TRACE FOSSILS AND LITHOFACIES ANALYSIS OF CRETACEOUS-TERTIARY TRANSITION IN THE OJI RIVER-AWKA AREA, SOUTHEASTERN NIGERIA

Shirley Onyinye Odunze-Akasiugwu

Department of Geology, Chukwuemeka Odumegwu Ojukwu University

IJASR 2021
VOLUME 4
ISSUE 6 NOVEMBER – DECEMBER **ISSN: 2581-7876**

Abstract: Detailed down-dip, bed-by-bed sedimentary logging of outcrops of the Cretaceous-Tertiary (K-T) transition in the Oji River-Awka area of southeastern Nigeria, was carried out to identify the stratigraphic components, the ichnological aspects and to integrate the lithofacies and ichnological characteristics to decipher the paleoenvironmental interpretation. Facies analysis reveals six lithofacies association, namely; Lower sandstone unit, lower mudrock unit, middle sandstone unit, middle mudrock unit, upper sandstone unit and upper mudrock unit. The sandstone components of the facies association are deposited in tidally influenced fluvial channel while the mudrock units represent sedimentation in proximal lagoon and offshore settings. The trace fossils encountered in the study area belong to three ethological categories: (i) domichnia (ii) Fugichnia and (iii) Fodichnia. Five ichnogenera identified belong to Cruziana and Skolithos ichnofacies, namely; *Ophiomorpha, skolithos, rhizocorallium, diplocraterion, teichichnus and thalassinoides.* The gross sedimentary characteristics, facies relations of the facies association and the trace fossil assemblage reflect deposition in shallow marine environments.

Keywords: Createcous-Tertiary transition, lithofacies, ichnology and ichnofacies

1. 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. A detailed outcrop study of rocks of the K-T transition (Late Maastrichtian-Palaeocene) in the Anambra basin will provide basis for environmental interpretation, knowledge of which is crucial for modeling of reservoirs within the basin fill. The basin has potentials to increase the country's hydrocarbon reserves. To contribute to the on-going re-evaluation of the origin, evolution and hydrocarbon potential of the Palaeogene succession in the Anambra Basin, this study aims at presenting a depositional model for rocks of the K-T transition in the Oji River-Awka area of Anambra Basin. Detailed mapping and systematic sampling of outcrops was carried out to establish lithofacies and biogenic characteristics used to reconstruct the depositional environment.

2. Study Area and Stratigraphic Setting

The study area is located on the gentle dip slope of the Enugu cuesta. It extends for about 35km from Oji, along the Enugu-Onitsha expressway, passing through Ugwuoba and Amansea, to Ifite Awka. The area stretches northward and southward to include Akukwa and Ishiagu environs respectively (Fig.1), to cover an approximate area of 160 square kilometers. It is bounded by longitudes 7°04'E - 7°17'E and latitudes 6°10'N - 6°17'N.

The study area is within the Anambra basin of the south-eastern Nigeria (Fig. 2). The basin occupies the south-western flank of the Benue trough, a NE-SW trending megastructure that is made up of other pull-apart basins. The stratigraphic evolution of the Anambra basin during the Campanian-Eocene period was controlled by episodic asymmetrical subsidence along the landward extension of the Atlantic Chain fracture associated with the initial opening of the Benue Trough (Ojoh, 1992; Obi, *et al.,* 2001 and Obi and Okogbue, 2004). The subsidence was in response to sediment load and post-Benue rift thermal contraction of the lithosphere (Popoff, 1990; Binks and Fairhead, 1992).

The K-T transition begins with the Nsukka Formation (Maastrichtian-Paleocene) composed of fluvio-deltaic sandstone, mudstone and thin limestone bands (Obi, 2000). The Nsukka

