International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Ichnology and Lithofacies Analysis of the Cretaceous-Tertiary Transition in the Okigwe-Agbobu Area, Anambra Basin Southeastern Nigeria

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Abstract— *Trace fossil assemblages and lithofacies associations of the Cretaceous-Tertiary transition in the Okigwe-Agbobu area, Anambra basin studied at outcrops along Enugu–Port Harcourt expressway, the Okigwe-Owerri, and the Okigwe-Onitsha roads were described and their paleoenvironmental interpretations discussed. Facies analysis reveals four lithofacies association, namely; cross-bedded sandstone facies, interbedded heterolith and shale facies, wave-rippled laminated sandstone facies, and heterolithic shale and siltstone facies. The trace fossils encountered in the study area belong to two ethological groups; domichnia and fodinichnia. Seven ichnogenera identified belong to Skolithos ichnofacies representing the tidal zone and Cruziana ichnofacies common in the subtidal zone. The gross depositional environment suggests a transition from fluvial through lagoonal setting to shoreface-foreshore environments.*

Keywords— *Anambra Basin: Depositional environment: Facies: Trace fossils.*

I. Introduction

The Cretaceous-Tertiary (K-T) Transition marks a period of global change in climate which affected the ecosystem as well as the depositional environments of rocks. The sedimentology of deposits of this period is poorly documented in Anambra basin. Lithofacies-based analysis of rocks of the K-T Transition (Late Maastrichtian-Palaeocene) in the Anambra basin will contribute to the on-going re-evaluation of the origin, evolution and hydrocarbon potential of the Palaeogene succession in the Anambra Basin, by presenting a depositional model for rocks of the K-T Transition in the study area. Therefore, the aim of the study is to identify outcropping lithologies of the K-T transition, recognize lithofacies and facies succession, and interpret facies associations in terms of environments of deposition. In addition, biogenic characterization is employed to present depositional model reconstructed from the processes that led to the formation of the Late Maastrichtian-Palaeocene sediment packages.

II. Study Area and Geological Setting

The study area lies within the Anambra Basin of southeastern Nigeria and delineated by latitudes 5°50¹N-5°55¹N and longitudes 7°15¹E-7°23¹E, (Figure 1). It encompasses the western part of Okigwe town and extends as far as Umulawlaw, Umuawa and Agbobu covering an aerial extent of about 250 Sqkm.

The Anambra Basin occupies the western flank of the NE – SW trending Benue Trough and evolved during the Santonian folding and uplifts of the Abakaliki Anticlinorium and displacement of the depocenter into the Anambra platform and Afikpo region (Murat, 1972 and Kogbe *et al*, 1976).

The stratigraphic succession of the basin includes Nkporo Group (Campanian-Maastrichtian), Mamu Formation and Ajalli Sandstone (Maastrichtian), Nsukka Formation (Maastrichtian-Paleocene), Imo Formation (Paleocene), Ameki Formation (Eocene) and the Oligocene Ogwashi-Asaba Formation (Obi, 2000; Oboh-Ikuenobe et al., 2005).

Sediments of the Cretaceous-Tertiary Transition in the study area belong to the Nsukka Formation (uppermost Maastrichtian-Danian) and the Imo Shale (Paleocene). The Nsukka Formation consists of alternating sequence of laminated, very fine grained sandstones and siltstones, brown and grey shales, sandy shales and mudstones with coal seams at certain horizons (Reyment, 1965; Obi, 2000; Obi et al., 2001). The Imo Formation comprises blue-grey clays and black shale with bands of calcareous sandstones, marl and limestone. The Imo Formation maintains a conformable relationship with the Nsukka formation, and marks the Cretaceous-Tertiary transition in south-eastern Nigeria.

