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Ichnology of the Enugu Formation: Implications for Campanian Sea Movements in Southeastern Nigeria

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ABSTRACT

Trace fossils from the outcrop section of the Enugu Formation in Anambra Basin, southeastern Nigeria, have been studied based on the varieties, types, mode of occurrence, orientation of the burrows, wall structures and fills. Five ichnogenera identified belong to the Skolithos and Cruziana ichnofacies and include; Skolithos isp. Thalassinoides isp., Planolites isp., Teichichnus isp. and Chondrites isp. The assemblage is suggestive of deposition in a nearshore setting influenced by stressed environmental conditions due to the mixture of marine and fresh water inflows. The lithologic characteristics, physical sedimentary structures, the distribution and the style of the bioturbation from the base to the top of the sequence, as well as the general absence of deeper marine ichnofacies suggest moderate to high energy conditions in a prograding shoreline and shallow marine environments.

Key words: Lithostratigraphy, ichnostratigraphy, ichnology, ichnofacies, bioturbation

INTRODUCTION

Ichnology, the branch of geology that studies traces of organismal behaviour such as burrows, tracks and trails made in various substrates, has grown tremendously in the last five decades as researchers have continued to expand its importance in sedimentologic studies (Egbu *et al*., 2009). Trace fossils are very useful in the interpretation of paleobathymetry, paleoenvironments and paleoecological stress (Seilacher, 1967). It also has its application in allostratigraphy and sequence stratigraphy for delineation of key stratal surfaces (Pemberton *et al*., 1992a, b; MacEachem *et al*., 1992; Taylor and Gawthorpe, 1993; Pemberton and MacEachem, 1995).

The sedimentology, stratigraphy and petroleum potential of the Enugu Formation have been studied by various scholars including (Nwajide and Reijers, 1996; Nwajide, 2005; Akaegbobi *et al*., 2009; Ojo *et al*., 2009).

Though Nwajide and Reijers (1996) noted the occurrence of many burrows such as planolites on the siltstone and fine sandstone members of the formation but none of the researchers gave serious attention to these ichnofossils.

This study therefore is aimed at documenting findings from the study of the ichnofossils of the Enugu Formation. The ichnofacies assemblages, distribution and the styles of bioturbation, physical sedimentary structures as well as the lithologic characteristics were employed in the interpretation of the depositional environment and the paleogeography of the Campanian in the southeastern Nigeria.

REGIONAL TECTONIC AND STRATIGRAPHIC SETTING

The origin of the Anambra Basin is intimately related to the development of the Benue Rift. The Benue Rift was installed as the failed arm of a trilate fracture (rift) system during the breakup of the Gondwana supercontinent and the opening up of the southern Atlantic and Indian Oceans in the Jurassic (Burke *et al*., 1972; Olade, 1975; Benkhelil, 1982, 1989; Hoque and Nwajide, 1984; Fairhead, 1988). The initial synrift sedimentation in the embryonic trough occurred during the Aptian to early Albian and comprised of alluvial fans and lacustrine sediments of the Mamfe formation in the southern Benue Trough. Two cycles of marine transgressions and regressions from the middle Albian to the Coniacian filled this ancestral trough with mudrocks, sandstones and limestones with an estimated thickness of 3,500 m (Murat, 1972; Hoque, 1977). These sediments belong to the Asu River group (Albian), the Odukpani formation (Cenomanian), the Ezeaku group (Turonian) and the Awgu Shale (Coniacian). During the Santonian, epeirogenic tectonics, these sediments underwent folding and uplift into the Abakaliki-Benue Anticlinorium (Murat, 1972) with simultaneous subsidence of the Anambra Basin and the Afikpo Sub-basins to the northwest and southeast of the folded belt, respectively (Murat, 1972; Burke, 1972; Mode and Onuoha, 2001). The Abakaliki Anticlinorium later served as a sediment dispersal centre from which sediments were shifted into the Anambra Basin and Afikpo Syncline (Hoque, 1977). The Oban Masif, southwestern Nigeria basement craton and the Cameroon basement complex also served as sources for the sediments of the Anambra Basin (Hoque and Ezepue, 1977; Amajor, 1987; Nwajide and Reijers, 1996). Figure 1 shows the structural units of the southeastern Nigeria sedimentary Basins and the Anambra Basin.

