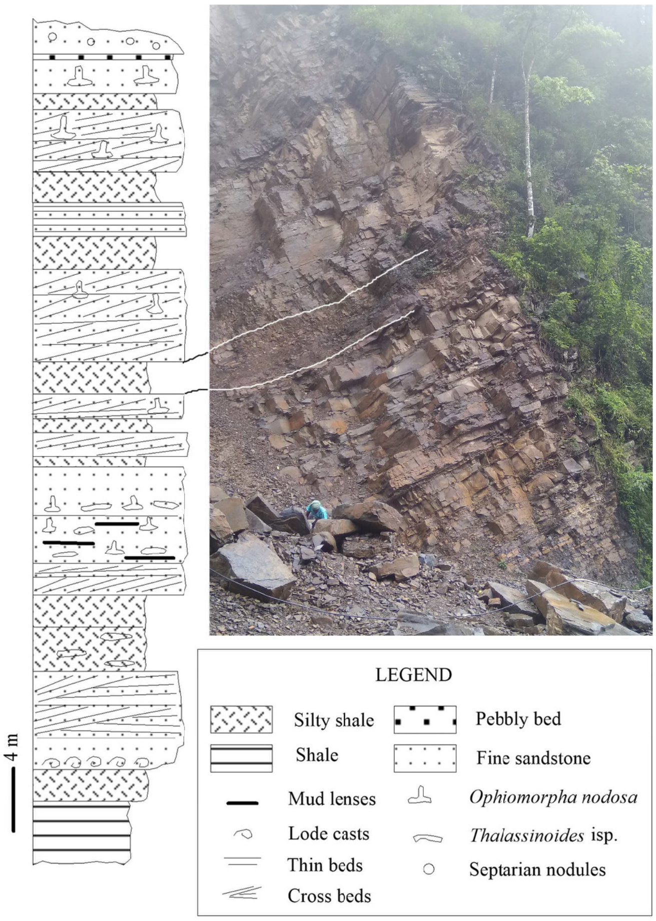

Fig.3. Lithocolumn and field photograph of the Peducha section.

Ichnogenus: *Gyrochorte* Heer 1865
Ichnospecies: *Gyrochorte comosa* Heer 1865 (Fig. 4d)

Diagnosis: Ridges on bedding planes with biserially arranged, obliquely placed transverse pads, both series separated by median furrow (Heer, 1865). Wall-like burrow with a top part (positive epirelief) consisting of two convex lobes with a median furrow a bottom part (negative hyporelief) consisting of two grooves and a median ridge. The burrow exhibits an irregular meandering or arcuate course, but more rarely it can be straight or gently curved (Gibert and Benner, 2002).

Materials: Three specimens observed and studied in the field only at Kigwema.

Description: Burrows are in the form of bilobate, horizontal traces, 4–6 mm wide and up to 3 mm high above bedding plane. Full relief is

Table 1. Stratigraphic Succession of Naga Hills (after Mathur and Evans, 1964; Agrawal and Ghosh, 1986; Gupta and Biswas, 2000)

Group	Formation(in Outer and Intermediate Hill Ranges)	Age	Lithology
	Alluviums and high level terraces	Quaternary and Recent	
	Dihing Formation	Pleistocene	
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
	Namsang Beds	Miocene to Pliocene	
Tipam Group	? Girujan Clay	Pliocene to?Miocene	
	Tipam Sandstone		Greenish to blue, moderate to coarse ferruginous sandstones with sandy shale and clay.
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Surma Group	Bokabil	?Late Miocene to Late Oligocene	Soft clays with minor sandstones.
	Bhuban		Alternations of sandstone and shale with more argillaceous horizons in the middle and minor conglomerates.
Barail Group	Renji/Tikak Parbat (Upper Barail)	Late Oligocene to Late Eocene	Primarily hard, massive sandstones.
	Jenam/Baragoloi (Middle Barail)		Mainly shales with some bedded sandstones and carbonaceous shale horizons.
	Laisong/Naogaon (Lower Barail)		Intercalation of bedded sandstone with relatively thin siltstone and shale beds. Horizon characterised by trace fossils and invertebrates, plant/leaf impressions.
Upper Disang/Lower Barail Transition Sequences which is gradational as well as (local) tectonic contact			
Disang Group	Upper Disang	Late Eocene to Late Cretaceous	Dark grey splintery shales with intercalation of thin siltstone and sandstone beds.
	Lower Disang		Dark grey to black shale. Shales slightly metamorphosed to phyllites and slates.
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			
Ophiolites		Maastrichtian to Jurassic	Ultramafics with mafic and felsic rocks; limestones, sandstones and conglomerates.
Basement complex	Unseen	?Pre-Cambrian or older	Possibly low to medium grade metamorphics belonging to Burmese landmass

common. The three dimensional patterns of the burrows within the sediments cannot be observed. The described specimens have indistinct pads; delicate internal structure corresponding to oblique spreiten can be poorly recognized. The specimens are similar to those illustrated by Fürsich et al. (2006) and hence assigned to *Gyrochorte comosa*.

