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Palaeoenvironmental significance of Trace Fossils from the Palaeogene sediments, South of Kohima Town, Nagaland, India

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Trace fossils recorded from the Palaeogene sediments exposed in the south of Kohima town, Nagaland are abundant and moderately diverse in nature. Total seventeen (17) ichnospecies from ten (10) ichnogenus have been recorded from eight horizons representing marine environments. Ichnospecies that have been recorded from these sediments include *Arenocolites* isp.*, Asterosoma ludwigae, Cochlichnus anguineus, Ophiomorpha* isp., *Ophiomorpha nodosa, Ophiomorpha rudis, Palaeophycus tubularies, Palaeodictyon strozii, Planolites* isp., *Planolites beverleyensis, Rhizocorallium zenker, Skolithos linearis, Skolithos verticalis, Taenidium* isp., *Thalassinoides horizontalis*, *Thalassinoides callianassae.* Analysis of the encountered ichnospecies and associated lithofacies suggest a deep water depositional regime influenced by turbidity processes. The unique occurrences of *Skolithos* association along with low energy setting ichnofacies suggest that the site has episodically been subjected to conditions of higher hydrodynamic phases.

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INTRODUCTION

Ichnofossil contents of Tertiary rocks of the Northeast India have been studied, in recent years, by several workers (Singh *et al*., 2008; Singh and Kushwaha, 2008; Singh *et al*., 2010; Rajkonwar *et al*., 2013; Khalo and Pandey, 2018 and Kichu *et al*., 2018). However, there are no published data on the trace fossils from the present study area.

The objective of this work is to study the trace fossil assemblages and to interpret them in terms of the depositional environment of the Palaeogene sediments exposed along Mezhu Ru between Phesama and Kigvema villages on Kohima-Imphal road, south of Kohima town. A total of seventeen inchnospecies from ten ichnogenus have been identified within the sediments of the study area. Ichnofacies identified include *Arenocolites* isp., *Asterosoma ludwigae, Cochlichnus anguineus, Ophiomorpha* isp., *Ophiomorpha nodosa, Ophiomorpha rudis, Palaeophycus tubularies Palaeodictyon strozii, Planolites* isp., *Planolites beverleyensis, Rhizocorallium zenker Skolithos linearis, Skolithos verticalis, Taenidium* isp., *Thalassinoides horizontalis, Thalassinoides callianassae.* As no published data are available, this work would provide important information on the geology and ichnology of the rocks under investigation.

STUDY AREA

Schuppen Belt, the Inner Fold Belt (IFB), and the Ophiolite Belt (Mathur and Evans, 1964) are the three NE-SW trending linear zones within the Assam-Arakan basin. Present study area forms a part of Kohima synclinorium within the IFB. The Tertiary succession within the Kohima Synclinorium comprises of dominantly argillaceous Disang Group, mixed sand-shale lithologies of Disang Barail Transition (Srivastava, 2002; Srivastava *et al.,* 2004) and arenaceous Barail Group of rocks. Present study area lies towards south of Kohima town and is bounded between $25^{0}36'00''$-$25^{0}37'00''$ N latitude and $94^{0}05'00''$E-$94^{0}10'00''$E longitude of the topographical sheet no.83 K/2 of the Survey of India (Fig-1). Sediments of the study area have been designated as Laisong Formation of the Barail Group by the Geological Survey of India (2011). However, due to their mixed lithologies, Lily and Pandey (2013) have called them Disang-Barail Transition. Lithofacies analysis by Srivastava *et al.* (2017) suggests a deep water slope-sub marine fan environment for these sediments with turbidite influences.

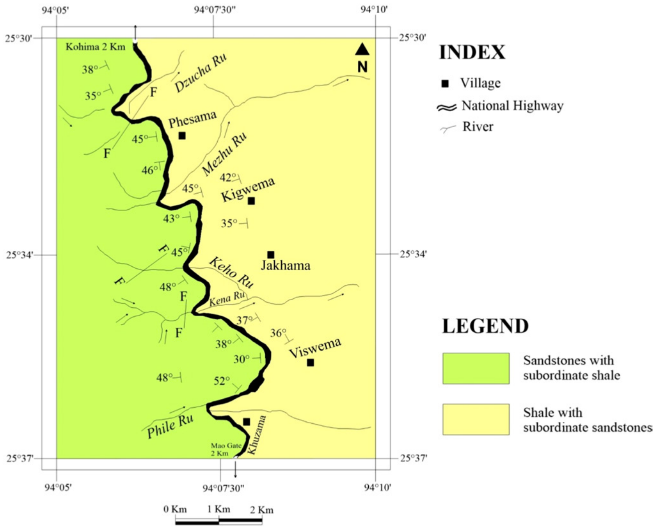

Fig. 1. Geological map of the study area (Lily and Pandey, 2013).

MATERIALS AND METHODS

Description of vertical profile section

Based on the facies parameters, such as lithology including grain size, bed geometry, sedimentary structures, palaeocurrent, altogether five (5) lithofacies have been identified within the Palaeogene sediments of the study area. Lower and upper portions of the vertical profile section are dominated by sandstones with erosional bases, whereas middle part of the vertical profile section is represented by alternating sand-shale-mudstone lithologies. Conglomeratic horizons have been recorded between 72 and 74 m marks. In the study area the bed thickness varies from a few centimetres to several meters. Sedimentary structures such as plane/cross/convolute laminations, low crested asymmetrical ripples, massive sandstone beds and bioturbated horizons have been observed. Trace fossils have been recorded from seven (7) horizons from both sandstones as well as shale/mudstones. Shale/mudstones are intensely bioturbated and most of the horizontal traces have been recorded from them whereas sandstones are moderately bioturbated. Vertical/inclined trace fossils have been recorded from sandy horizons only. Horizontal traces dominate over vertical / inclined traces. Identified lithofacies along with their probable depositional environments are given in the following table (table-1).

Environment Interpretation

Presence of massive sandstone beds with erosive bases, sole marks, slump/debris, plane/convolute laminations, sand-mud couplets, intensely bioturbated shale/mudstones and chaotic surface suggest a slope –sub marine fan environment (Figure-3a,b,c,d). These features are common in the environments where sediments have been transported to the depositional site by turbidity/mass gravity transportation processes (Walker, 1976; Shanmugam and Moila 1982; Shanmugam, 1985; Stow, 2005; Biswas and Mukhopdhyaya, 2011; Srivastava *et al*., 2017). Presence of Bouma divisions though incomplete also corroborates the above inferences. Most common associations are T_{abc} and T_{ae}. This is further supported by the presence of conglomerate and mud-supported clasts which are the characteristic features of the slope environment (Stow, 1985).

Trace fossils were recorded and photographed along Mezhu Ru (river) which passes through the study area, between Phesama and Kigwema villages of Kohima District. A few of the trace fossils were recorded from adjacent areas also. They were studied in *situ* as it was not possible to collect them owing to their brittle /weathered nature. A vertical profile section of 84 metres was constructed along the Mezhu Ru where all the details were noted and trace fossil horizons were marked. Encountered sedimentary features were also noted and photographed. Identification and description of the trace fossils/ lithofacies were done in the laboratory.

TRACE FOSSILS

Trace fossils furnish valuable information on the conditions of sedimentation, especially whether it was rapid or slow, continuous, or discontinuous. Intense bioturbation commonly occurs in areas of slow sedimentation and probably has more to do with time available than with the abundance of trace makers (Howard, 1975). Distribution of trace fossil assemblages are largely controlled by depth-related parameters such as gradients in water temperature, salinity, dissolved oxygen, nutrient distribution, turbulence, sedimentation rates, and current activity (Rhoades, 1975; Seilacher, 1978; Vaziri and Fursich, 2007). Changes in these parameters would affect the type, distribution and abundance of the trace fossils.(Fallomi and Grimm,1990; Uchman, 2004). Although this application of trace fossil has proved valuable, it must be used with caution (Crimes, 1977). Trace fossils were studied and photographed on the out crop itself as it was not possible to collect them. Trace fossils from the study area can be divided into simple branched and network forms.