After the installation of the Anambra Basin following the Santonian epeirogeny, the Campanian-Early Maastrichtian transgression deposited the Nkporo Group (the Enugu Formation, Owelli Sandstone, Nkporo Shale, Afikpo Sandstone, Otobi Sandstone and Lafia Sandstone) the basal unit of the basin, unconformably overstepping the basement complex, the Asu River, the Eze-Aku and Awgu Formation in places. This was followed by the Maastrichtian regressive event during which the coal measures (the Mamu, Ajali and Nsukka Formations) were deposited.

Figure 1 is the geologic map of southeastern Nigeria showing the study area.

Stratigraphy: Many authors have described the stratigraphic successions in the Anambra Basin (Simpson, 1954; Reyment, 1965; Agagu *et al*., 1985; Amajor, 1989; Nwajide and Reijers, 1996; Nwajide, 2005). The Nkporo Group constitutes the basal lithostratigraphic unit in the Anambra Basin and was deposited during Late Campanian-early Maastrichtian period. The Nkporo Formation consists of dark shales and mudstones with subordinate sandstones, oolitic ironstone and shelly limestone with commonly burrows of Skolithos isp., Ophiomorpha isp. and Thalassinoides isp. The Enugu Formation, a lateral equivalent of the Nkporo Formation, consists of grey, blue or dark shale, occasional white sandstones and striped sandy shale beds. The Owelli Sandstone comprises of fining upward successions of hard ferruginous sandstones, cross-bedded sandstone, shale, siltstone, coal, kaolinitic clay, vitrinite and wood fragments. The Mamu Formation, the Ajali Sandstone and the lower Nsukka Formation were deposited conformably during the Maastrichtian stage over the Nkporo Group. The Mamu Formation (lower coal measure of geological survey of Nigeria) overlies the Nkporo Group and consists of shale, heteroliths, sandstones and coal (Kogbe, 1989). The Ajali Sandstone is dominated by sandstones in which kaolinitic clay interbeds are common and overlies the Mamu Formation. The Nsukka Formation (Reyment, 1965) overlies the Ajali Sandstone. It consists of an alternating succession of sandstones and shales with thin coal seams. Table 1 shows the stratigraphic framework of the Anambra Basin and the position of the Enugu Formations within the stratigraphic column.