Remarks: *Gyrochorte* has been reported from India by Ghare and Kulkarni (1986) and Patel et al. (2008). They are commonly interpreted as traces of animal like polychaeate worm (Weiss, 1941) passing through the sediment in inclined position, selecting sediment for food over the entire length of its body. The sediment was transported backward along the body by the animal as documented by ridges on bedding planes (Heinberg, 1973). According to Gibert and Benner (2002) the tracemaker must have been a detritus-feeding annelid, in an opportunistic strategy colonizing sandy bottoms after high energy event deposition. Fuchs (1988) and Hallam (1970) presumed that the traces were produced by tunnelling amphipods. Fürsich et al. (2018) observed *Gyrochorte* as the trace of a deposit-feeding worm-like organism, which moved through the sediment in an oblique position and can termed as a pascichnion.

Ichnogenus: *Ophiomorpha* Lundgren 1891
Ichnospecies: *Ophiomorpha nodosa* Lundgren 1891 (Fig. 4e)

Diagnosis: *Ophiomorpha* are simple to complex burrow systems distinctly lined with agglutinated pelletoidal sediment (after Howard and Frey, 1984, modified by Uchman, 1998). *Ophiomorpha nodosa* shows burrow walls consisting predominantly of dense regularly distributed discoid, ovoid, or irregular polygonal pellets (Frey et al. 1978).

Materials: Five specimens each collected from location 'C' and Kigwema with many more field observation. Specimen Nos. MIM/TF/ON/01c,02c,03c,04c,05c; MIM/TF/ON/01k,02k,03k,04k,05k.

Description: Horizontal to vertical; mainly straight tubes, occasionally branched burrow systems showing Y-shaped branching. Individual cylindrical tubes range from 30–60 mm in diameter, with oval cross-sections, and around 160–200 mm long. Burrows having smooth interior and very distinct exterior surfaces; densely covered by muddy ovoid pellets 3–8 mm in diameter. Filling of the tubes is fine and medium sand, similar to the host rock.

Remarks: In modern environments, *Ophiomorpha* is produced by callianassid crustaceans (Uchman and Gazdzicki, 2006). Pellets are usually interpreted as supporting the structure during and after burrow construction (Bromley and Ekdale, 1998). The ichnogenus is found to occur in a wide environmental range from shallow-water deposits represented mainly by *O. nodosa* to deep-sea environments represented mainly by *O. rudis* (Tchoumatchenco and Uchman, 2001); most typical of the relatively high-energy, proximal, *Skolithos* ichnofacies (Pemberton et al. 2001). Geological range is from Permian (Chamberlain and Baer, 1973) to Pleistocene (Desai, 2015).

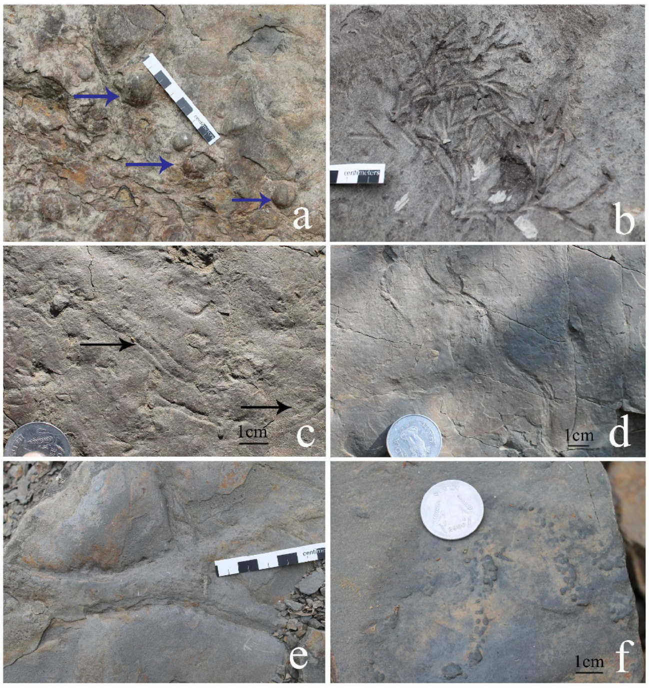

Fig. 4. a. *Bergaueria hemispherica,* top view in fine sandstone. **b.** *Chondrites targionii* as seen on bedding plane in very fine sandstone. **c.** *Curvolithus simplex* in hypichnial view in silty shale. **d.** *Gyrochorte comosa* as epirelief in fine sandstone. **e.** *Ophiomorpha nodosa* preserved as endichnion traces in fine sandstone. **f.** *Paleomeandron elegans* preserved in silty shale (Scales are in cm).

Ichnogenus: *Paleomeandron* Peruzzi 1881
Ichnospecies: *Paleomeandron elegans* Peruzzi 1881
(Fig. 4f)

Diagnosis: Wide first order meanders consisting of small, generally more-or-less regular or rectangular and quadrangular, second order meanders with double-pointed corners; large meanders several centimetres long.