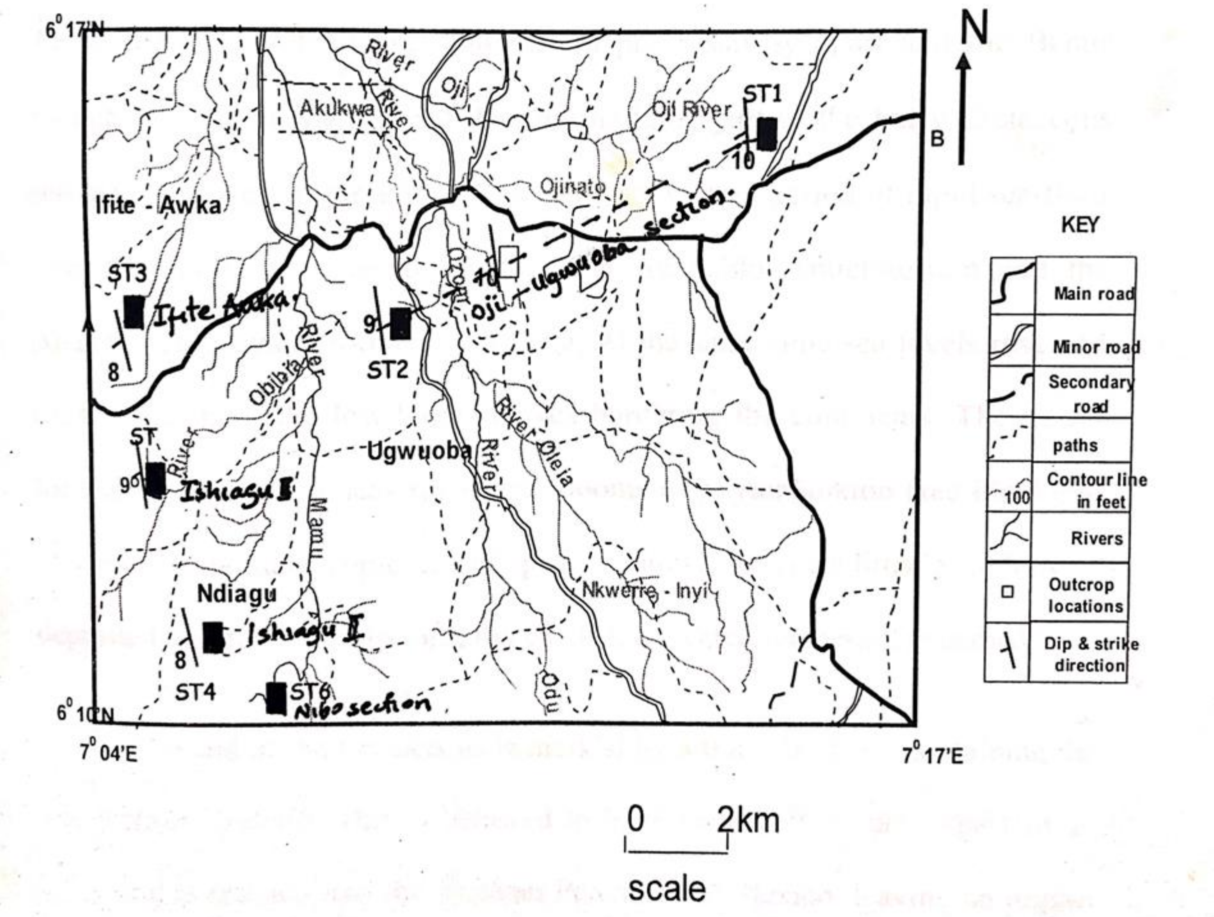

Fig. 1 Map of the study area showing the location and accessibility of the key outcrops