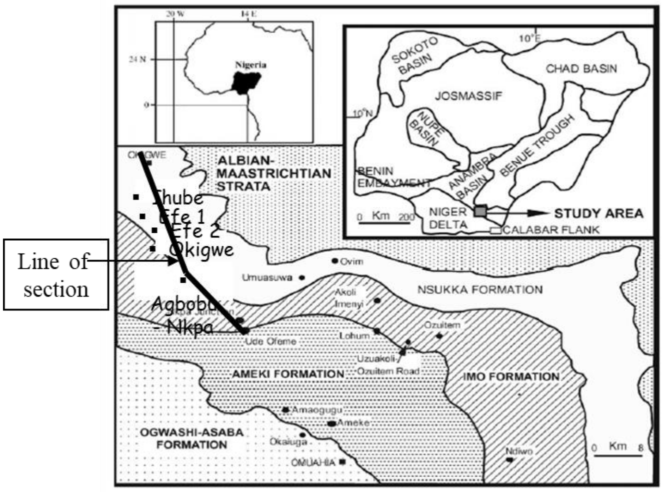

Fig. 1. Geological map of parts of Anambra Basin showing the study area

III. Methodology

Seven key and composite outcrops sections of Nsukka and Imo Formation seen along Enugu–Port Harcourt expressway, the Okigwe-Owerri, and the Okigwe-Onitsha roads were systematically logged for rock type, stratal contacts, physical

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ISSN (Online): 2455-9024

and biogenic sedimentary structures to interprete prevailing hydrodynamic processes at the time of deposition.

Identified lithofacies were classified into facies associations by integrating lithologic data and ichnological data to aid in interpretation of depositional environment of the formations. The trace fossils present were described and classified into various ethological classes, ichnogenera and ichnofacies.

IV. Result and Discussion

The outcrop sections described at Ihube, Umuawa, Efe River Section I and II, Okigwe, Umuna and Agbobu were differentiated into four lithofacies associations based on sedimentological and ichnological criteria. The facies associations are namely, cross-bedded sandstone facies, interbedded heterolith and shale facies, wave-rippled laminated sandstone and heterolithic shale and siltstone facies.

Cross-bedded sandstone facies (Figure 2) is well exposed by the Efe River in the Okigwe area, along the Okigwe-Onitsha and Enugu-Port Harcourt highways. The facies consists of multistory sandstone units of variable thickness containing abundant *Skolithos and Cruziana* ichnofacies, chiefly *Ophiomorpha* (Figure 3a), *Skolithos*, *Thalassinoides* (Figure 3b), *Paleophycus* and *Arenicolites*. The facies association can be subdivided into three main intervals, namely:

(1) *Conglomerate facies* that are up to 5 m-thick at each interval, and are characterized by large-scale planar and trough cross-bedding. The sandstone is medium-coarse grained and poorly to moderately sorted.

(2) *Cross-bedded sandstone* facies comprising fine- to coarse-grained, moderately- to well-sorted beds. This unit is characterized by both planar and trough cross-stratification, reactivation surfaces, and scattered extraformational clasts. Drapes of mud and disseminated plant matter occur on the foresets of the cross beds. Pebbles and ferruginized bands occur at various horizons within the unit.

(3) *Mudstone-sandstone facies* consisting of horizontally bedded, wavy laminated bands of light-colored clay and very fine-grained sandstone with unit thickness ranging between less than 10cm to over 80cm. Clay intervals may be sandy, massive, crudely laminated and mottled or white, gray, or brown. There were local occurrences of fragmented bivalve shells.

Interpretation: This facies is interpreted to be a high energy active channel deposit based on texture and sedimentary structures. Cross bedding is attributed to wave-induced uni-directional currents as well as shallow tidal currents developed in an open near shore environment. Reactivation surfaces provide evidence of tidal influence typical in a subtidal setting (Smith, 1988). The presence of extraformational clast suggests fluvial environment but with some influence of tide or wave due to their scattered nature. Thus, this channelized uni-directional cross bedded sandstone is interpreted to be deposited in fluvial to tidally influenced fluvial environment