Material: One specimen from Kigwema (Specimen no. MIM/TF/PE/01).

Description: *Paleomeandron elegans* has second-order undulations and sharp corners; ramous shaped; biramous curved strings and has been included with *Desmograpton* in the group of biramous meanders graphoglyptids (Seilacher, 1977b), characterized by widely spaced meanders. Two ichnospecies were found at the soles of siliciclastic turbidites: *P. elegans* and *P. transversum*. The present ichnospecies has meander width of about 20–30 mm and the width of the curved string is 8–10 mm.

Remarks: *Paleomeandron* isp. are paschichnia or fodinichnia and are of deep marine deposits (Seilacher, 1977a; Tunis and Uchman, 1996). However, Shukla and Srivastava, (2008) reported *Paleomeandron* from low-energy ponds within the marshy environment. The present study observed that *Paleomeandron* isp. are found in association with sediments which are characteristics of shallow marine around proximal shelf area. Geological range is from Upper Cretaceous to Eocene (Uchman, 2003). Though the specimen under study is poorly preserved, it has similarity with *Paleomeandron elegans*, fig. 93B, Uchman (1998).

Ichnogenus: *Paleophycus* Hall 1847
Ichnospecies: *Paleophycus tubularis* Hall 1847
(Fig. 5a)

Diagnosis: Straight to sinuous, horizontal, unbranched, thinly-lined, cylindrical to sub-cylindrical burrows with non-ornamented walls (Pemberton and Frey, 1982).

Materials: Two specimens collected from Kiruphema (Specimen nos. MIM/TF/PT/01, 02).

Description: Slight to prominently curved or even meandering (two meanders at maximum), thinly-lined horizontal and unbranched burrows. Surface walls are irregularly smooth and lack striations or annulations. Burrow diameters typically are about 10–15 mm and the length about 350–400 mm. The burrow fill is identical to the host rock. Crossing over between specimens observed.

Remarks: The specimens observed are thinly lined and are very much like *P. tubularis;* probably produced by worm-like producer living in water-saturated sediment produced in marine environments. They represent passive sedimentation within an open dwelling burrow constructed by predaceous or suspension feeding organisms, predominantly annelids (Pemberton and Frey, 1982).

Ichnogenus: *Scolicia* de Quatrefages 1849.
Ichnospecies: *Scolicia plana* Ksiazkiewicz 1970
(Fig. 5b)

Diagnosis: Variably and commonly selectively preserved, simple, winding, meandering to coiling bilobated or trilobated backfill burrows with two parallel, locally discontinuous sediment strings along their lower side. Cross section is approximately oval in outline. Lower side between the strings is flat or slightly concave up. Backfill laminae composite may be biserial on the upper side. Washed-out forms preserved as hypichnial bilobate ridges (Uchman, 1995). *Scolicia* in which the flat median ridge is longitudinally divided by a shallow furrow or crest (after Uchman, 1998).

Materials: Three specimens collected and more field observations at Kiruphema. Specimen nos. MIM/TF/SPL/01/02/03.

Description: Meandering, smooth, bilobate hypichnial ridge, about 25 mm wide and up to 5 mm high, divided by a semi-circular axial furrow about 10 mm wide. Preserved as semi-relief in fine-grained sandstone.

Remarks: Uchman (1995) reviewed this ichnogenus and included *Taphrhelminthopsis*, *Laminites*, *Subphyllochorda* and *Taphrhelminthoida* as toponomic variants of *Scolicia*; the producers are irregular echinoids of the *Spatangus* group, with two drainage tufts that produce the drain channels. The medial string is considered faecal in origin; its darkness compared to the surrounding sediments, suggest active feeding as the trace maker passed through the sediment. Holothurians or large polychaete are considered as the most likely trace makers. The deposit-feeding behaviour of the tracemaker makes *Scolicia* an elite ichnofabric forming trace fossil (Ekdale and Bromley, 1991). *Scolicia* was produced by spatangoid echinoids that burrowed to the depths of 20 cm and shallower (Goldring et al., 2007). The oldest deep water *Scolicia* comes from Tithonian turbidite deposits of the Kostel Formation in Bulgaria (Tchoumatchenco and Uchman, 2001). It has also been reported from Holocene sediments (Ratcliffe and Fagerstrom, 1980).

Ichnospecies: *Scolicia strozzii* (Savi and Meneghini, 1850)
(Fig. 5c).

Diagnosis: Straight to tightly meandering hypichnial bolobate ridge, preserved as semi-relief. Median groove separates the prominent zones of the ridge which are more or less semi-circular in ross-section; tendency to meander. Width, depth, height and proportion of the morphological elements may vary from specimen to specimen (after Uchman, 1998).

Materials: Two specimens observed in the field and one collected from Kigwema. Specimen nos. MIM/TF/SS/01.