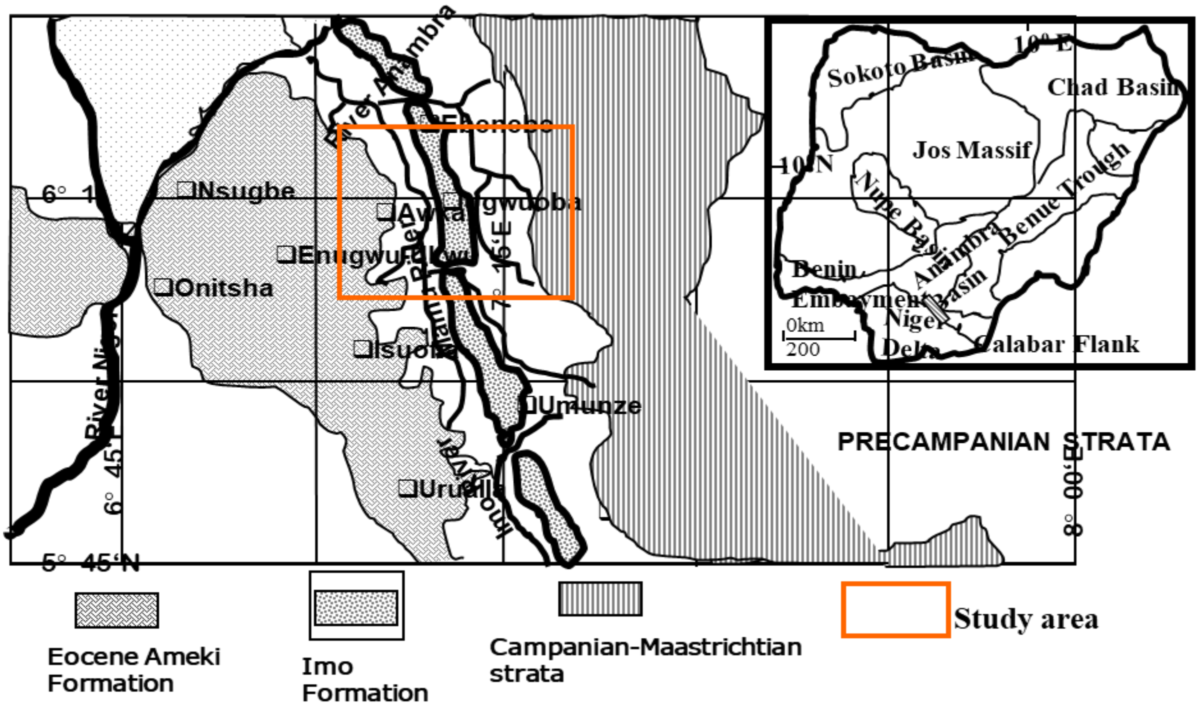

Fig. 2. Geological map of the Anambra basin showing the study area.

Formation is succeeded by the Imo Formation (Paleocene) consisting of blue-grey clays, shallow marine shale, limestone and calcareous sandstone.

The Ameki Formation directly overlies the Imo formation and is composed of rapidly alternating shale, sandy shale, mudstone, clayey sandstone (Adegoke et al., 1980; Arua, 1980; Anyanwu and Arua, 1990) and fine-grained fossiliferous sandstone with thin limestone bands (Reyment, 1965; Arua, 1986). The last Paleogene succession comprises of the Ogwashi-Asaba Formation (Eocene-Oligocene). Alternation of coarse-grained sandstone, lignite seams, and light colored clays of continental origin dominated this formation (Kogbe, 1976; Jan du chene et. al, 1978; Nwajide, 1979; Arua, 1986).

3. Methodology

Five lithologic sections were logged in detail and sampled for further analysis in the laboratory. Detailed descriptions of the sections were carried out to obtain sedimentary characteristics and ichnology data which aided interpretation of depositional environments. The trace fossils present were systematically described and their distribution recorded.

4. Result and Interpretation

4.1. Lithofacies Association

Six lithofacies association were delineated in the study area. They include:

Lower sandstone facies (Ls; Fig.3): This unit has an estimated thickness of about 195m and is well exposed at Oji. At the base, it is wave rippled; cross laminated and has trough and planar cross beds. This unit passes upward into poorly sorted conglomerate and then into channelized sandstone of about 15m-35m thick. The base of each unit is sharp and they are commonly associated with scattered extraformational clasts of various sizes. The unit contains *ophiomorpha* burrows belonging to *cruziana ichnofacies* and reactivation surfaces.