SYSTEMATICS

Ichnogeneus *Arenicolites* Salter, 1857
Ichnospecies *Arenicolites* isp.
(Fig. 4a)

Description: It is U-shaped burrow showing full relief, without spreite and wall lining, and is perpendicular to the bed, where in-filled material is different from the host rock. This has been recorded from Sandstone facies.

Remarks: This is generally produced by the suspension-feeding worm or wormlike animals (Hantzschel,1975; Hakes, 1976; Crimes *et al*., 1981) or crustaceans like organisms (Goldring, 1962). *Arenicolites* are known to occur in diverse

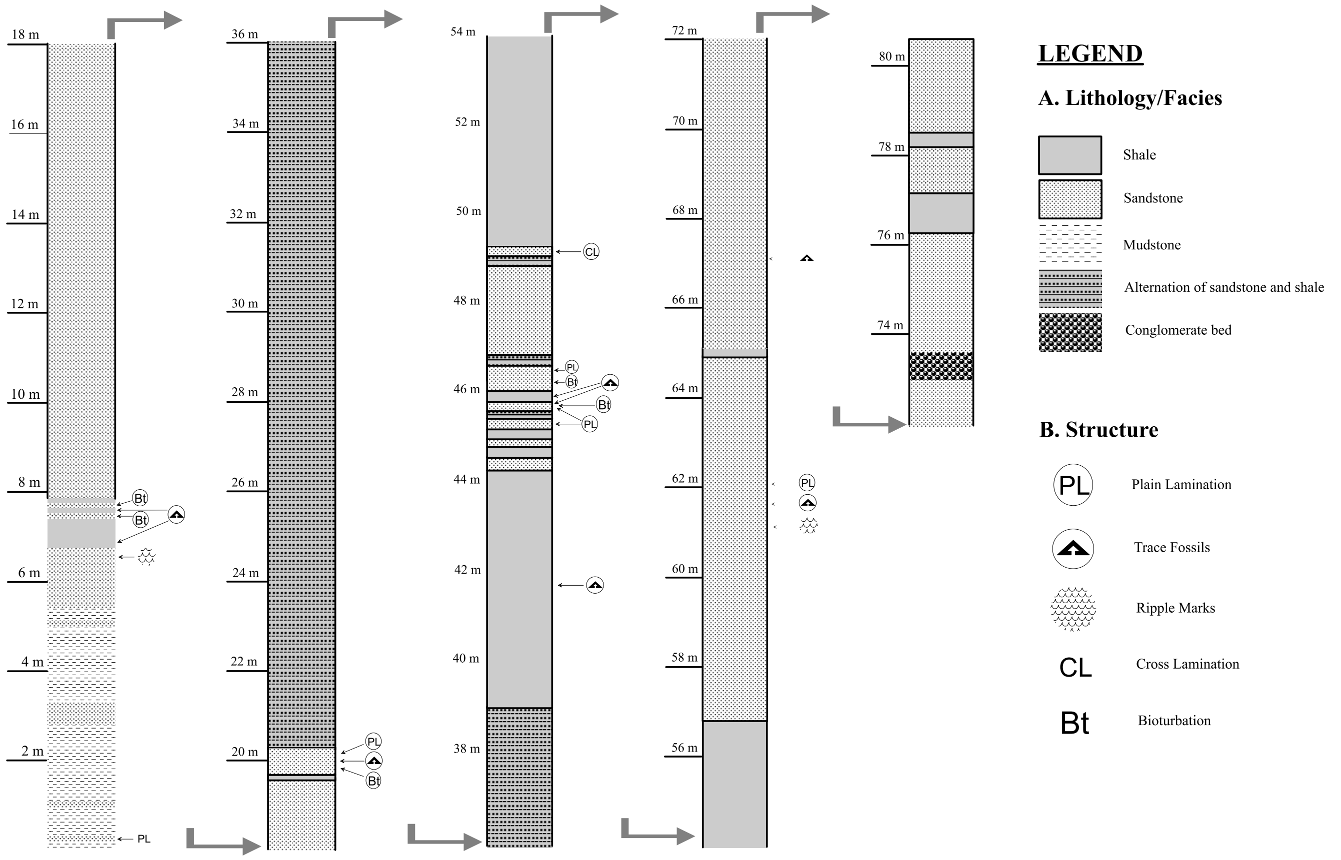

Fig. 2. Vertical Profile Section along Mezhu Ru (River) on Kohima-Imphal Road.

environments (Goldring, 1962; Fillion and Pickerill,1990).

Ichnogenus *Asterosoma* Von Otto, 1854
Ichnospecies *Asterosoma ludwigae* Schlirf, 2000
(Fig. 4b)

Description: This ichnospecies is reported for the first time from these sediments and has been recorded from the fine grained sandstones. *Asterosoma ludwigae* is a star shaped trace fossil, radiating out from a central axis and are bulbous with tapering towards the end. This is elliptical/ circular in cross section and is inclined to the bedding plane. Burrow sediments are slightly coarser than the host sediments. The burrow fill material is composed of weakly arranged concentric lamina.

Remarks: This is interpreted as deposit feeding-burrows of worms/annelids (Bromely and Uchman, 2003; Bradshaw, 2010). Patel *et al.* (2013) have reported *Asterosoma ludwigae* from the siliciclastic sediments of Kachchh basin. This has also been reported from sandy horizons of Talchir Formation by Sarkar *et al.* (2009).

Ichnogenus *Cochlichnus* Hitchcock, 1858
Ichnospecies *Cochlichnus anguineus* Hitchcock, 1858
(Fig. 4c)

Description: This is smooth, horizontal, unlined, and un-branched feeding trails having same sediments as the surrounding and showing sinusoidal nature. Meanders are without ornamentation. This ichnospecies has been recorded from mudstone facies.

Remarks: Because of its sinuosity it has been identified as *C. anguineus*. *Cochlichnus* are the crawling traces and probably is the feeding structure (Eager *et al.*, 1985). *Cochlichnus* has been reported in sediments of supposedly low salinity palaeoenvironment (Hakes, 1976). This ichnospecies is reported from shallow to deep marine settings.

Ichnogeneus *Ophiomorpha* Lundgren,1891
Ichnospecies *Ophiomorpha annulata* Ksiazkiewicz,1977
(Fig. 4d)

Description: This is mostly horizontal, hypichnial, or rarely branched cylinder. The cylinders are straight to slightly winding, covered, commonly with delicate scratches or small, perpendicularly arranged granules. In some specimens, the branches form knots.

Remark: This ichnofacies has been recorded from sandstone lithology. *O. annulata* is a dwelling structure. These are very common in Palaeogene Alpine turbidite successions (Uchman 1995, 2001).

Table-1: Lithofacies and probable depositional environment for the Palaeogene sediments of the study area.

Facies/Lithology	**Sedimentary Structure**	**Trace Fossils**	**Probable Environment**	**Reference**
Conglomerate/ mud supported clasts	----------------	Absent	Slope/Sub-marine channel/Inner fan	Mutti and Ricci Lucchi, (1972); Walker, (1976); Stow, (1985); Shanmugham and Moila (1982); Mutti (1985); Shanmugham *et al.* (1985), Ghani and Alam (1999) and Srivastava *et al.* (2013, 2017)
Medium grained Sandstone	Plane lamination/ ripple/ moderate bioturbatation	Common at the top of the bed	Sub-marine channel/Inner fan/turbidite	
Alternating sandstone-shale	Plane lamination/ Week boiturbatation	Rare	Sub marine middle fan/turbidite	
Mudstones	Intense bioturbation	Common	Low energy/ outer fan	
Shale	Intense bioturbation	Common	Low energy/outer fan	

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

Description: These are sub-vertical, horizontal to inclined tunnels showing full relief. Length and diameter vary in different burrow populations. Burrows are filled with sediments similar to the surrounding substrate. Shafts are mostly horizontal with pelleted walls.