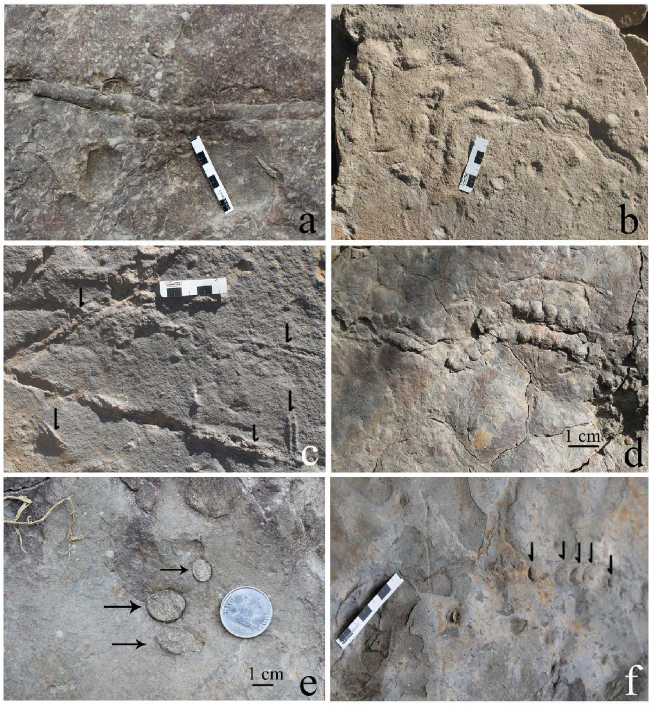

Fig. 5. a. *Paleophycus tubularis* in fine sandstone. **b.** *Scolicia plana* as negative epirelief in fine sandstone. **c.** *Scolicia strozzii* also as negative epirelief in fine sandstone. Half arrows indicate the traces. **d.** *Scolicia vertebralis* in silty shale. Half arrows indicate the meniscates. **e.** *Skolithos linearis* in fine sandstone. **f.** *Taenidium diesingi* in silty shale. Bar scales in the photographs are in centimetres.

Description: Winding, bilobate, smooth hypichnial trace; about 3 mm wide and the ridges 2 mm high. The width of each specimen is more or less constant. The median groove is narrow and its base extends to the level of the surrounding lower surface of the bed (cf. Uchman, 1995). The lateral ridges slope gently toward the trough and are generally smooth. Pre-depositional in origin. The associated sediments are fine grained sandstone.

Remarks: The ichnotaxon is cast of the furrow formed after washing out the *Scolicia* burrow by erosion. Narrow median groove imply the burrow cut by erosion in the middle part, so the cast is higher and wider and hence the slope of the ridge is gentle. The straightness and mildly curve nature suggest *Scolicia strozzii* var. *vagans* (cf. Uchman, 1995). *Scolicia strozzii* was produced at shallow tiers by the co-occurrence of *Palaeodictyon strozzii* (Ksi¹¿kiewicz, 1977; Seilacher, 1977a). Oldest *Scolicia* are reported from Palaeozoic (Tchoumatchenco and Uchman, 2001) and even young ones from Holocene (Ratcliffe and Fagerstrom, 1980).

Ichnospecies: *Scolicia vertebralis* Ksiazkiewicz 1977 (Fig. 5d)

Diagnosis: The trace is epichnial trilobe furrow comprising of a median lobe and two lateral fringes. The shape of the median lobe, difference in the width of the median and lateral lobes is characteristic of this trace.

Materials: Three field observation at Kiruphema.

Description: They are observed as epichnial two or three lobed, winding and meandering traces in fine-grained turbiditic sandstones. *Scolicia ?vertebralis* has a winding course and displays remnants of meniscate backfill. A narrow central groove and one strand along its base are present. The width of the entire trace fossil is about 25 mm and the full length found preserved is about 200 mm. The median lobe is about 4 mm wide and two lateral fringes that are 11 mm wide.

Remarks: *Scolicia vertebralis* is possibly a preservational variant of *S. prisca* and, therefore, its status is not clarified (Uchman, 1998). They are less common than *Scolicia plana* and *Scolicia prisca* (Ksiazkiewicz, 1970; 1977). In the particular location at Kiruphema the specimens are found in association with small form of *Treptichnus pendum*, *Gyrochorte comosa*; medium sized *Thalassinoides paradoxicus* and *Curvolithus simplex*. Holothurians are considered as the most likely trace makers. The deposit-feeding behaviour of the tracemaker makes *Scolicia* an elite ichnofabric forming trace fossil (Ekdale and Bromley, 1991).

Ichnogenus: *Skolithos* Haldeman 1840
Ichnospecies: *Skolithos linearis* Haldeman 1840 (Fig. 5e)

Diagnosis: *Skolithos* consists of unbranched, vertical to steeply inclined, cylindrical or sub-cylindrical, lined or unlined burrows, with or without funnel shaped top. Wall distinct or indistinct; smooth to rough; occasionally annulated. Fill massive and burrow diameter may vary slightly along its length (Schlirf, 2000; Schlirf and Uchman, 2005). *Skolithos linearis* correspond to cylindrical to sub-cylindrical structures, perfectly straight and vertical to slightly curved or inclined. Burrow wall distinct to indistinct, may be annulated (Alpert, 1974; Schlirf, 2000).