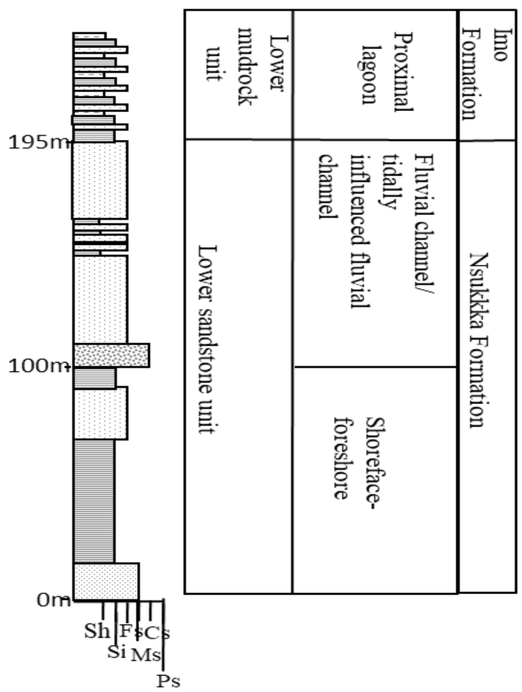

Fig. 3. Sedimentological log of Oji outcrop showing recognized lithofacies

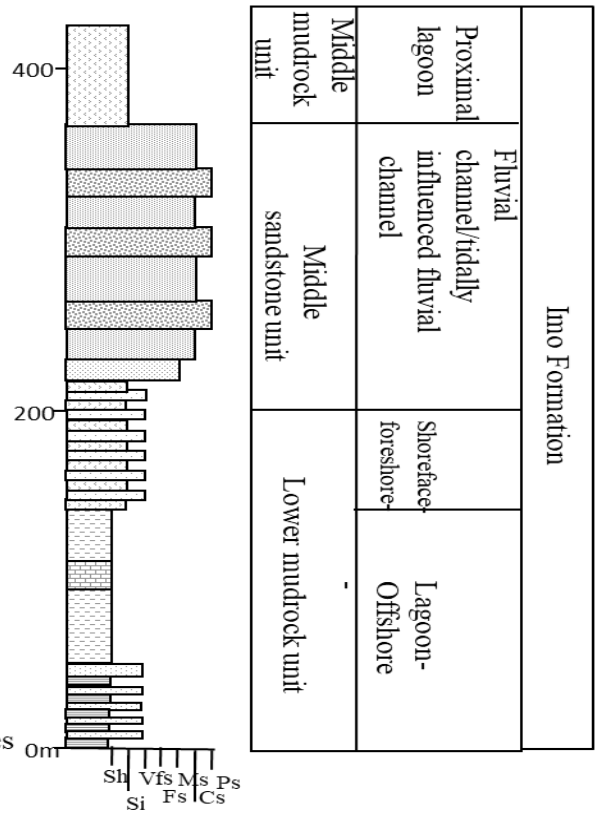

Fig. 4. Sedimentological log of Oji-Ugwuoba outcrop showing recognized lithofacies

Lower mudrock facies (*Lm; Fig. 4):* This lithofacies association was observed at Oji-Ugwuoba area along the Enugu-Onitsha express way. The unit begins with clay-shale interbedded with thin lenses of very fine grained, wavy or lenticular-bedded sandstones. It passes upward into bluish-grey/black carbonaceous shale interbedded with thin bands of sharp-based limestone. The sandstone/siltstone intervals are wave ripple laminated, micaceous and contain fragile shells of inoceramids, ferruginized concretions and disseminated plant matter, as well as *teichichnus. Ophiomorha, rhizocorallium and Diplocraterion.* The bluish-grey/black shale exhibit 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. The upper part of this facies is characterized by sharp-based low angle, cross laminated siltstones and wave rippled very fine-grained sandstone.

Interpretation: The lower mudrock unit is interpreted to document a transgressive event. The interbedding of fine-grained sandstone and clay-shale at the basal part of the section and the fact that they have wave-ripple lamination and lenticular bedding, are evidence that there were frequent fluctuations in current strength. According to Prothero and Schwab (1996), such conditions are common in intertidal and subtidal settings. The co-existence of disseminated plant material and inoceramid shells is reflective of both terrestrial and open marine sources of the sediments. The presence of trace fossils of the *Skoloithos* and *Cruziana* ichnofacies (*Teichichnus, Ophiomorpha, Rhizocorallium* and *Dipolocraterion)* are indicative of low to high wave/current energy typical of estuarine/proximal lagoon environment.

The overlying black fissile carbonaceous shale containing limestone lenses indicates progressive deepening of the environment. The typical black color of the shale is possibly due to high content of organic material. Mode (1991) stated that such accumulation of organic matter is possible in a reducing environment. The presence of fossiliferous limestone composed of casts, moulds and whole shells of bivalves and gastropods indicates a well-lighted, shallow marine environment (offshore) having normal salinity and oxygen content. Nwajide (1996) attributed the occurrence of fossiliferous limestone to maximum deepening of the marine.

Sharp-based low angle, cross laminated siltstone and wave-rippled very fine-grained sandstone which cap the mud rock unit is interpreted to reflect shallow shoreface sedimentation along storm dominated coastlines (Walker and Plint, 1992). The sedimentation pattern is indicative of sudden short term change from low to high energy conditions associated with spasmodic storm events (Brenner and Davis, 1973; Cheel and Leckie, 1993). The general upward increase in sand content is indicative of sea shallowing and effective progradation.

Middle sandstone facies (Ms; Fig. 4): This unit has an estimated thickness of about 195 meters and is well exposed at Ugwuoba. At the base, it is wave rippled; cross laminated and contains trough and planar cross beds. This unit passes upward into poorly sorted conglomerate and then into channelized sandstone unit of 15m-35m thick. The base of each unit is sharp and they are commonly associated with scattered extraformational clasts of various sizes. It contains profuse *Ophiomorpha* structure, large scale planar and trough cross bedding and reactivation surfaces.
Interpretation: This unit is interpreted as a high energy active channel deposit based on texture ad sedimentary structure. Cross bedding is attributed to wave induced unidirectional 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 and finally the presence of extraformational clast indicates fluvial environment but their scattered nature indicates some influence of tide or wave. Thus, this channelized unidirectional cross-bedded sandstone is interpreted as a wave to tidal influence fluvial deposits.