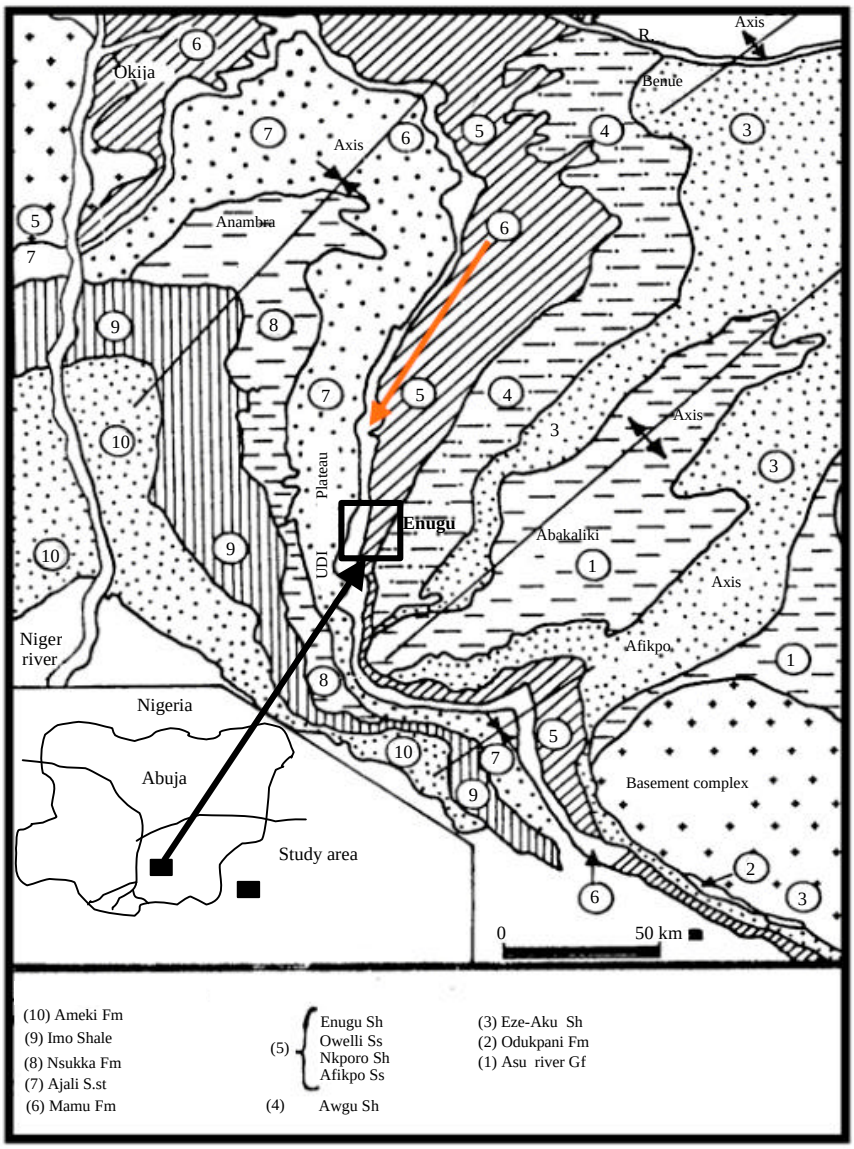

Fig. 1: Geologic map of Southeastern Nigeria showing the study area (Modified from Hoque, 1976)

MATERIALS AND METHODS

The outcrop of the Enugu formation studied was logged from the base to the top (Fig. 2 and 3). Trace fossils found in the outcrop were studied based on the following:

- Variety, types and mode of occurrence
- Attitude/orientation of burrows
- Wall structure, fills and dimensions of burrow cross-sections

Table 1: Stratigraphic Sequences in the Anambra Basin (after Nwajide, 2005)

Age	Basin	Stratigraphic units
Thanetian	Niger delta	Imo Formation
Danian		
Maastrichtian	Anambra basin	**Coal measures** • Nsukka Formation • Ajali Sandstone • Mamu Formation Nkporo Fm./ Enugu Fm./Owelli Sst./ Afikpo Sst./Otobi Sst./Lafia Sst.
Campanian		
Santonian	Southern benue trough	Awgu Formation

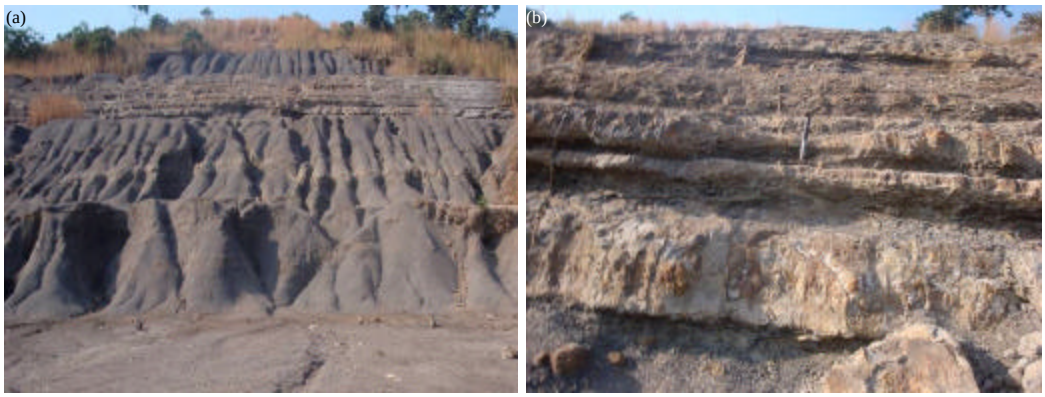

Fig. 2(a-b): Outcrop of the Enugu Formation near flyover about 200 m away from, (a) NNPC filling station and (b) Heterolithic unit at the middle part of the outcrop

The ichnofacies assemblages in the formation were established. The ichnofacies assemblages together with the lithological characteristics and physical sedimentary structures in the Enugu formation formed the bases for the interpretation of the depositional environment and paleogeography of the Campanian in the southeastern Nigeria.