Materials: Ten field observation at Kigwema. Specimen nos. MIM/TF/SK/01/02/03.

Description: The specimens are predominantly vertical to sub-vertical, straight, cylindrical; diameter is about 15 mm. Length ranges between 100–150 mm. Filled with structureless, medium sand, similar to the host rock. More or less isolated burrows occur and predominantly as small, ring-like projections on top of bedding planes.

Remarks: Archetypal *Skolithos* ichnofacies are related to relatively high energy environments, shallow water conditions, in nearshore to marginal marine settings (Fillion and Pickerill, 1990). Marine *Skolithos* is mainly interpreted as a domichnion structure made by polychaetes like *Arenicola*, *Onuphis*, *Sabellaria* and phoroids or annelids (Schlirf and Uchman, 2005). Geological range is from Precambrian (Alpert, 1975) to Holocene (Dashtgard and Gingras, 2012).

Ichnogenus: *Taenidium* Heer 1877
Ichnospecies: *Taenidium diesingi* Unger 1850
(Fig. 5f)

Diagnosis: Weakly sinuous to nearly straight *Taenidium*, the fill consisting of even alternations of meniscus-shaped packets of two types of sediment of more or less equal thickness, sediment packets considerably shorter than wide (after D'Alessandro and Bromley, 1987) cylindrical.

Materials: Three field observation at Kigwema and photographs.

Description: Concave and convex, hyporelief, endichnial burrows horizontal to weakly inclined to bedding, straight to gently curved backfilled burrows and the fills consisting of meniscate pack packets. The meniscates are symmetrical and equally spaced and shows prominent relief. The width of the menisci is <8 mm and intraspace between the menisci is <6 mm. The burrow is ~160 mm long and 20 mm wide.

Remarks: Uchman (1999) observed that the pellets arranged in the menisci are the characteristics of *Taenidium diesingi*. He further observed the similarity of the features with those of the materials illustrated by Unger (1852: pl., fig. 2) (Text fig. 11) from the Upper Cretaceous marly flysch of the Fehrnen Mount near Appenzell in western Switzerland. *T. diesingi* occurs from the Cennomanian to the Miocene (Tortonian) (Uchman, 1995).

Ichnogenus: *Thalassinoides* Ehrenberg 1944.
Ichnospecies: *Thalassinoides paradoxicus* Woodward 1830
(Fig. 6a)

Diagnosis: Horizontal, branching framework of smooth-walled, unlined burrows, lacking vertically oriented offshoots. Burrow diameter consistent within individual specimens; constrictions or swellings at both junctions and inter-junction segments are notably absent (Emended after Myrow, 1995 in Blissett and Pickerill, 2004).

Materials: Three specimens collected with more field observation at Kigwema, Specimen nos. MIM/TF/TP/01kg/02kg/03kg; three specimens collected from Kiruphema, Specimen nos. MIM/TF/TP/01ki/02ki/03ki, with field photographs.

Description: Smooth-walled, irregularly branched; mainly Y-shaped. Burrow diameter varies from 10 mm to 20 mm with intermittent enlargements in the bifurcation points. Size of burrow fills different from that of the host material.

Remarks: The high irregularity of size and geometry of burrow system allow us the assignation of the studied specimens to *Thalassinoides paradoxicus*. It is generally interpreted as a fodinichnial (Bromley, 1996) or domichnial structure, passively filled, mainly attributed to crustaceans (Frey and Pemberton, 1984). They are facies-crossing form, being related to a variety of marine environments, from tidal flat and shoreline to offshore outer shelf and deep-sea (Myrow, 1995), but most typically registered in shallow-marine environments. Usually related to oxygenated, soft and fairly cohesive substrates (Bromley, 1996); occur in firm ground and in the first stage of hard ground development (Myrow, 1995); related with the *Glossifungites* ichnofacies (Savrda et al. 2001). Geological range is Cambrian (Myrow, 1995) to Recent (cf. Yanin and Baraboshkin, 2013).

Ichnogenus: *Treptichnus* Miller 1889.
Ichnospecies: *Treptichnus pedum* Seilacher 1955
(Fig. 6b).

Diagnosis: Sub-horizontal burrow consisting of one series of down bowed or J- to U-shaped segments joined near or at their ends in a uniserial pattern that may be irregular, zigzag, or arcuate.

Materials: Fifteen specimens observed at Kiruphema with field photographs. Collected specimen nos. MIM/TF/TRP/01ki/02ki/03ki.

Description: Shallow, U-shaped segments connected in a zigzag, or irregular, or other patterns near their ends. The burrow patterns are sometimes sinuous and looping made by successive upward probes through the sediments. At places they exhibit branching twig like structures. In such cases it resulted in a trace pattern reminiscent of a twisted rope like structures and overlapping of burrows. Burrows show width about 5 mm and length between 10–15 mm.