Middle mudrock facies (Mm, Fig. 5): This unit has an estimated thickness of about 108m. The unit was described at Unizik permanent site and at Ishiagu. It begins with bioturbated/mottled mudstone containing interbeds of wave rippled laminated sandstone/siltstone. This basal interval gives way upward to black, fissile shales interbedded with limestone. The upper part of the unit consists of a heterolithic unit of fine to medium grained sandstone intercalating with clay and characterized by *Thalassinoides.*

Interpretation: Based on the gross sedimentary structures and lithological characteristics, the middle mudrock unit is interpreted as reflecting largely lagoon-offshore depositional system.

Upper sandstone facies (Us, Fig. 5): The upper sandstone unit is well exposed at the

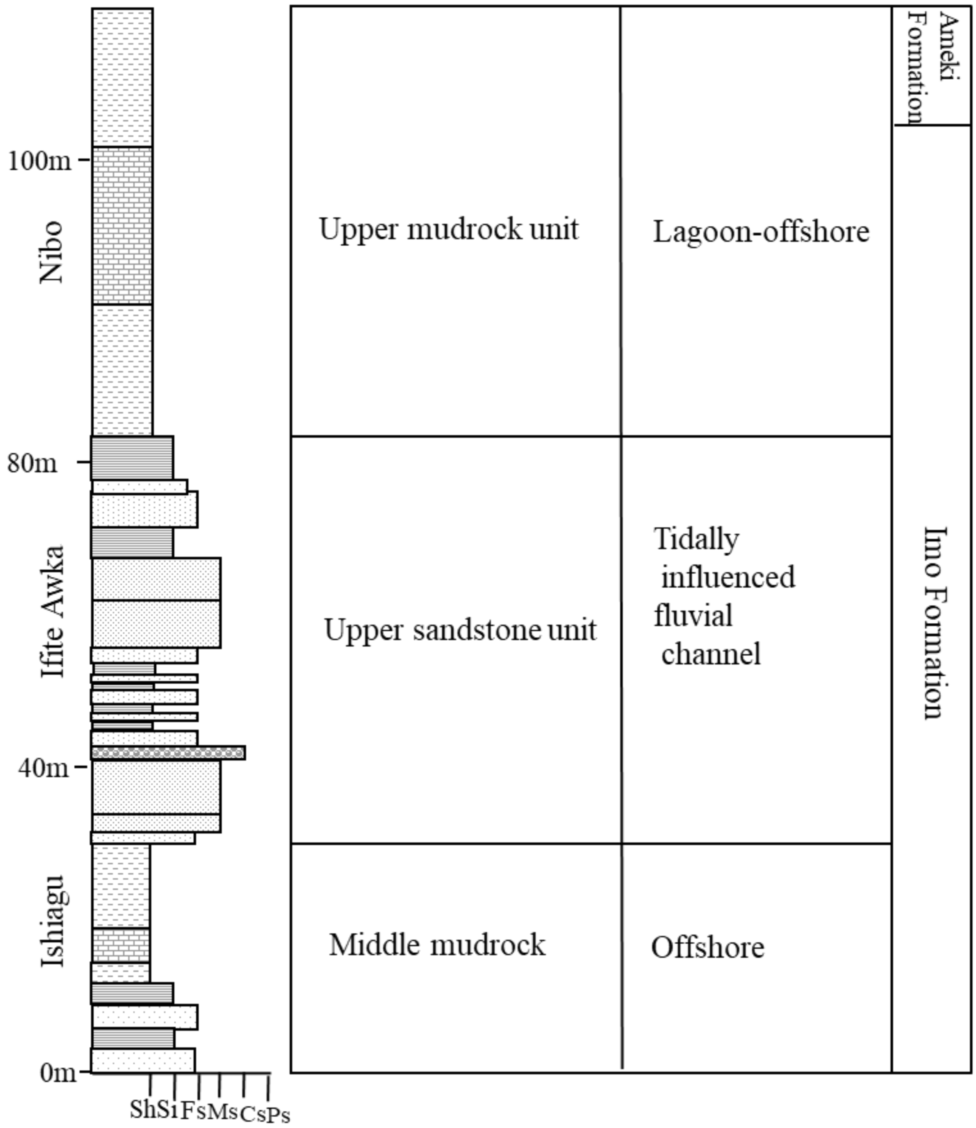

Fig. 5. Composite sedimentological logs of Ishiagu-Ifite Awka-Nibo outcrops showing recognized lithofacies

Ifite-Awka sandstone quarry and at Ishaigu. It is composed of a basal wave ripple laminated, poorly sorted and profusely cross-bedded sandstone that contains pebbles randomly oriented along forest planes of planar cross beds. It grades upward into clean well sorted sandstone.