Remarks: Interpreted as dwelling burrows of decapods Crustacean**,** ranging in age from Permian to Holocene. *Ophiomorpha* occurs predominantly in shallow water near shore deposits (Weimar and Hoyt 1964; Frey*,*1978) but has also been reported, since the Mesozoic (Bottjer *et al*., 1987) from deep sea deposits (Kern and Warme,1974; Crimes, 1977; Crimes *et al*., 1981). These post depositional traces have also been reported from the lobes of sub marine fans (Cummings and Hodgson, 2011b).

Ichnogenus *Ophiomorpha* Lundgren, 1891
Ichnospecies *Ophiomorpha rudis* Ksiazkiewicz, 1977
(Fig. 4f)

Description: These are vertical to oblique, endichnial or exichnial, straight, sand-filled cylinders, covered locally with irregular granules or with short oblique ridges, which are casts of scratch marks. These are preserved in full relief.

Remarks: *O. rudis* is a typical ichnospecies of sandy deep-sea sediments and has appeared since Tithonian (Uchman, 2001, 2009). This is post depositional trace (Uchman and Wetzel, 2012) and belongs to *Ophiomorpha rudis* ichnosubfacies. According to Bromley (1996) *Ophiomorpha* is produced by crustaceans and is a dwelling structure. *Ophiomorpha rudis* is a very deep-feeding burrow system, probably, produced by shrimp-like crustaceans, which possibly fed by means of farmed microbes on decomposed phytodetritus.

Ichnogenus *Palaedictyon* Meneghini,1850
Ichnogeneus *Palaedictyon strozzii* Meneghini, 1850
(Fig. 6 g&h)

Description: Palaedictyon strozzii, a pre-depositional structure, is characterized by thin tunnels and shafts forming hexagonal to polygonal shaped honeycomb like network of ridges or furrows and typical of ancient deep ocean basins found to be associated with turbidite deposits (Selley, 2000;Uchman, 2001; Starek and Simo, 2015).

Remarks: These are identified as dwelling burrow system used for cultivating/trapping bacteria and other microbes. This is supposed to be formed by marine animals such as worms. However, some of the workers suggest that they are formed by unknown producer (Seilacher, 1977). In modern sea it is represented by *Paleodictyon nodosium* (Rona *et al.*, 2009).

Ichnogenus *Palaeophycus* Hall, 1847
Ichnospecies *Palaeophycus tubularies* Basseler,1915
(Fig. 5a)

Description: This ichnospecies is simple unbranched, and elongated, with smooth surface, horizontal and slightly curved in shape and, filled with the same sediments as the host rock. Distinction between *Palaeophyucs* from *Planolites* is made on the basis of its lined aspect and dominantly cylindrical shape in cross section.

Remarks: This is considered a dwelling trace and a facies crossing one, produced probably by polychaetes (Pemberton and Frey, 1982; Uchman, 1995).Present specimen is identified as *P.tubularies* on the basis of its horizontal smooth, straight and unbranched nature of the burrow. From the Bagh beds of M.P this ichnospecies has been reported by Badwe (1987) and Kundal and Sangwar (1988). Singh *et al*. (2010) have reported this from the Surma Group of Manipur.

Ichnospecies *?Parataenidium*
(Fig. 5b)

Description: These burrows are parallel to the bedding plane and are slightly curved. *Parataenidium* are the backfilled, tubular burrows similar to *Taenidium* except backfill is separated at two distinct horizontal levels. The

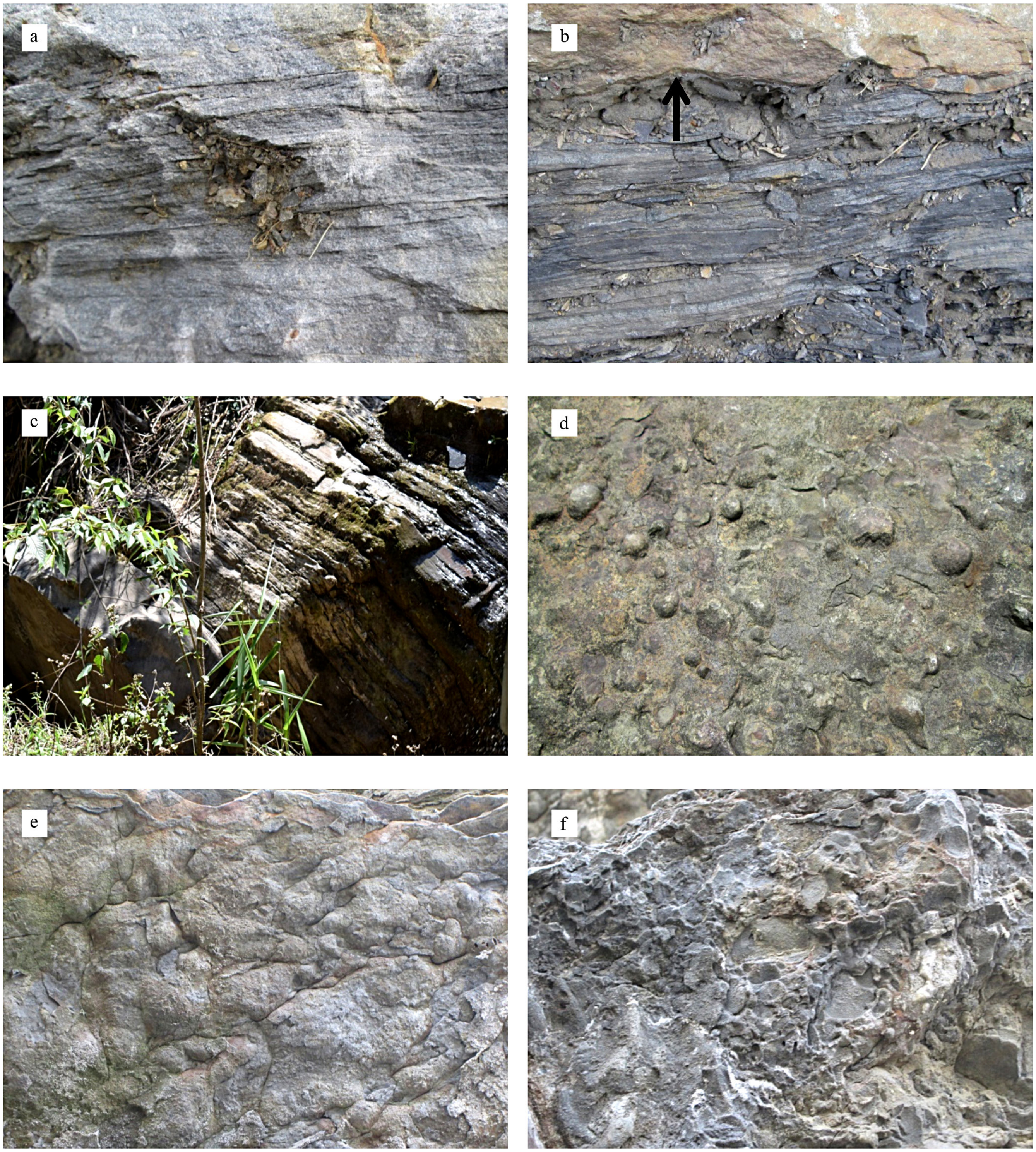

Fig. 3. Field photographs showing (a) Incomlete Bouma divisions (b) Shale-sandstone alternations,erosional base of sandstone bed, upper part of the photograph (c) Shale-sandstone alternations with channeled sandstone (d) Conglomeratic horizons (e) Sole mark (f) chaotic surface

levels are separated by a discontinuity and differentiated by composition and/or fabrication; upper level is globular or barrel-shaped sediments beads while the lower part is structure less.