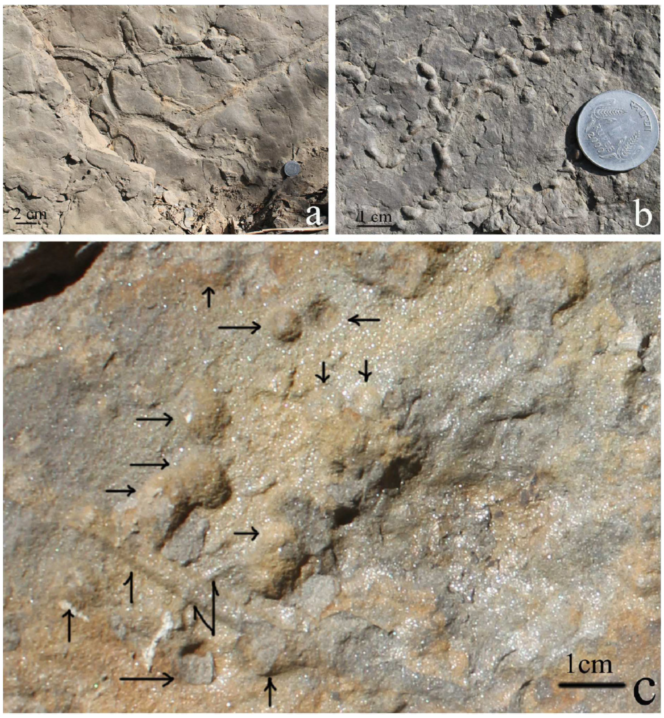

Fig. 6. a. *Thalassinoides paradoxicus* in silty sandstone at Kiruphema. **b.** *Treptichnus pedum* in silty shale at Kiruphema. **c.** Crustacean sand spherules in fine sandstone at the Peducha quarry.

Remarks: *Treptichnus pedum* formerly *Phycodes pedum*, *Manykodes pedum* (Dzik, 2005) or most of the time named *Trichophycus pedum* has a fairly complicated and distinctive burrow pattern. That is, along a central, sometimes sinuous or looping burrow it made successive probes upward. Surface trails produced by modern priapulid worms exhibit the same probing morphology as *Treptichnus*, suggesting a close anatomical relationship between the trace-maker and modern priapulids (Vannier et al. 2010). Insect larvae or other arthropods are also likely producers (Miller, 1889). Most *Phycodes pedum* can be assigned to *Treptichnus* (Jensen and Grant, 1998). *T. pedum* is indicative of shallow marine siliciclastic facies (Srivastava, 2012b). According to Buatois (2018) *T. pedum* is not only present in the low-energy offshore of wave-dominated marine settings, but it occurs at considerably shallower water in intertidal and shallow-subtidal zones of tide-dominated systems, as well as in mouth bars of deltaic systems and lower shoreface to offshore transition zones of wave-dominated marine settings. The first appearance of *T. pedum* marked the Ediacaran–Cambrian (E-C) boundary (Buatois, 2018; Srivastava, 2012a).

Crustacean Sand Spherules (?)

Rather sporadic sand spherules were observed on flat surface of planar cross-bedded fine sandstone (Fig. 6c) at the Peducha quarry. Ichnospecies such as *Ophiomorpha nodosa, Skolithos linearis* and *Thalassinoides paradoxicus* (*Skolithos* ichnofacies) are also found in the horizon where the sand-balls are seen. The host fine sandstone bed is among the sandstone-shale-siltstone intercalation. The stratigraphic position of the bed containing the sand-balls is close to the basal part of the Barail Group, that is, in the Laisong Formation. It is important to note here that, though the occurrence of the sand-balls is not so widespread, an attempt is being made here to report such an uncommon observation, whatsoever debatable it may be. Effort shall also be made as a further step of research in order to strengthen the present observation.

Materials: One fine-sandstone block containing sand spherules (about 30 in numbers) collected from Peducha quarry. Specimen no. is MIM/TF/SB/01pe.

Description of the sand spherules: Globular sand-balls or otherwise sand spherules occur sporadically as knobby relief on the surface of fine-sandstone bed about 10 cm thick. These sand spherules have more or less smooth surfaces. External sculpture and visible internal structures are not perceptible. The size of the presently described sand spherules varies from 2 mm to 20 mm. Size of such sand spherules ranges from 2 – 5 mm (Noda, 1990) and 2 – 5 mm (small sized spherules) and 5.5 – 16.5 mm (large sized spherules). They are found to compose of fine-grained brownish (weathered) sandstones which are more or less similar to the host sediments. The boundary between sand-balls and their surrounding is distinct. Some of the sand spherules are found to manifest rust colour.

Remarks: The studied sand spherules may be correlated with crustacean origin from the point of view that the horizon/bed containing sand-balls also contain *Ophiomorpha nodosa* traces though other characteristic features of crustacean origin such as cylindrical faecal pellets, track ways and crustacean body fossils were not come across. According to Noda (1973), crustacean faecal pellets could be easily transported from the original place, trackways are also difficult to preserve, and their body fossils are usually scarce to occur according to their morphology and ecology. It may also be noted that the preservation potential of feeding pellets of crabs is very low. So, reports on sandstone spherule trace fossils are very occasional and only two research papers in the related subject are available (Noda, 1990; Šimo and Starek, 2015).