The top of the unit is characterized by thickly bedded, channelized sandstone with 15cm-30cm thick sandy white-grey clays. It contains planar and trough cross-beds, mud flasers, mud clasts, lenticular bedding (Fig. 6a) and *ophiomorba* burrow (Fig. 6b). U-tube burrows were also identified in the Ifite-Awka section (Fig. 7). The thickness of this unit is about 60m.

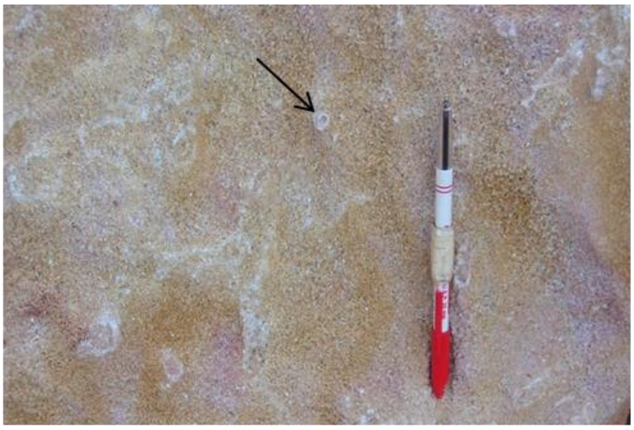 

Fig.6 (a) Ophiomorpha burrows at Ifite-Awka outcrop and (b) lenticular bedding at Ishiagu composite exposure

Fig. 7 U-tube burrows at the Ifite-Awka outcrop

Interpretation: The top section of this unit is interpreted to be a channel with flood plain sediments. The profuse cross-bedding is indicative of active unidirectional currents typical in fluvial environments. The coarsening upward setting of this sandstone at the lower part of this unit is typical of fluvial environment and rapid shallowing of the sea. The well sorting and clean nature of the upward fining sandstone is typical of foreshore/beach environments. *Ophiomorpha* is indicative of high energy regimes. The presence of wave ripples, poor sorting, dirty and random orientation of pebbles could be related to the spasmodic storm events in wave dominated environments. Thus the environmental interpretation of this unit is wave-tidally influenced fluvial environment.

Upper mudrock facies (Um): Its thickness is about 70m and is represented by a succession of siltstone, clay-shale and black fissile shale with fossiliferous bands of limestone exposed at Nibo. The clay is mottled and the siltstone has bivalve impression and contains the *Skolithos* ichnofacies.

Interpretation: This unit has same sedimentological and lithological characteristics as the lower mudrock unit. Thus it is interpreted to be of shallow marine origin, moving from lagoon to offshore settings.

5. Ichnology

The ichnofossils documented from the study area include *Ophiomorpha isp,teichichnus isp, Diplocraterion isp, Rhizocorrallum isp, and Thalassinoides isp*. The ichnogenera can be assigned to three ethological categories (Table 1) and two ichnofacies (cruziana and skolithos) respectively.

Table 1. Ethological classification of traces fossils from the study area

Ethology	Trace fossil	Remarks
Domichnia	*Ophiomorpha, skolithos, and rhizocorallium* (Seilacher 1964, Ekdale et. al., 1984)	Dwelling trace usually indicate filter-feeding in well-aerated environments
Fugichnia	*Diplocraterion* (Ekdale et. al.,1984)	Fugichnia are found in cases of rapid

		sedimentation, in beach, storm-bed and turbidite sediments
Fodinichnia	*Teichichnus* and *thalassinoides* (Seilacher 1964, Permberton and Frey, 1982)	They are feeding burrows

5.1 Ethology Classification

Fodinichnia refers to mining structures resulting from the combined activities of dwelling and feeding in sediments. It is constructed by some endobenthic deposit feeders living in the burrows; through the systematic mining of sediments for food.

Domichnia are living burrows and borings constructed by sessile crustacean burrows and semi-sessile marine animals particularly suspension feeders. Dwelling trace usually indicate filter-feeding in well-aerated environments.