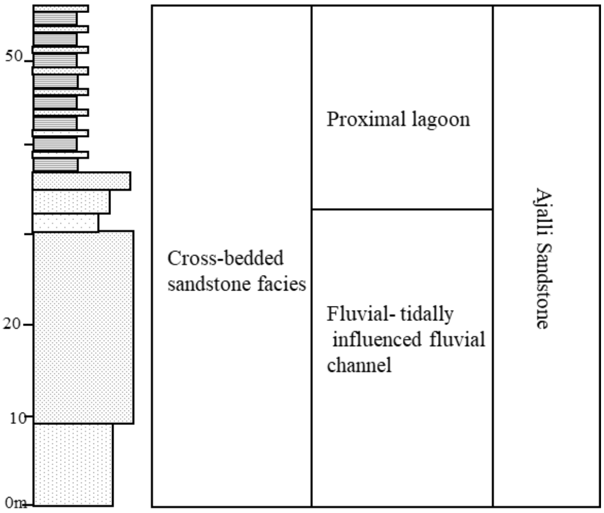

Fig. 2. Stratigrahic profile of the Efe river section

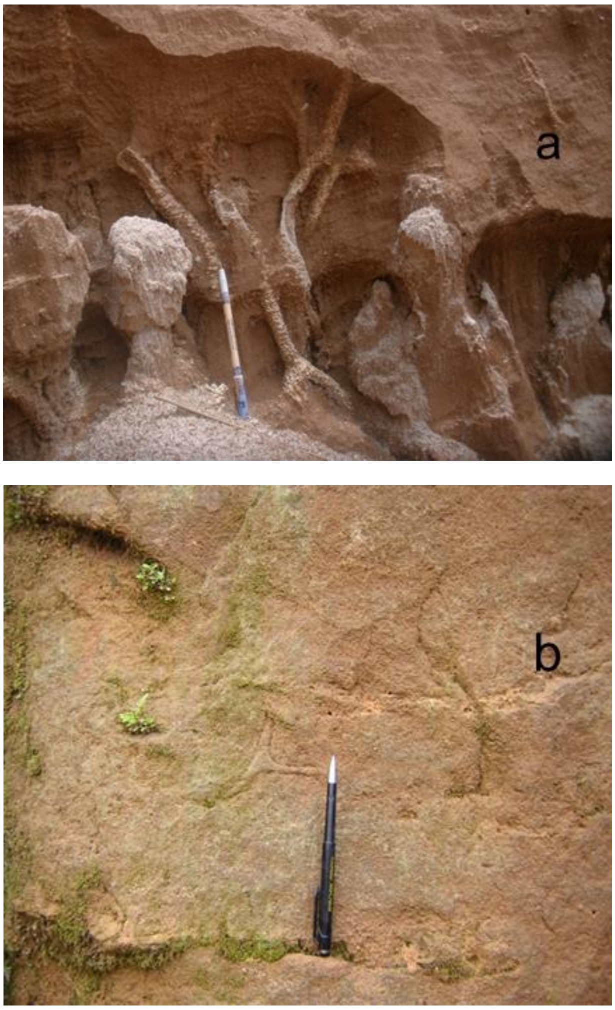

Fig. 3. (a) Robust *Ophiomorpha* structures and (b) *Thalassinoides* ichnogenera from the cross-bedded sandstone facies

Interbedded heterolith and shale facies association (Figure 4) overlies the cross-bedded sandstone facies. The constituent lithofacies include cross-bedded sandstone, gypsiferous clay-

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ISSN (Online): 2455-9024

shale, heterolithic facies, and fossiliferous blue/black shale and limestone facies.

The cross bedded sandstone are fine-medium grained, and have a variety of current-generated sedimentary structures, including low-angle cross beds, herringbone cross-stratification, flaser bedding and climbing ripples.

The clay-shales are gypsiferous and interbedded with thin lenses of very fine grained, lenticular-bedded sandstones, which contain fragile shells of inoceramids, ferruginized concretions, and disseminated plant matter.

Heterolithic facies comprises of regular alternations of thick or thin fine grained sandstone, siltstone and shale layers. The muddy intervals are strongly bioturbated, horizontally bedded, wavy laminated, and contain abundant *Skolithos* trace fossils. *Diplocraterion*, *Planolites*, and *Thalassinoides*, which are common trace fossils of the *Skolithos* and *Cruziana* ichnofacies (Pemberton et al., 1992), are present.

The upper part of the facies association consists of interbedded fossiliferous bluish-grey/black carbonaceous shale and thin bands of sharp-based limestone. The bluish – grey/black shale exhibits paper-thin fissility. Limestone occurs both as nodules and primary thin bands composed largely of abundant casts, molds and whole shells of articulate and disarticulate bivalves and gastropods.