Further it is observed that, feeding pellets are generally produced mainly by fiddler crabs and ghost crabs (Brachyura, Ocypodidae) (Muñiz et al., 2010), sand bubbler crabs (Brachyura, Dotillidae) (Chakrabarti et al., 2006; Wong et al., 2011) and soldier crabs (Brachyura, Myctiridae) (Davie et al., 2010) in the upper foreshore and backshore of tropical and subtropical regions. Dotillidae and Myctiridae are modern groups of crabs without any fossil record (Schweitzer et al., 2010). The oldest fossil record of Ocypodidae is dated as lower Miocene (Brito, 1972); and fossil burrows interpreted as produced by Ocypodid crabs have been recognized in the fossil record, and their identification is considered an important indicator of paleo-shoreline position in sedimentary sequences (Frey et al., 1984). Comparable modern sand spherules are also described differently as feeding pellets (Muñiz et al., 2010); excavation pellets (Gibert et al., 2013) or discard pellets (Unno and Semeniuk, 2008).

The paleoecological condition under which sand spherules were produced by excavating or dominant feeding activity of fiddler crabs is estimated to be done on wide sand shoal in calm sea shore condition under good climatological condition for the preservation of wet sand-balls (Noda, 1990). As far as the sedimentological and ecological characterization of shorelines in geological past is concerned, crustacean sand spherules produced restrictedly on the shoreline are quite significant (Chakrabarti, 1972; Frey et al. 1984).

DISCUSSION

Ichnological analyses of the sediments of the Upper Disang Formation and the Lower Barail Formation (Late Eocene to Early Oligocene) of Nagaland in four localities namely ‘C’ (near Chakabhama village), Kigwema, Kiruphema and Peducha indicate occurrence of three ichnofacies namely *Skolithos*, *Cruziana* and *Nereites*. However, manifestation of *Skolithos-Cruziana* mixed ichnofacies cannot be ruled out towards the base of the Laisong Formation which is transitional with the Upper Disang Formation; because it is a common feature in the Disang-Barail Transition Sequences. The Disang-Barail Transition Sequences in Nagaland is characterised by mixed occurrence of *Ophiomorpha nodosa, Skolithos linearis* and *T. paradoxicus*, which mainly constituted the *Skolithos-Cruziana* mixed ichnofacies in Manipur in the Disang-Barail Transition Sequences (Rajkumar et al. 2008). Occurrence of traces of *Skolithos* ichnofacies implies high energy environment in the foreshore and shoreface zones of beaches, bars, spits, tidal flats, tidal deltas and estuarine point bars (Seilacher, 1967). Such environmental facts is also supported by the observance of sedimentary features such as herringbone structures, pot casts, cross-beds, hummocky cross beds, gutter casts, etc. The dominance of vertical forms over the horizontal forms in the Peducha locality suggests a higher energy level. The mixed *Skolithos-Cruziana* association characterized estuarine environment (cf. Howard and Frey, 1975). The presence of *Cruziana* ichnofacies indicated marginal marine setting, such as estuaries, bays and lagoons in a typical beach-to-offshore profile as well as their occurrence below fair weather wave base but above the storm wave base (Frey and Seilacher, 1980); they are associated with sedimentary structures such as, rippled and trough-cross beddings, hummocky cross-stratifications, etc. *Cruziana* ichnofacies is also reminiscent of activities of mobile carnivores and deposit feeders exploiting relatively nutrient-rich, fine-grained sediments deposited in low-energy, offshore environment. The presence of *Nereites* ichnofacies is indicative of deep and quiet environments. However, the co-existence of *Chondrites targionii* with *Thalassinoides paradoxicus* in shaly fine-sandstone characterized by the presence of ripple marks in Kigwema locality imply the possibility of an otherwise (?localized) shallow marine depositional setting. Here, it is important to mention that the virtual absence of *Zoophycos* ichnofacies in the studied localities does not imply total absence of the ichnofacies in the Disang-Barail transition sediments. Because, *Zoophycos* isp. is well encountered in similar lithofacies of the same stratigraphic units in adjoining region of Manipur. The absence may only be due to deficiency in surveillance of such ichnospecies in the field. Otherwise, it could be due to lateral variation in distribution of the ichnospecies.