RESULT

Lithostratigraphy and Ichnostratigraphy: The outcrop is about 40 m thick and a road cut exposure. The base of the outcrop comprises of grayish shale of about 5.3 m thick. Upwards there are thin interbeds of carbonaceous and ferruginous sandstone, siltstone and gypsum. The ferruginized sandstone beds are yellowish brown in colour. The carbonaceous sandstones are dark, massive, well indurated and contain some concretions. The beds generally thicken upwards. The section is capped by light grey and indurated shale intercalated with white sandstone (Fig. 3). Burrows are abundant on the heterolithic units especially the shale and consist dominantly of Skolithos isp., Thalassinoides isp., Planolites isp., Chondrites isp. and Teichichnus isp. (Fig. 4). Physical sedimentary structures include parallel laminations (shale) and wave ripple lamination (the heterolithic unit).

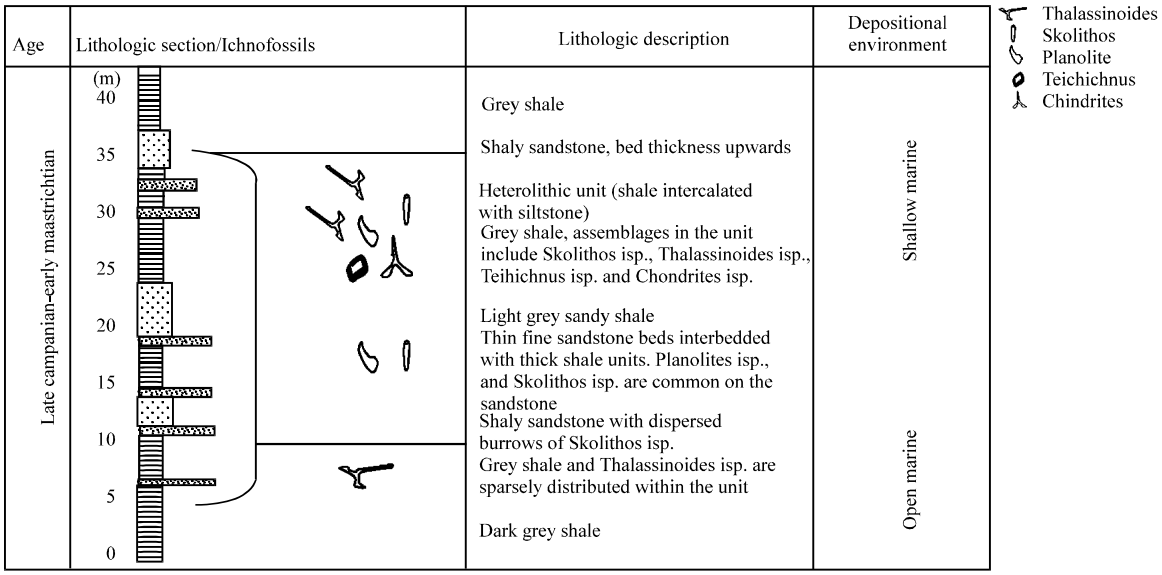

Fig. 3: Stratigraphic section of the Enugu formation exposed near flyover about 200 m away from NNPC filling station, Enugu

Ichnology: Ichnology is considered a relatively young branch of the earth sciences. It can be defined as the branch of geology that deals with traces of organismal behaviour such as burrows, fossilized footprints, tracks or other traces.

The ichnofossils documented from the Enugu formation include Skolithos isp., Planolites isp., Teichichnus isp., Thalassinoides isp. and Chondrites isp. (Fig. 4). The ichnogenera belong to two ethological classes (fodnichnia and domichnia, Table 3) and two ichnofacies (Skolithos and Cruziana).

Classification of ichnofossils: Seilacher (1964) established six categories into which animal traces may be grouped based on their ethology or behaviour (Table 2). This is hinged on the fact that different groups of animals with similar life habits produce traces with similar basic characteristics even though the animals may be morphologically quite different.