Remarks: The upper feeding burrow is interpreted to represent sediment of feeding while the lower part burrow is locomotory origin. They are usually present in shallow marine.

Ichnogenus *Planolites* Nicholson,1873
Ichnospecies *Planolites beverleyensis* Billings, 1862
(Fig. 5c)

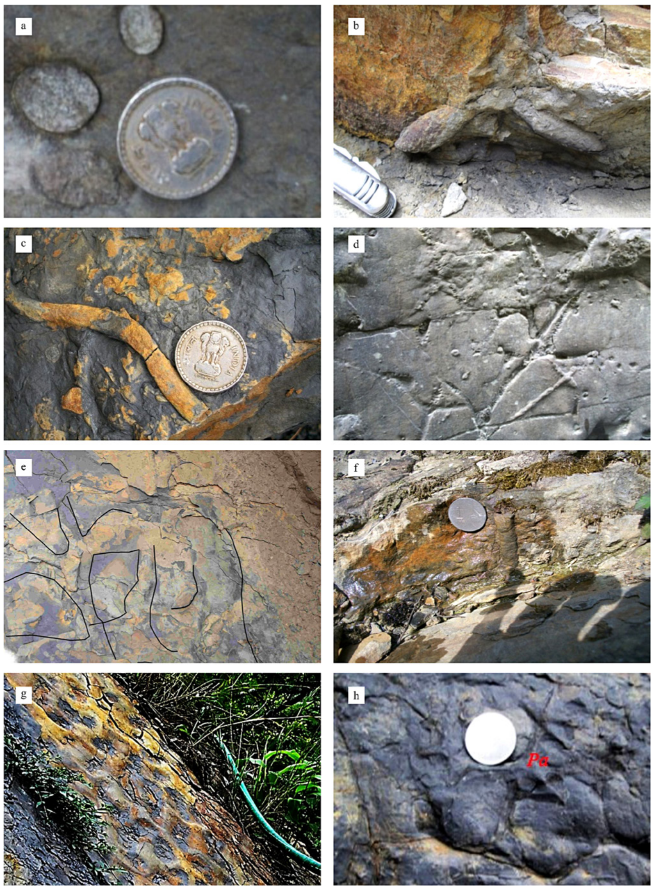

Fig. 4. (a). *Arenocolites* isp (b) *Asterosoma ludwigae* (c) *Cochlichnus anguineus* (d) *Ophiomorpha annulata* (e) *Ophimorpha nodosa* (f) *Ophiomorpha rudis* (g&h) *Palaeodictyon strozii*

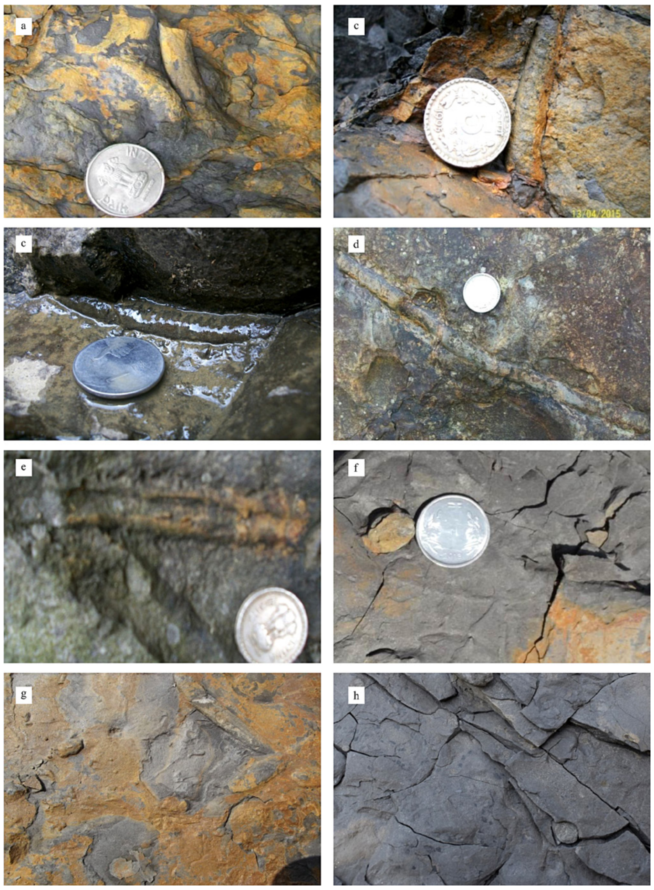

Fig. 5. (a) *Palaeophycus tubularies* (b)*? Parataenidium Planolites* (c) *Planolites beverleyensis* (d) *Planolites* isp (e) *Rhizocorallium* (f) *Skolithos linearis* (g&h) *Skolithos vertcalis*

Description: *Planolites beverleyensis* is predominantly cylindrical, smooth walled, straight to gently curved, unbranched, and oriented to the bedding plane. It occurs as a single isolated specimen. Dimensions vary in different populations.

Remarks: According to Pemberton and Frey (1982) *Planolites beverleyensis* is unbranched and generally oriented more or less parallel to the bedding plane. Burrow lining is absent. It has been considered as the product of vermiform deposit feeder. It has been reported from many localities in India by many workers (Borkar and Kulkarni,1992; Kundal and Dharshivkar,2006;Singh *et al*,2010,Khalo and Pandey, 2018).

Ichnogenus *Planolites* Nicholson,1873
Ichnospecies *Planolites*
(Fig. 5d)

Description: These are simple, straight, indistinctly bounded tunnel-like horizontal traces. Burrows are generally unlined and filled with materials that differ from the surrounding matrix in terms of composition, colour, texture and fabric.

Remarks: These traces are produced by deposit feeding animals (Howard and Frey,1984). They have been reported both from shallow and deep marine waters.

Ichnogenus *Rhizocorallium* Zenker 1836
Ichnospecies *Rhizocorallium*
(Fig. 5e)

Description: These are straight, short U- shaped tube parallel to the bedding plane showing scratch markings on the outer side of the tube. Scratches are abundant and more or less abundant.

Remarks: Rhizocorallium is one of the oldest known and widely distributed trace fossils through the Phanerozoic and has been interpreted as a feeding or dwelling burrow belonging to *Cruziana* ichnofacies (Knaust, 2013). Generally found in littoral-neritic zone (Miller and Knox, 1985) but has also been reported from deep marine deposits (Knaust, 2013). According to him *Rhizocorallium* of Palaeozoic and Mesozoic are restricted to the *Cruziana* ichnofacies representing shallow-marine environments, whereas similar forms of Cenozoic are found in deep-marine deposits. Polychaetes are the most likely producers of marine *Rhizocorallium.*