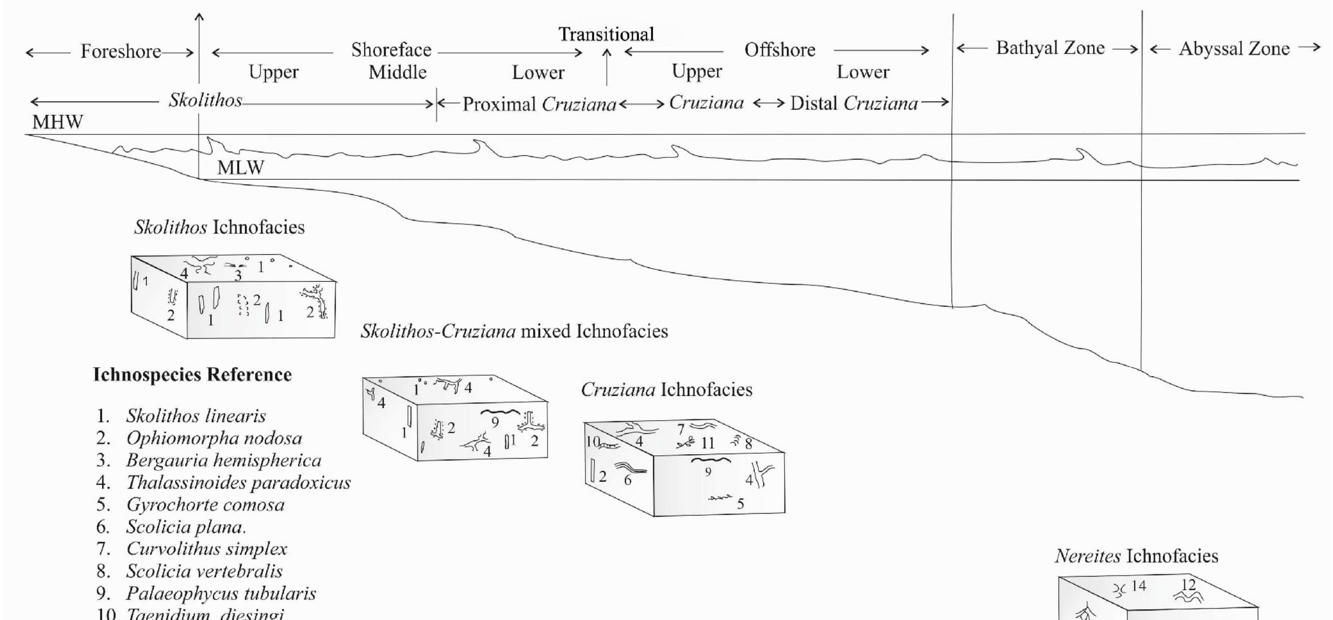

Fig. 7. Shore profile showing the relative positions of the various ichnofacies observed with reference to the part of the basin where the Disang-Barail Transition Sequences flysch sediments of the studied sections deposited, suggesting the variation in environment of deposition.

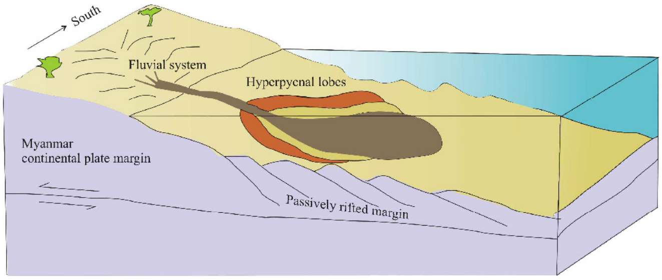

Fig. 8. Cartoon showing the proximal to distal hyperpycnal-delta-fed turbidite system which produced the Disang-Barail Transition Sequences of the Naga Hills in the passively rifted western continental margin of the Myanmar landmass.

It may be mention here that Khalo and Pandey (2018) reported *Zoophycos* isp. from the Phek district of Nagaland.

The shoreface profile showing the distribution of *Skolithos*, *Skolithos-Cruziana*, *Cruziana* and *Nereites* ichnofacies in the flysch basin where the Upper Disang-Lower Barail Transition Sediments were deposited may be referred from Fig.7.

Taking into consideration the tectonic setting of the Disang-Barail flysch basin (Soibam, 1998; 2000), the occurrence of *Nereites* ichnofacies in between the *Skolithos* and *Cruziana* ichnofacies may represent intermittently subsiding basin rather than the broad abyssal plain. Such a depositional setting may be explained by pulsatic stretching of the flysch basin, because the basin was resulted due to passive rifting of the western continental margin of the Myanmar landmass (Soibam et al. 2013). Allen et al. (2008) also indicated that the Palaeogene Indo-Burman Ranges, that is the IBR/IMR, contain a significant component of arc-derived material, interpreted as derived from the Burmese portion of the Mesozoic–Tertiary arc to the east based on thermo-chronological analyses of detrital grains, isotopic analyses of bulk rock, and petrographic and heavy mineral data. The possible way in which the Indo-Myanmar flysch basin has been formed may also be referred from Sanasam (2013) and Soibam et al. (2015). In addition, the mechanism on passive continental margin basin development and deposition of flysch sediments can also be referred from Gerhard (2000). Figure 8 is a cartoon representing the likely depositional system of the Disang-Barail Transition Sequences of the Naga Hills demonstrating a proximal to distal hyperpycnal-delta-fed turbidite system in the passively rifted western continental margin of the Myanmar landmass.

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