Ichnofacies: The two ichnofacies identified on the outcrops of the formation includ:

- Skolithos ichnofacies e.g., Skolithos and Chondrites (Nwajide and Hoque, 1979; Amajor, 1984; Mbuk *et al*., 1985; Anyanwu and Arua, 1990; Mode, 1993)
- Cruziana ichnofacies e.g., Planolites, Thalassinoides and Teichichnus (Banerjee, 1982; Mode, 1993)

Mode of occurrence: The Skolithos isp. and Planolites isp., occur in the fine sandstone while the shale beds of the heterolithic units at the middle and towards the upper part of the outcrop document the assemblage that include; Thalassinoides isp., Teichichnus isp. and Chondrites isp., Thalassinoides sp., are sparsely distributed within the basal shale in the area:

Table 2: Major categories of ichnofossils ethological classes (after Frey, 1978)

Categories of trace fossils	Definition
Fodinichnia (feeding traces)	Typical feeding structures representing extensive subsurface foraging by deposit-feeding organism
Domichnia (dwelling traces)	Simple tubes, simple shafts or an integrated systems of shafts and tunnels made mainly by endobenthic suspension feeders and certain predators and scavengers as more or less permanent domiciles
Repichnia (crawling traces)	Trackways and epistratal or intrastratal trails made by organisms traveling from one place to another
Cubichnia (resting traces)	Shallow depressions made by animals that temporarily settle onto, or dig into the substrate surface
Pascichnia (grazing traces)	Grooves, pits and furrows, many of them are discontinuous made by mobile deposit feeders at near the substrate surface
Escape structures	Trace fossils of various kinds modified or made a new by animals in direct response to substrate degradation or aggradation

Table 3: Ethological classification of the trace fossils from the Enugu formation

Domichnia	Skolithos (Benton and Harper, 1997; Mode, 1997). Domichnia represent traces produced in full oxygenated pore and bottom water (shallow waters) (Bromley, 1996)
Fodinichnia	Planolites, Thalassinoides, Teichichnus and Chondrites (Hantzschel, 1962; Frey and Howard, 1970; Kennedy, 1970; Pemberton and Frey, 1982, 1984 cited in Mode, 1997). Fodinichnia represents traces of non vagile deposit feeders (Bromley, 1996)

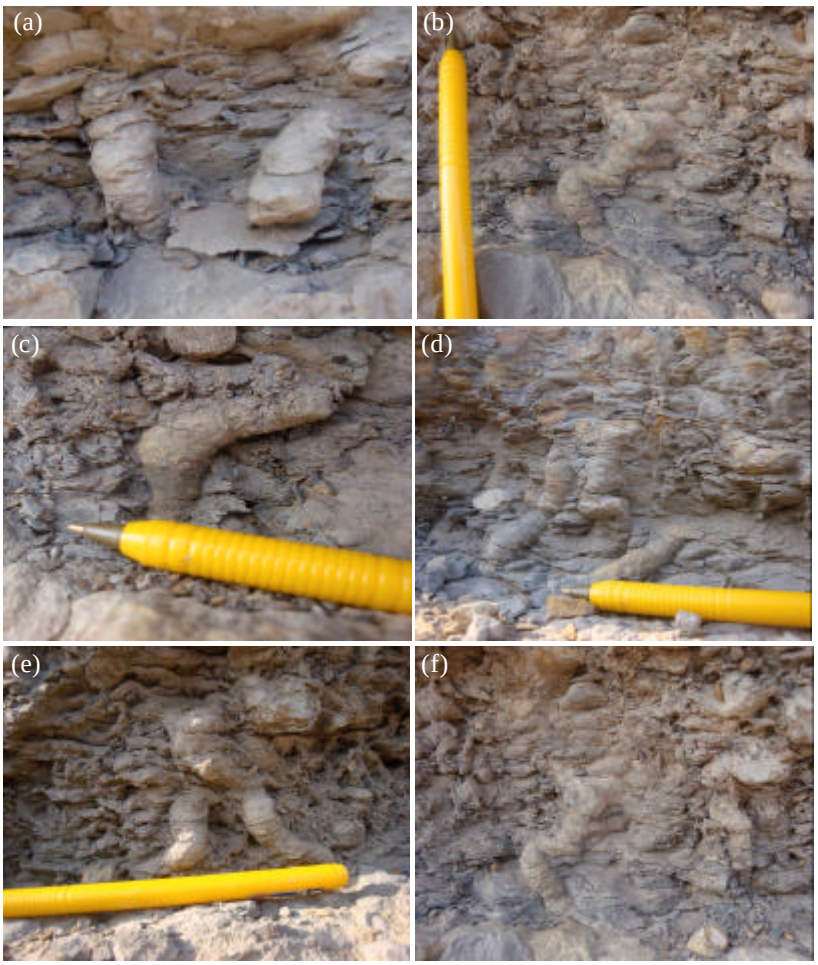

Fig. 4(a-f): Ichnofossil assemblages from the Enugu formation exposed 200 m away from NNPC filling station near flyover, Enugu