Interpretation: The basal part of the interbedded heterolith and shale facies is interpreted as estuarine/lagoonal deposit based on the models of Allen (1993) and Allen and Posamentier (1993). The gypsiferous and sandy lenticular clays are interpreted as freshwater to brackish water, low-energy swamp to lagoonal or tidal flat deposits. Brackish water conditions are reflected by the presence of the *Skolithos* and *Glossifungites* ichnofacies (Kamola, 1984). The co-existence of disseminated plant material and inoceramids is reflective of both terrestrial and open marine sources for the sediments. Alternating thin units of sandstones and mudstones indicate rhythmic sedimentation (Boersma and Terwindt, 1981). The fact that these units are associated with wave ripple lamination, lenticular bedding and flaser bedding, suggests that there were frequent fluctuations in current strength. Such conditions are common in subtidal and intertidal settings (Prothero and Schwab, 1996).

The upper part of the facies reflects progressive deepening from proximal to distal lagoon/offshore environment.

Wave-rippled laminated sandstone facies association is well exposed at the Agbobu-Umuawa road junction and along the Okigwe-Umuna road (Figure 5). At the Agbobu- Umuawa road junction, it is made of thickly bedded, rippled bedded unit, channelized sandstone with 15cm-30cm thick sandy and white-gray clays (Figure 5; A). The channelized sandstone contains planar and trough crossbeds, mud clasts, flasers and lenticular bedding. The thickness of this unit is about 60m.

The upper interval is exposed at the Okigwe-Umuna road outcrop (Figure 5; B). This unit is made up of basal wave ripple laminated, clean, well sorted sandstone that coarsens upwards and contains mud flasers and pebbles oriented along forest planes of planar cross beds.

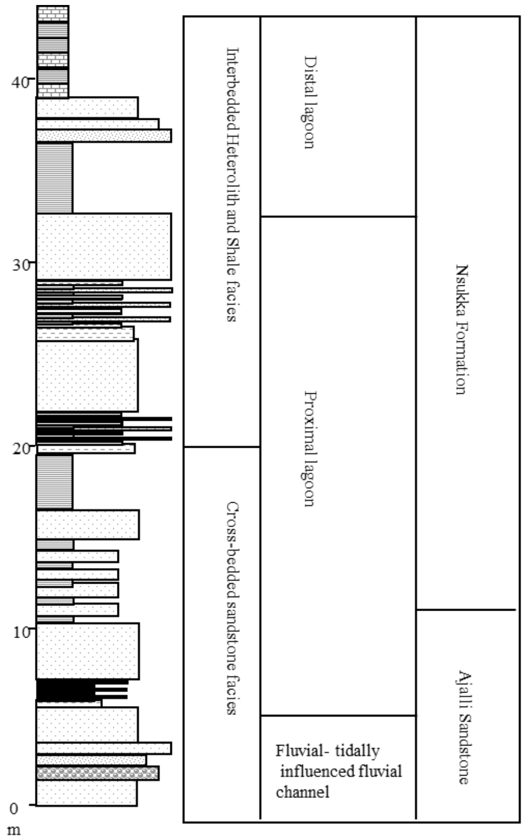

Fig. 4. Stratigraphic profile of the Ihube section

Interpretation: This facies association is interpreted to be deposited in a fluvial channel. Fluvial channel facies are identified by fining-upward textures and unidirectional paleocurrent pattern. Floodplain and overbank facies are represented by the light-colored mudstone and fine-grained sandstone units associated with the channel facies. The presence of *Ophiomorpha*, *Skolithos*, and *Arenicolites* indicates sandy high-energy setting (Pemberton et al., 1992).