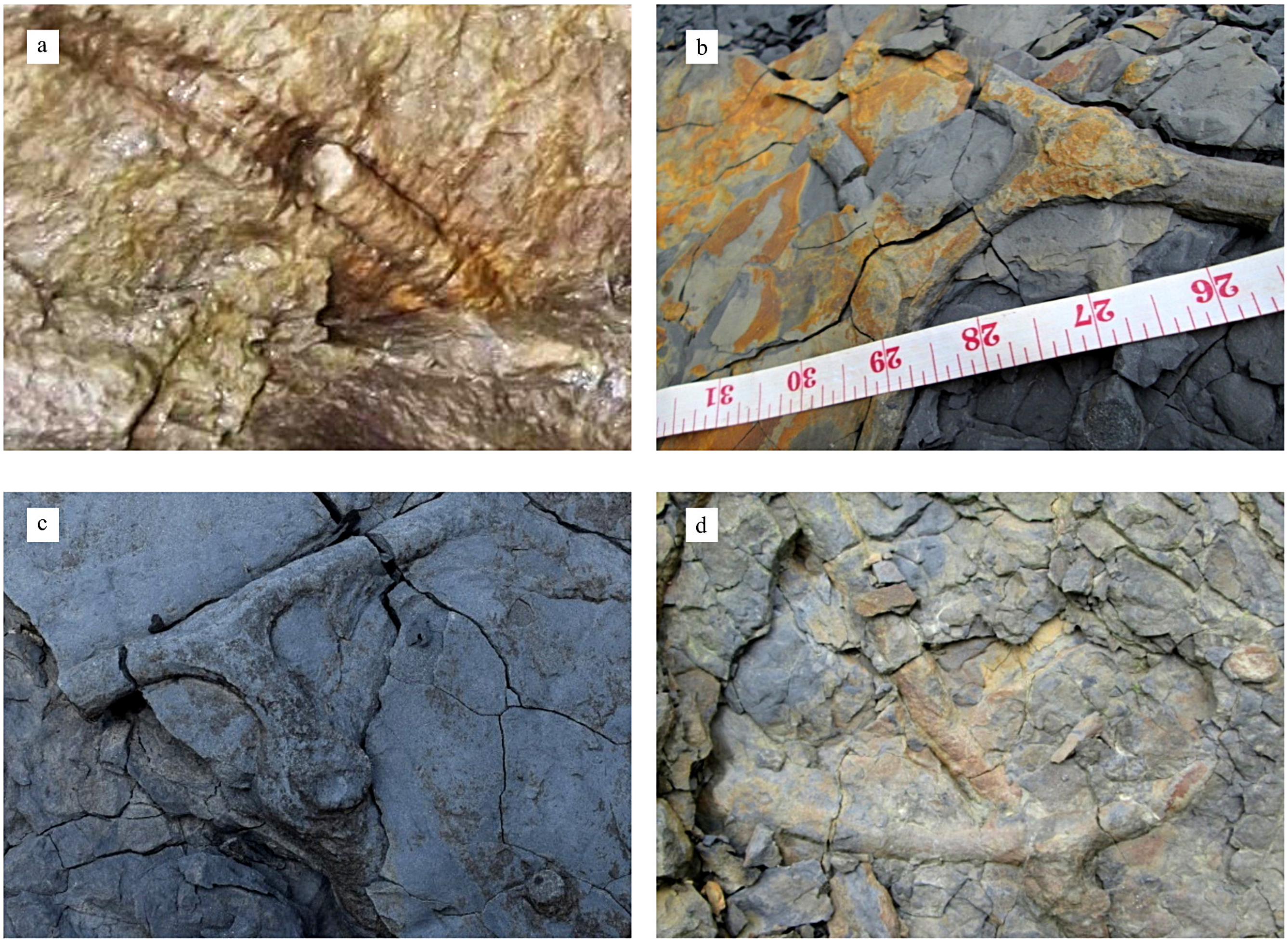

Fig. 6. (a) *Tanaedium* (b & c) *Thalassionoids horizontalis* (d) *Thalassionoids callianassae*

Ichnogenus *Skolithos* Haldeman,1840
Ichnospecies *Skolithos linearis* Haldeman,1840
(Fig. 5f)

Description: These are, isolated vertical, unbranched, burrows, perpendicular to the bedding plane. Rough surface, infilling material is different from the surrounding sediments.

Remarks: Skolithos are usually shallow marine traces. Alpert (1974) and Pemberton and Frey (1982) suggested that *Skolithos* may have been dwelling burrows of suspension feeding polychaetes.

Ichnogenus *Skolithos* Haldeman,1840
Ichnospecies *Skolithos verticalis* Hall,1843
(Figs. 5 g & h)

Description: These are unbranched vertical cylindrical structures showing full relief where burrows are filled with sand size particles.

Remarks: This ichnospecies is reported from various environments from high energy shallow marine to deep sub marine channels. *Skolithos* is widely recognised in shallow water intertidal (Seilacher, 1967) and also in shallow marine environment (Alpert, 1974; Fillion and Pickerill,1990). However, Crimes *et al.* (1981) has reported them from the channelized inner fan facies. *Skolithos* is generally interpreted as dwelling burrows of suspension of feeding worms or phoronoid (Fursich, 1974).

Ichnogenus *Taenidium* Heer, 1877
(Fig. 6a)
Ichnospecies *Taenidium* isp

Description: These are thinly lined, cylindrical straight burrows and are differentiated from other ichnospecies on the basis of the irregular, asymmetrical menisci in the backfill.

Remarks: Taenidium is believed to have been produced by worm like organisms and have been reported from the sediments of Cambrian to Quaternary ages (Carvalho *et al.*, 2005). This has been reported both from shallow to deep marine setting.

Ichnogenus *Thalasssinoids* Ehrenberg, 1944
Ichnospecies *Thalasssinoids horizontalis* Myrow,1995
(Figs. 5 g, h & 6 a)

Description: These are smooth, three dimensional horizontal burrow system showing Y/T shaped branching and swelling at the junction of branching. Burrows are filled with the same colour and texture as the surrounding sediments.

Remarks: Thalassinoides is a facies-crossing form, most typically of shallow marine environment and is produced mainly by crustaceans. According to Follmi and Grimm (1990), the crustaceans producing *Thalassinoides* may survive transportation under anoxic condition for a limited number of days. They have also been found associated with deep marine turbidites (Uchman,1995;Vaziri and Fursich,2007).

Ichnogeneus *Thalassinoides*
Ichnospecies *Thalassinoides callianassae* Ehrenberg, 1944
(Fig. 5d)

Description: Burrows consisting of cylindrical shafts and horizontal tunnels forming branched and interlacements. External surfaces of burrow casts are usually smooth and the tubular wall lining is usually missing. Burrows bifurcate in the Y manners with their diameters increasing at bifurcation sites to form bulbs and irregular inflations. Burrows sediments are different than the host rock and they are slightly coarser in grain size.

Remarks: This is a dwelling structures produced by decapoda and is a facies-crossing form. According to Follmi and Grimm (1990), the crustaceans producing *Thalassinoides* may survive transportation under anoxic condition for a limited number of days. They have been found associated with deep marine turbidites (Uchman,1995;Vaziri and Fursich,2007).

Table-2. Behavioural and ichnofacies classification (Seilacher, 1964, 1967a) of the trace fossils from the study area.

Sl. No	Ichnospecies	Ethological Group	Ichnofacies
1.	*Arenocolites*	Domichnia/ Fodinichnia	Skolithos/Cruziana
2.	*Asterosoma ludwigae*	Fodinichnia	Cruziana/Nerites
3.	*Cochlichnus anguineus*	Pascichnia	Cruziana
4.	*Ophiomorpha rudis*	Fodinichnia	Nerites
5.	*Ophiomorpha annulata*	Domichnia/ Fodinichnia	Skolithos/Cruziana
6.	*Ophiomorpha nodosa*	Domichnia	Skolithos/Cruziana
7.	*Paleodictyon strozii*	Domichnia	Nerites
8.	*Palaeophycus tubularies*	Fodinichnia	Cruziana
9.	*Paratanaedium*	Fodinichnia	Cruziana
10.	*Planolites beverleyensis*	Fodinichnia	Cruziana
11.	*Planolites*	Fodinichnia	Cruziana
12.	*Rhizocorallium*	Fodinichnia	Cruziana/Nerites
13.	*Skolithos lineraes*	Domichnia	Skolithos
14.	*Skolithos verticalis*	Domichnia	Skolithos
15.	*Tanaedium*	Fodinichnia	Cruziana
16.	*Thalasssinoids horizontalis*	Domichnia	Skolithos/Cruziana
17.	*Thalasssinoids callianassae*	Domichnia	Skolithos/Cruziana

Behavioural classification

Many traces have served a dual function and therefore assigned to one of several categories. Nevertheless, when studying traces, one should have some notion of behaviour classification. The following description is based mainly on Seilacher(1953).