- **Planolites:** Occur on the heterolithic (fine sandstone) unit as tunnel of uniform diameter (generally not up to 30 mm), horizontal to sub vertical and commonly sand-filled with unlined smooth walls
- **Thalassinoides:** Display an irregular network of tunnels, commonly branched with variable diameters (Fig. 4). The burrows are horizontal, mud- filled and have smooth unlined walls
- **Skolithos:** Consist of tunnel of uniform diameters, vertical and have smooth walls. The ichnogenera occur mostly on the fine sandstones
- **Chondrites:** This occurs on the shale as branched burrow of equal diameter, generally less than 3 mm, vertical and mud filled
- **Teichichnus:** Occur on the shale (heterolithic unit) as horizontal to sub-vertical mud filled burrows

IMPLICATION FOR DEPOSITIONAL ENVIRONMENT AND PALEOGEOGRAPHY

The ichnofacies concept pioneered by Seilacher (1954, 1958, 1963, 1967) is based upon the observation that certain ichnofossil assemblages tend to occur under particular set of environmental conditions. The assemblages are controlled by physical, chemical and biological factors of the environment which include rate of deposition, oxygen availability, hydraulic energy, substrate consistency, salinity level, turbidity and quality of suspended or deposited food materials (Mode, 1997). According to Seilacher (1963, 1964, 1967), the skolithos-cruziana-zoophycos-nereites ichnofacies succession can be useful in the reconstruction of shallow to deep water sedimentary successions. Since, bathymetry is not the governing factor in determining ichnofacies, the study employed both lithologic characteristics, physical sedimentary structures as well as the ichnofacies in the interpretation of the depositional environment and the paleogeography of the Campano-maastrichtian in the southeastern Nigeria.

The ichnological assemblages consisting of Thalassinoides isp., Planolites sp., Teichichnus sp. and Skolithos sp., have been attributed to deposition in a coastal (nearshore) setting influenced by stressed environmental conditions due to the mixture of marine and fresh water inflows (Benynon and Pemberton, 1992; Pemberton *et al.*, 2001; Uchman *et al.*, 2004). Such assemblage reflects the fluctuating environmental parameters being characterized by low diversity, presence of typical marine forms (Skolithos, Thalassinoides, Planolites, Teichichnus and Chondrites) and the mixtures of traces characteristic to both Skolithos and Cruziana ichnogenera (Bromley, 1996). The ichnofacies assemblage that consists entirely of dispersed traces of Thalassinoides as documented by the lower shale unit is suggestive of nearshore area that has undergone episodic or constant environmental changes (Maceachern and Pemberton, 1992; Pollard *et al.*, 1993). It could also be attributed to poorly aerated bottom waters which were inhospitable to almost all trace making organisms (Mode, 1993). The change in the depositional energy is confirmed by the transition from the horizontal (low energy) to sub vertical and vertical (higher energy) burrows from the lower shale to the heterolithics at the upper part of the outcrop. The outcrop documents only skolithos-cruziana ichnogenera (shallow water ichnofacies). There is general absence of deeper water ichnofacies (zoophycos-nereites), suggesting that the Campanian epeiric sea was shallow. Skolithos is suggestive of high energy (intertidal or shallow subtidal marine) environments. It is also typical of areas subjected to high sedimentation mobility (Benton and Harper, 1997; Zonneveld *et al.*, 2001; Mapals *et al.*, 2005; Savary *et al.*, 2004). This normally occurs in shallow

marine shales/silt and storm sand. The coarsening upward succession of the lithofacies, physical sedimentary structures (parallel and wave ripple laminations) and the ichnofacies assemblage in the study area suggests deposition in a low to high energy prograding shallow marine setting.

CONCLUSION

The shallow water ichnofacies (Skolithos and Cruziana) were identified on the study area and include; the Skolithos isp., Thalassinoides isp., Planolites isp., Teichichnus isp. and Chondrites isp. Such assemblage is a characteristic of nearshore environment prone to stress due to the influx of fresh water. The coarsening upward succession of lithology, physical sedimentary structures as well as the distribution and the style of bioturbation are suggestive of deposition in a prograding shallow marine environment. The dispersed traces of Thalassinoides at the basal shale unit could suggest anoxic bottom condition.

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