Fugichnia are traces that specifically reflect escape behavior. They are structures produced by the upward movement of animals (worms, bivalves or starfish) seeking to escape from beneath a layer of sediment that has been dumped suddenly on top of them (e.g. during storm or turbidity current deposition).

5.2 Ichnofacies

The two ichnofacies identified from the outcrops in the study area include:

- *Cruziana* ichnofacies : *Teichichnus, thalassinoides* and *rhizocorallum* (Ekdale et. al., 1984; Frey et. al, 1990 , Pemberton, 1992)
- *Skolithos* ichnofacies: *Ophiomorpha and diplocraterion* (Ekdale et. al., 1984; Frey et. al, 1990 , Pemberton, 1992)

5.3 *Occurrence*: *Ophiomorpha* occurred in the Lower sandstone unit, lower mudrock unit, middle sandstone unit and upper sandstone unit lithofacies respectively. *Diplocraterion isp* occurred in the lower mudrock unit lithofacies. The lower and middle mudrock unit lithofacies document the assemblage that include; *teichichnus isp, rhizocorallium isp*; and *thalassinoides isp* respectively.

5.4 Systematic Paleontology

Ichnogenus *Rhizocorallium Zenker, 1836*
Rhizocorallium isp

Fig. 8 (3)
Description: This trace fossil is a long, 1cm thick, u-shaped burrows with sinuous, bifurcating or planispiral spreite. They are usually parallel-oblique to bedding. They are dwelling and feeding burrow of a suspension feeder.
Discussion: They are found in shallow to deep marine settings.

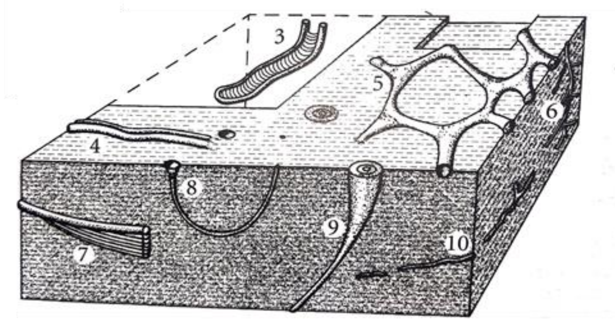

Fig. 8. Pictorial view of the *Cruziana* ichnofacies showing trace fossil ; (3) *Rhizocorallium* ,(5) *Thalassinoides* and (7) *Teichichnus (Benton and Harper, 1997).*

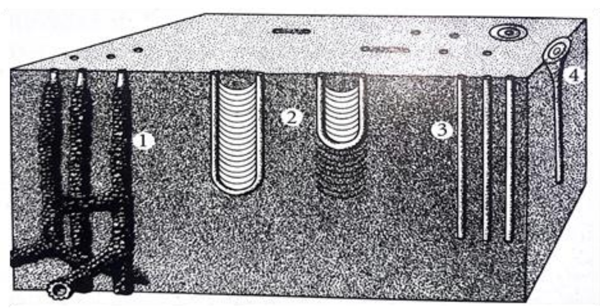

Fig. 9. Pictorial view of the *Skolithos* ichnofacies showing trace fossil ; (1) *Ophiomorpha* , (2) *Diplocraterion* and (3) *skolithos (Benton and Harper, 1997).*

Ichnogenus *Thalassinoides suevicus* Rieth, 1932
Thalassinoides isp

Fig. 8 (5)
Description: These burrows are mainly horizontal branching systems and preserved at sedimentary interfaces as convex hyporelief. The burrows are large and characterized by an irregular width that can exceed 110 mm, and their length can reach more than 1 m bending occasionally (Carvalho, 2016). The burrows are Y shaped and frequently have swellings in divergence areas (i.e., turning chambers).

Discussion: These thrive in intertidal situation (mid and distal continental shelf environment) that may be much affected by storm activity.
Ichnogenus *Teichichnus* Seilacher, 1955
Teichichnus isp

Fig. 8 (7)
Description: *Teichichnus* consists of irregularly arranged spreiten structures resembling troughs filled up in a vertical plane, preserved in full reliefs. The preserved parts of the troughs are 1–7 cm long and 4 mm wide. In vertical plane, all traces probably show a shape of a very broad "U" letter.
Discussion: *Teichichnus* burrows occur in lower marine shoreface, intertidal settings, lagoons and brackish water settings like marine estuaries.

Ichnogenus *Ophiomorpha* Lundgren, 1891
Ophiomorpha isp

Fig. 9(1)
Description: *Ophiomorpha* burrows are vertical and horizontal burrows made by crustacean organisms. The internal walls of the burrows are smooth while the outer surfaces are lined with ovoid pellets.