Trace fossils recorded in the present work can be classified in to following categories on the basis of their behaviour (Table-2).

DISCUSSION

Traces have been recorded from both shales/mudstones and sandstones lithologies. Shales/mudstones are intensely bioturbated whereas sandstones are moderately bioturbated. Horizontal traces dominate over vertical forms and have been recorded mainly from the shale /mudstone lithologies (E of Bouma divisions).They comprise of simple, branched and network forms. The ichnofossil assemblage of these sediments is represented mainly by domichnia/fodinichnia benthos of *Cruziana* and *Nerites* ichnofacies. Analysis of these ichnofacies suggests that the Palaeogene sediments of the study area have been deposited under deep water environmental conditions where sediments were brought to the depositional site by the turbidity processes. Presence of plane/cross/convolute laminations alongwith low crested current ripples, chaotic beds and numerous incomplete Bouma divisions (T_{abc} and T_{ae}), plus massive sandstones with erosive bases also corroborate the above (Walker, 1976; Shanmugam and Moila 1982; Shanmugam, 1985; Stow, 2005; Biswas and Mukhopdhyaya, 2011; Srivastava *et al*., 2017). Presence of *O. rudis, O. annulata, O. nodosa, R. zenker, S. linearis, S. verticalis, Tanaedium* isp. alongwith *P. strozzii* points towards a deep water environmental condition with influence of turbidites (Seilacher, 1974; Crimes *et al*., 1981; Uchman, 1991; Knaust, 2013; Starek and Simo, 2015 and many more). *Ophiomorprha rudis* and *Palaeodictyon strozzii,* belong to *Nerites* ichnofacies (Seilacher, 1967) which is divided into *Ophiomorpha rudis* and *Palaeodictyon strozzii, ichnosubfacies.* These ichnosubfacies are characteristic of deep sea fans where turbidity is the main process. (Seilacher, 1974; Crimes *et al*., 1981; Uchman,1991; Starek and Simo, 2015). Heard and Pickering (2008) and Uchman (2009) have suggested that *Ophiomorpha rudis* ichnosubfacies are typical of deep sea fans. According to Uchman, (2009) *Ophiomorpha rudis* ichnosubfacies occurs in channel and proximal depositional lobe facies of deep-sea fans or in thick-bedded facies of deep-sea clastic ramps. He further suggests that this alongwith the *Nerites* and *Paleodictyon* ichnosubfacies, can be used for determination of bathymetric trends. Uchman (1995, 2001) has reported *Paleodictyon* from medium to thin bedded turbidites. In the modern sea *Palaeodictyon* is represented by ichnospecies *Palaeodictyon nodosium* (Rona *et al.,* 2009).

Presence of shallow water traces (*Arenacolites*, *Rhizocorallium* and *Asterosoma*) in deep water settings are not uncommon as have been reported by Crimes (1977) from Eocene deep sea sand fan, Spain and by Kern and Warme (1974) from Upper Cretaceous Point Loma Formation, California. Crimes (1977) has also suggested that in deep-water environments in which shallow-water traces appear, with increasing depth, the ratio of shallow water to deep water traces decrease. Similar trend has also been observed in the present study. Starek and Simo (2015) suggested that occasional high energy settings may contain so called shallow water traces locally. Bromley and Uchman (2003), Bradshaw (2010) and Knaust, (2013) have reported *Rhizocorallium* and *Asterosoma* from deeper water turbidite/ open marine environments. According to Knaust (2013) Palaeozoic/Mesozoic *Rhizocorallium* were restricted to Cruziana ichnofacies only but similar forms were reported from deep marine deposits during Cenozoic. Eager *et al.* (1985) also described varieties of *Rhizocorallium* from the base or top of thin turbidite beds in the mid-Carboniferous sediments. Carvalho and Rodrigues (2007) have suggested decapoda as probable producers of *Asterosoma ludwigae* and have correlated it with the active tectono-sedimentary events. While studying Guincho section (Jurassic, Portugal) they have suggested that the producers of *Asterosoma* were possibly transported to a deep environment where they had successfully adopted to the new environment due to their eco-physical abilities.

Presence of shelf trace fossils alongwith deep water traces may be due to transportation of trace makers to deeper areas through downslope or storm induced currents (Wetzel, 1984, 2008; Follimi and Grimm, 1990; Carvalho and Rodrigues, 2007). Uchman and Demircan (1999) suggest that it could be due to some fauna adapted to deep water environment. It appears that the primary control on trace fossil distribution in marine realm is the nature of substrate, food availability and the rate of sedimentation rather than bathymetry. Presence of both vertical and horizontal forms suggests episodic fluctuating energy conditions.

While studying the Gurnigel and Schlieren flysch units (Paleocene–Eocene) in Switzerland, Crimes *et al*. (1981) demonstrated that the channelized inner fan facies contain the so-called shallow-marine ichnotaxa (*Arenicolites, Skolithos*), but meandering and network forms are absent. Cummings and Hodgson (2011b) considered the ratios of pre- to post-depositional forms as the most powerful tool in the characterization of the trace-fossil distribution in different parts of the depositional system in the Late Cretaceous–Eocene deep-sea fan sediments of the Basque Basin, northern Spain. They concluded that the higher diversity and intensity of bioturbation (as in present case) and domination of the pre-depositional forms is typical of marginal parts of channel environments and lobes. In the axial part of lobes, post-depositional forms exclusively occur with a dominance of *Ophiomorpha*. With increasing water depth and decreasing sediment grain size, fodinichnia such as *Palaeophycus* appears.

From the above discussion it can be envisaged that the Palaeogene sedimentation in the study area was mainly controlled by the slope-sub marine fan environment where sediments were brought to the depositional site by turbidity /mass gravity transportation related processes. Dominance of horizontal traces and intense bioturbation points towards a reduced energy level and increased life processes. Presence of some vertical forms in these sediments suggests occasional rise in the energy conditions which can again be correlated with turbidity related processes and lowering of the sea level. The lowering of sea level and turbidity related processes could have been the result of the subduction of the Indian plate below the Burmese plate and/or the upliftment of the sediments formed under earlier tectonic regime in the NE. These processes would have forced the sea to recede towards south thereby lowering the sea level and initiating the turbidity related processes.

CONCLUSIONS

Abundant and moderately diverse traces have been recorded in both sandstones and shales. Ethologically, these ichnogenus display dwelling and feeding activities of the infaunal organisms. The dominance of horizontal forms over the vertical forms suggests a reduced energy and changes in environmental parameters. They also suggest increased activities of mobile carnivores and deposit feeders exploiting relatively nutrient-rich, fine-grained sediments deposited in low-energy conditions. The unique co-occurrences of shallow water traces with deep water suggest that the site has episodically been subjected to conditions of higher hydrodynamic phases. Presence of Bouma sequence suggests the influence of turbitity processes which are generally correlated with lowering of the sea level. The lowering of the sea level could be the result of the tectonics of the region. Study also suggests that the occurrence of trace fossils in marine environment is more to do with the availability of food and the energy conditions rather than the bathymetry alone.

Presence of such features in the sediments of the study area also points towards a tectonically active basin with varied bathymetric ranges indicating pulsating phases which could have been the result of continued plate interactions during the deposition of these sediments.

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REFERENCES

Alpert, S. P. 1974. Systematic review of the genus *Skolithos*. Journal of Paleontology, 48: 661-669.