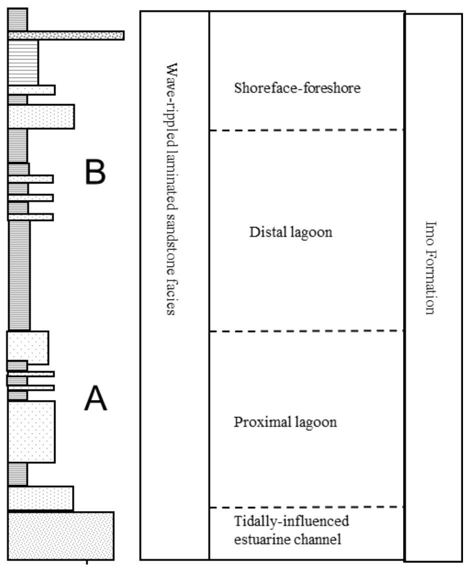

Fig. 5. Composite stratigraphic profile of the Outcrop at Agbobu-Umuna Junction

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Herringbone cross-bedding, reactivation surfaces, and mud drapes probably relate to ebb-flood tidal cycles (Yang and Nio, 1985; Leckie and Singh, 1991; Shanley et al., 1992).
The coarsening upward sandstone at the lower part of this unit suggests that this channel was cut into a pre-existing shoreface - foreshore environments.

Heterolithic shale and siltstone facies (Figure 6) underlies the eastern edge of the study area. The unit was encountered and described along the Iyikpa stream channel and along the Okigwe-Umuna road. It is largely represented by bluish-gray/black fissile shale, that contains thin lenses of limestone and thin bands of sharp-based hummocky cross-stratified sandstones to wave ripple laminated micaceous siltstones. The limestone contains a wide variety of marine fauna including bivalves, molluscs, nautiloids, protozoans and fish teeth (Arua, 1986, Oboh-Ikuenobe et al, 2005).
Interpretation: This facies association reflects shallow shelf deposition. The facies suggest suspension sedimentation of siliciclastic and carbonate grains on an oxygen-deficient sea bottom. Evidence of anoxic conditions is provided by good preservation of original lamination, and abundant nektonic and planktonic fossils. Interbedded hummocky cross-stratified sandstones are typical of shallow shelf sedimentation (Walker, 1984; Walker and Plint, 1992) and indicate sudden short-term change from low- to high-energy conditions often associated with spasmodic storm events (Brenner and Davis, 1973; Walker and Plint, 1992; Cheel and Leckie, 1993).

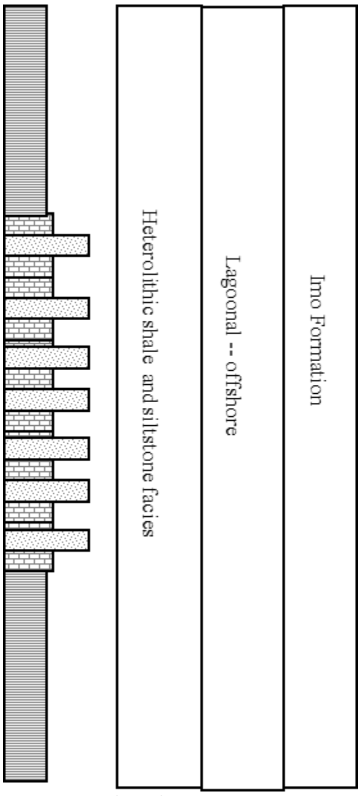

Fig. 6. Stratigraphic profile of the Okigwe-Umuna Road section

V. CORRELATION

To demonstrate lithofacies equivalencies and differentiation in the study area, and to establish their positions within the stratigraphic framework of Anambra Basin; the rocks of the study area was grouped into four facies association.

Based on stratigraphic relationships and similarity of gross sedimentary characteristics, the facies associations described were correlated with formations in the Anambra Basin (Table 1).

TABLE 1. Correlation between facies associations of the study area and stratigraphic Formation of Anambra Basin

Facies Association	**Stratigraphic Formations of Anambra Basin (Nwajide and Reijers, 1996)**
Heterolithic shale and siltstone facies	Imo Formation
Wave-rippled laminated sandstone	Imo Formation
Interbedded heterolith and shale facies	Nsukka Formation
Cross-bedded sandstone facies	Ajalli Sandstone

VI. ETHOLOGY

Ethology is the description of trace fossils based on the behavior or activity of the organism forming the trace. Seilacher (1964) classified behavioral patterns of trace fossils into six categories and they are; repichnia (locomotion traces), cubichnia (resting or nesting traces), pasichnia (grazing trails) and fodinichnia (deposit feeding burrows), domichnia (dwelling structures), and fugichnia (escape traces). Other behavioural traces in sediments are agrichnia (farming activities) and praedichnia (predation traces).