Badve, R. M. 1987. A reassessment of Stratigraphy of Bagh Beds, Barwah area, Madhya, with description of trace fossils. Journal of Geological Society of India, 30: 106-120.

Biswas, A. and Mukhopadhyay, B. P. 2011. Signature of a Palaeogene Submarine fan from the Jenam Formation, Barail Group, Assam-Arakan Orogen, Northeast India. Journal of the Geological Society of India,78: 510-522.

Borkar, V. D. and Kulkarni, K. G. 1992. On the occurrence of Planolites Nicholson from the Bhaduka Limestone of the Wadhwan Formation (Cretaceous), Kathiawar, Gujarat. Journal of the Geological Society of India, 40: 468-473.

Bottjer, D. J., Droser, M. L. and Jablonski, D. 1987. Bathymetric trends in the history of trace fossils, In New Concept in the Use of Biogenic Sedimentary Structures for Paleoenvironment Interpretation (ed.D.J.Bottjer), Pacific Section SEPM, Los Angeles, 57-65.

Bradshaw, M. A. 2010. Devonian trace fossils of the Horlick Formation, Ohio Range, Antarctica: Systematic description and palaeoenvironmental interpretation; Ichnos 17: 58–114.

Bromley, R.G. 1996. Trace fossils,Biology,Taphonomy and Applications, 2nd ed. Chapman & Hall, 361p.

Bromley, R.G. and Uchman, A. 2003. Trace fossils from the Lower and Middle Jurassic Marginal marine deposits of the Sorthat Formation, Bornholm Formation, Denmark. Bulletin of the Geological Society of Denmark, 52: 185–208.

Carvalho, C. Neto de and Rodrigues, N. P. C. 2007. Compound Asterosoma ludwigae Schlirf, 2000 from the Jurassic of the Lusitanian Basin (Portugal): conditional strategies in the behaviour of Crustacea. Journal of the Iberian Geology, 33(2): 295-310.

Carvalho, I de S, Carlos, A. Fernandes, S Andreis, R. R. Allard, R. and Trouw, J. 2005. The Ichnofossils of the Triassic Hope Bay Formation, Trinity Peninsula Group, Antarctic Peninsula. Ichnos, 12: 191–200.

Crimes, T. P. 1977. Trace fossils of an Eocene deep-sea fan, northern Spain. In Trace fossils 2, T. P. Crimes and J. C. Harper (eds.), 71-90. Geology Journal, Special Issue No. 9. Liverpool: Steel House Press.

Crimes, T. P., Goldring R. Homewood, P. Stuijvenberg, J. and Winkler, W. 1981. Trace fossil assemblage of deep sea fan deposits, Gurnigel and Schlieren flysch (Cretaceous-Eocene), Switzerland. Eclogae Geologicae Helvetiae,74, 953-995.

Cummings, J.P., Hodgson, D.M., 2011b. Assessing controls on the distribution of ichnotaxa in sub-marine fan environments, the Basque Basin, Northern Spain. Sedimentary Geology 239: 162–187.

Cummings, J.P and Hodgson, D. M. 2011(b). Assessing controls on the distribution of ichnotaxa in sub-marine fan environments, the Basque Basin, Northern Spain; Sedimentary Geology 239: 162–187.

Eager, R. M. C., Baines, J. G., Collisnson, J. D., Hardy, P. G., Okolo, S. A. and Pollard, J. E. 1985. Trace fossil assemblage and their occurrence in Silesian (Mid Carboniferous) deltaic sediments of the Central Pennine basin, England. In: Curren, H.A.(ed), Biogeneic structures: Their uses in interpreting depositional environments.,SEPM, 35: 99-149.

Fillion, D. and Pickerill, R. K. 1990. Ichnology of the upper Cambrian? To Lower Ordovician Bell Island and Wabana groups of eastern Newfoundland. Palaeontographica Canadiana, 7: 119 p.

Follmi, K. B. and Grimm, K. A. 1990. Doomed pioneers: Gravity-flow deposition and bioturbation in marine oxygen-deficient environment. Geology, 18: 1069-1072.

Frey, R. W. 1978. Behavior and ecological implications of trace fossils. In Trace fossil concepts. P. B. Basin (ed.), 46-72. Short Course No. 5, SEPM, Tulsa, Oklahoma.

Fursich, F. T. 1974(a). On Diplocraterion Torell 1870 and the significance of morphological features in vertical, spreiten-bearing U-shaped trace fossils. Journal of Paleontolgy, 48(5): 952-962.

Ghani, M.R. and Alam, M. M. 1999. Trench-slope controlled deep sea clastics in the exposed lower Surma Group in the southeastern fold belt of the Bengal basin, Bangladesh. Sedimentary Geology, 127: 221-236.

Goldring, R. 1962. The trace fossils of the Baggy Beds (Upper Devonian) of north Devon England. Paleont. Zeitschr, 36: 232-251.

GSI, Miscellaneous publication No. 30 Part iv, 1 (part-2) 2011: Geology and mineral resources of Manipur, Mizoram, Nagaland & Tripura.47-76.

Hakes, W. G. 1976. Trace Fossil and Depositional Environment of Four Elastic Units, Upper Pennsylvanian Megacyclothem, Northeast Kansas. University of Kansas Paleontological contribution 63.

Heard, T. G. and Pickering, K. T. 2008. Trace fossil as diagnostic indicators of deep marine environments, Middle Eocene Ainsa-Jaca basin, Spanish Pyrenees; Sedimentology, 55: 809-844.

Howard, J. D. 1975. The sedimentological significance of trace fossils. In The study of trace fossils. R. W. Frey (ed.), 131-46. Berlin: Springer.

Howard, J. D. and Frey, R. W. 1984 Characteristic trace fossils in nearshore to offshore sequences, Upper Cretaceous of east-central Utah, Canadian Journal of Earth Science, 21: 200-219.

Kern, J. P. and Warme, J. E. 1974. Trace Fossils and Bathymetry of the Upper Cretaceous Point Loma formation,San Diego, California, Bulletin of Geological of America, 85(6): 893–900.

Khalo, A. and Pandey, N. 2018. Palaeoenvironmental significance of ichnofossils assemblages from the Palaeogene sediments of Inner Fold Belt, Naga Hills, NE India; Journal of Geological Society of India, 91: 201-208.

Kichu Moalong, A., Srivastava, S. K. and Khesoh, K. 2018. Trace fossils from Oligocene Barail sediments in and around Jotsoma, Kohima, Nagaland. Journal of Palaeontological Society of India, 63(2): 197-202.

Knaust, D. 2013. The ichnogenus Rhizocorallium: Classification, trace markers, Palaeoenvironments and evolution. Earth Science Review, 126: 1-47.

Kundal, P. and Dharshivkar, A. P. 2006. Ichnofossils from the Neogene and Quaternary deposits of Dwarka-Okaha area Jamnagar District, Gujarat. Journal of the Geological Society of India, 68(2): 299-315.

Kundal, P. and Sanganwar, B. N. 1998. Stratigraphy and palichnology of Nimar sandstones, Bagh beds of Jobat Area, Jhabua Distrct, Madhya Pradesh. Memoir Geological Society of India, 51: 619-634.

Mathur, L.P. and Evans, P. 1964. Oil in India 22nd sessions. Int. geol. Cong. New Delhi., India. 85p

Miller, M. F. and Knox, L.W. 1985. Biogenic structures and depositional environments of a Lower Pennsylvanian coal-bearing sequence, northern Cumberland Plateau, Tennessee, U.S.A. In: Curran, H.A. (Ed.), Biogenic Structures and Their Uses in Interpreting Depositional Environments: SEPM Special Publication No. 35: 67–97.