The trace fossil assemblage from the study area is categorized into two ethological groups; domichnia and fodinichnia (Table 2).

TABLE 2. Ethological Classification of trace fossils from the study area

Ethology	**Trace fossil**	**Remarks**
Domichnia	*Ophiomorpha, Skolithos, Diplocraterion Palaeophycus, and Arenicolites* (Seilacher 1964, Ekdale et. al., 1984)	Dwelling burrow of suspension feeders
Fodinichnia	*Thalassinoides* and *Planolites* (Seilacher 1964, Permberton and Frey, 1982)	Burrow structures that result from combined activities of deposit feeding and dwelling by endobenthic organisms

Cross bedded sandstone facies association is associated with both dwelling burrows (*Ophiomorpha*, *Skolithos, Paleophycus and Arenicolites*) and feeding burrows (*Thalassinoides* and *Planolites*). The heterolithic facies of the interbedded heterolith and shale facies association contains fodinichnia burrows (*Planolites*, and *Thalassinoides*) and a dwelling trace (*Diplocraterion*). The wave ripple laminated sandstone facies association is associated with dwelling burrows of suspension feeders (*Ophiomorpha*, *Skolithos*, and *Arenicolites*). No trace fossil was observed in heterolithic shale and siltstone facies association.

VII. SYSTEMATIC ICHNOLOGY

The trace fossils identified on the outcrops from the study area belong to seven ichnogenera; *Ophiomorpha*, *Skolithos*,

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Thalassinoides, Paleophycus, *Arenicolites*, *Diplocraterion* and P*lanolites*. The ichnogenera belong to two ichnofacies namely *Skolithos* representing the tidal zone (*Ophiomorpha, Diplocraterion and Skolithos;* Ekdale et. al., 1984, Frey et. al, 1990 and Pemberton, 1992) and *Cruziana* common in the subtidal zone (*Thalassinoides, Palaeophycus, Arenicolites* and *planolites;* Ekdale et. al., 1984; Frey et. al, 1990, and Pemberton, 1992).

The systematic description of the ichnofossil taxa is given below:

Ichnogenus *Ophiomorpha* Lundgren, 1891
Ophiomorpha nodosa Figure 7 (1)
Description: *Ophiomorpha nodosa* occur mainly as horizontal cylindrical burrows with pelleted wall. They are rarely up to 2.5cm in diameter.
Remarks: *Ophiomorha nodosa* and *Thalassinoides* generally indicate moderate to high energy conditions. Its environmental setting ranges from marine environment to shoreface and brackish water environment.

Ichnogenus *Diplocraterion* Torell, 1870
Diplocraterion isp Figure 7 (2)
Description: *Diplocraterion* is a vertical, U-shaped, single-spreite burrow of a suspension-feeding animal.
Remarks: It is found in intertidal and shallow subtidal environments and in deep-water environments like fans and distal shelves

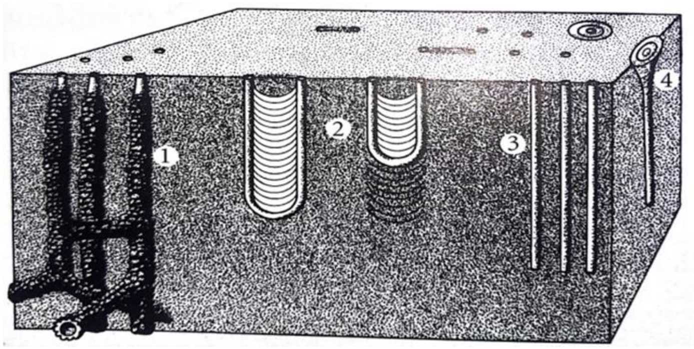

Fig. 7. Pictorial view of the Skolithos ichnofacies showing trace fossil ; (1) *Ophiomorpha*, (2) *Diplocraterion* and (3) *Skolithos* (Ekdale et. al., 1984; Frey et. al., 1990).