Mutti, E. 1985. Turbidite systems and their relations to depositional sequences. In. Zuffa, G.G. (ed.), Provenance of Acenites, Nato Advanced Scientific Institute Series C: Mathematical and Physical Sciences, 65-93.

Mutti, E. Ricci-Lucchi, F. 1972. Turbidites of Northern Apennies: Introduction to facies analysis. International Geological Review, 20, 125-126 (English translation by T.H. Nelson 1978).

Patel, S. J., Joseph, J. K. and Bhatt, N.Y. 2013. Sequence stratigraphic analysis of the mixed siliciclastic-carbonate sediments (Middle Jurassic) of the Patcham Island, Kachchh, Western India: An ichnological approach. Special Publication of the Journal of the Geological Society of India, 84–111.

Pemberton, S. G. and Frey, R. W. 1982. Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma. Journal of Paleontology, 56: 843-81.

Pemberton, S. G. Maceachern, J. A., Gingras, M. K. and Zhang, J. 2000. Significance of ichnofossils to guide genetic stratigraphy. Science in China (series D), 43(5): 542.

Rajkonwar, C. Tiwari, R. P. and Patel, S. J. 2013. Arenocolites helixus isp. nov. and associated ichnofossils from the Bhuban Formation,Surma Group (Lower-Middle Miocene) of Aizawl, Mizoram, India. Himalayan Geology, 34(1),18-37.

Rona, P. A. Seilacher, A.,Colomban, de Vargas Gooday, A. J., Bernhard, J. M., Bowser, S. , Vetriani, C. Wirsen, C. O., Mullineaux, L., Sherrell, R. Frederick, G. J. Lowh, S., Lutz, R. A. 2009. *Paleodictyon nodosum*: A living fossil on the deep sea floor Deep sea research part II. Topical studies in Oceanography, 56(19-20): 1700-1712.

Sarkar, S., Ghosh, S. K. and Chakraborty, C. 2009. Ichnology of late Palaeozoic ice-marginal shallow marine succession: Talchir Formation, Satpura Gondwana basin, Central India. Palaeogeogeography Palaeoclimate Palaeoecology, 283: 28-45.

Seilacher, A. 1953. Studien zur Palichnologie über die methoden der Palichnologie. Neues Jahrbuch für Geologie und Paläontologie 98: 87-124.

Seilacher, A. 1967. Bathymetry of trace fossils. Marine Geology, 5: 413-428.

Seilacher, A. 1978. Use of trace fossils for recognizing depositional environments. In Trace fossil concepts, P. B. Basin (ed.), 175-201. Short Course No. 5, SEPM, Tulsa, Oklahoma.

Selley, R. C. 2000. An introduction to sedimentology. New York: Academic Press.

Shanmugam, G. and Moila, R. J. 1982. Eustatic control of turbidites and winnowed turbidites. Geology 10: 131-135

Shanmugam, G. Moila, R. J. and Damuth, J. E. 1985. Eustatic control of submarine fan development. In Bouma, A.H., Normark ,W.R., Barnes, N.E. (eds.). Sub marine fans and related turbidite Systems, Springer-Verlag, NewYork, 23-28.

Singh, M. C. and Kushwaha, R. A. S. 2008. Ichnofossils from Eocene-Oligocene deposits between Bijang and Tupul, Manipur, India. Journal of Indian Association of Sedimentolist 27(1): 35-44.

Singh, R. K. Rodrigez- Tower, F. J. and Ibotombi, S. 2008. Trace fossils of the Upper Eocene-Lower Oligocene Transition of the Manipur Indo-Myanmar Ranges (Northeast India). Turkish Journal of Earth Science, 17: 821-834.

Singh, M. C. Kundal, P. and Kushwaha R. A. S. 2010. Ichnology of Bhuban and Bokabil Formations,Oligocene-Miocene deposits of Manipur Western Hill, Northeast India, Journal of Geological Society of India, 76: 573-586.

Srivastava, S. K. 2002. Facies Architecture and depositional model for Palaeogene Disang-Barail Transition,North-West of Kohima, Nagaland, unpublished Ph.D thesis, Nagaland University, Kohima.

Srivastava, S. K., Pandey, N. and Srivastava, V. 2004. Tectonic sedimentary Evolution of Disang-Barail Transition NW of Kohima, Nagaland, India. Himalayan Geology, 25: 121-128.

Srivastava, S. K. 2013. Source of Silica Cement for the Siliciclastics at Disang-Barail Transition, North-West of Kohima, Nagaland, India. International Journal of Earth Science and Engineering; 06(2): 386-391

Srivastava,S.K., Bevio, Liba and Vevosu Chuzo. 2017. Lithofacies Analysis of the Palaeogene sediments in parts of Kohima Synclinorium, Nagaland, India: Implications for the Depositional Environment Himalayan Geology, 38(1), 30-37.

Starek, D. and Simo, S. 2015. Trace fossils from Eocene turbidite deposits: A case study from the Slovak-Moravian Carpathians. Acta Geologica Slovaca, 7(2): 129-138.

Stow, D. A. V. 1985. Deep sea clastics: where are we and where are we going? In. Brenchley, P.J., Williams, B.P.J. (eds.), Sedimentology: Recent developments and applied aspects Geological Society of London Special Publication,18: 67-93.

Uchman, A. 1991. Diverse tiering patterns in Palaeogene flysch trace fossils, Magura nappe, Carpathian Mountains, Poland. Ichnos, 1: 287-292.

Uchman, A.1995. Taphonomy and palaeoecology of flysch trace fossils. The Marnoso-aranacea Formation and associated facies (Miocene,Northern Appennies, Italy), Beringeria, 15: 1-115.

Uchman, A. and Demicran, H. 1999. Trace fossils of Miocene deep sea fan fringe deposits from the Cingoz Formation, southern Turkey. Annales Societatis Geologorum Poloniae, 69: 125-153.

Uchman, A. 2001. Eocene flysch trace fossils from the Hecho Group of Pyrenees, Northern Spain. Beringeria, 28: 3-41.

Uchman, A. 2004(b). The Ophiomorpha rudis ichnosubfacies of the Nereites ichnofacies.In: Buatois, L.A., Mángano, M.G. (Eds.), Abstracts Ichnia 2004, First International Congress on Ichnology, Museo Paleontológico Egidio Feruglio, Trelew, 79–80.

Uchman, A. 2009. The Ophiomorpha rudis ichnosubfacies of the Nerites ichnofacies: characteristics and constraints. Palaeogeography, Palaeoclimate, Palaeoecology, 276: 107-119.

Uchman, A. and Wetzel, A. 2012. Deep sea fans.In: Knaust, D., Bromley, R.G.(eds.) Trace fossils as indicators of sedimentary environments. Developments in sedimentology, 64, Elsevier, Amsterdam, 643-67

Vaziri, S. H. and Fursich, F. T. 2007. Middle to Upper Triassic Deep water Trace fossils from the Aushin Formation, Nakhlak Area,Central Iran, Journal of Science of Islamic Republic, Iran. 18(3),253-268.

Walker, R. G. 1976. Facies models 2. Turbidites and associated coarse clastic deposits. Geoscience Canada, 3(1), 25-36.

Weimer, R. J. and Hoyt, J. H. 1964. Burrows of *Callianassa major* Say, geologic indicators of littoral and shallow neritic environments, Journal of Paleontology, 38: 761-767.

Wetzel, A. 1984. Bioturbation in deep sea fine grained sediments: influences of sediments texture,turbidte frequency and rates of environmental change. In: Stow, D.A.V. and Piper D.J.W.(eds.). Fine grained sediments: Deep water processes and facies. Geological Society of London, Special publication, 15: 595-608.

Wetzel, A. 2008. Recent bioturbation in the deep sea South China Sea: a uniformitarian ichnologic approach. Palaios, 23: 601-614.