Ichnogenus *Skolithos linearis,* Haldeman 1840
Skolithos isp Figure 7(3)
Description: *Skolithos* traces are vertical cylindrical burrow produced by organisms that thrive most in high energy shallow marine environment.
Remarks: The Skolithos ichnofacies is characteristic of slightly muddy to clean, well-sorted sand in the littoral zone typical of beach foreshore and shoreface environments. They may also be found in estuarine fluvial systems, tidal deltas, and deep sea fans with shifting media.

Ichnogenus *Thalassinoides* Ehrenbergy, 1944
Thalassinoides isp Figure 8(1)
Description: *Thalassinoides* are 3-D cylindrical burrows with branches interconnected by vertical shafts. They are made by crustaceans during deposit feeding and dwelling.
Remarks: They thrive in shallow marine and deep marine turbidite system.

Ichnogenus *Paleophycus* Hall, 1847
Paleophycus isp
Description: *Palaeophycus isp* is a long, horizontal, smooth-walled, unornamented sub-cylindrical to cylindrical burrow that occurs along the bedding planes of the host rock. The burrow which is generally composed of the same lithology as the host rock (Lima and Netto, 2012) varies in diameter from 0.1 cm to 0.5cm.
Remarks: Their environmental setting ranges from continental to lower shoreface and offshore transition zone sediments (MacEachern and Pemberton 1992).

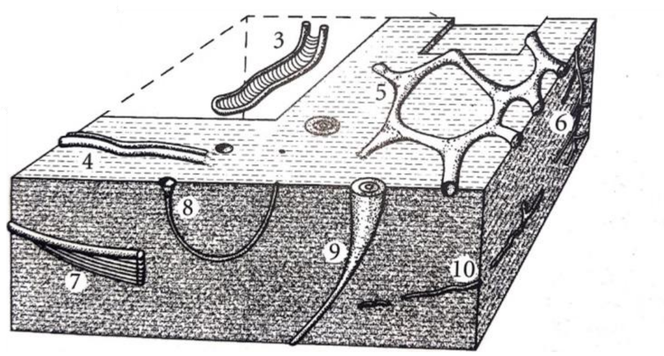

Fig. 8. Pictorial view of the Cruziana ichnofacies showing trace fossil; *Thalassinoides*, (2) *Arenicolites* (7) *Planolites* (Ekdale et. al., 1984; Frey et. al., 1990).

Ichnogenus *Arenicolities* Salter, 1857
Arenicolities isp Figure 8(2)
Description: *Arenicolities* are u-shaped dwelling traces without spreiten that are produced by suspension-feeding worms or by deposit-feeding worms. The tubes are cylindrical, smooth-walled and oriented perpendicular/inclined to the bedding lane (Diez-Canseco et al., 2016).
Remarks: This ichnotaxa is reported from environmental setting ranging from eolian, marine, freshwater lacustrine and fluvial.

Ichnogenus *Planolites* Nicholson, 1873
Planolites isp, Figure 8(3)
Description: Relatively large, unlined, smooth-walled, horizontal to undulant, straight to sinuous cylindrical in-filled feeding structure produced by deposit-feeding vermiform organisms.
Remark: They are found in continental to shallow marine and deep marine deposits

VIII. Conclusion

Sedimentological, stratigraphic analysis and ichnological analysis reveal that the K-T sediments in the Okigwe-Agbobu area, Anambra Basin Southeastern Nigeria can be differentiated into four facies association namely, cross-bedded sandstone facies, interbedded heterolith and shale facies, wave-rippled laminated sandstone facies, and heterolithic shale and siltstone facies. These facies associations represent deposition in a variety of shallow marine environments from open marine (offshore) to shoreface water depths.

The trace fossil assemblage from the study area belongs to two ichnofacies, *Skolithos* and *Cruziana*. This study has thus revealed that the paleodepositional environment of the K-T transition in the study area ranges from fluvial through lagoonal setting to shoreface-foreshore environments.

ACKNOWLEDGMENT

Special thanks to an anonymous reviewer for fruitful discussions that improved the study.

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