Ichnogenus *Diplocraterion* Torell, 1870
Diplocraterion isp

Fig. 9 (2)
Description: *Diplocraterion* is a dwelling U-shaped burrow of a suspension feeder with spreite. The tube can be indicative of protrusive (downward movement) or retrusive (upward movement) burrowing relative to position of spreite.

Discussion: The *Skolithos* ichnofacies including *Ophiomorpha* and *diplocraterion* all typically indicate intertidal situations where sediment is removed and deposited sporadically, and the organisms have to be able to respond rapidly in stressful conditions.

6. Summary and Conclusion

Lithofacies analysis has been used in this study to interpret the depositional environments of various outcropping rock units within the study area. The six recognized lithofacies of the K-T strata from the study area represent sediment packages deposited in lagoon, fluvial channel, shoreface-foreshore and offshore environments. These reflect characteristics of sediment deposited during transgressive and regressive events, which span from coastal to shelfal environments.

The trace fossil assemblage identified in the study area belongs to the shallow water ichnofacies (*Cruziana* and *Skolithos*) comprising of *Teichichnus, thalassinoides, rhizocorallum; and Ophiomorpha and diplocraterion* respectively. The lithologic characteristics, physical and biogenic sedimentary structures indicate that the paleodepositional environment of the K-T transition in the study area is a shallow marine setting.

Acknowledgements

Special thanks to anonymous reviewers for their insightful discussions and constructive criticism that improved this study.

References

1. Adegoke, O.S., Arua, I., and Oyegoke, O. (1980). Two new nautiloids from Imo Shale (Paleocene) and Ameki Formation (Middle Eocene), Anambra State, Nigeria. Journal of Mining and Geology, v. 17, p. 85-89.
2. Anyanwu, N.P.C. and Arua, I. (1990). Ichnofossils from the Imo Formation, and their paleoenvironmental significance. Journal of Mining and Geology, v. 26, p. 1-4.
3. Arua, I. (1980). Paleocene macrofossils from the Imo Shale in Anambra State. Journal of Mining and Geology, 17(1): 81-84.
4. Arua, I. (1986). Paleoenvironment of the Eocene deposits in the Afikpo syncline, southern Nigeria. Journal of African Earth Sciences, v. 5, No. 3, p. 279-284.
5. Benton, M.J. and Harper, D.A.T. (2009). Introduction to paleobiology and the fossil record. ISBN 978-1-4051-86469
6. Binks, R. M. and Fairhead, J. D. (1992). A plate tectonic setting for Mesozoic rifts of West and Central Africa. Tectonophysics. 213, 141- 151.
7. Brenner, R.L. and Davies, D.K. (1973). Storm-generated coquinoid sandstone: Genesis of high energy marine sediments from the upper Jurassic of Wyoming and Montana. Geological Society of American Bulletin, 84/5, 1685-1698.
8. Cheel, R. J. and Leckie, D. A., (1993). Hummocky cross-stratification In: Sedimentology Review volume 1 (edited by V. P. Wright) pp. 103-122. Blackwell Science Publication London.
9. Ekdale, A.A., Bromley, R.G. and Pemberton, S.G. 1984. *Ichnology*; *The use of trace fossils in sedimentology and stratigraphy*. Society of Economic Paleontologists and Mineralogists, Tulsa, Ok.
10. Frey, R.W., Pemberton, S.G. and Sanders, T.D.A. 1990. Ichnofacies and bathymetry: a passive relationship. *Journal of Paleontology* 64, 155-8.
11. Jan Du Chene, R., Onyike, M.S., and Sowumi, M.A. (1978). Some new Eocene pollen of the Ogwashi-A.saba Formation, Southeastern Nigeria. Rev. Esp. micropal. 10, pp. 285-322.
12. Kogbe, C.A. (1976). Paleogeographic history of Nigeria from Albian times. In: Geology of Nigeria (Edited by Kogbe, C.A.) Elizabethan Publication, Lagos. pp. 237-252.
13. Neto de Carvalho, C. (2016). The massive death of lobsters smothered within their Thalassinoides burrows: the example of the lower Barremian from Lusitanian Basin (Portugal). Comunicações Geológicas v. 1 Especial 1, p. 143-152.
14. Nwajide, C.S. (1979). A lithostratigraphic analysis of the Nanka Sands, southeastern Nigeria. Journal of Mining and Geology, Volume 16, pp.103-109.
15. Nwajide CS and Reijers TJA (1996). The Geology of the southern Anambra Basin, In: *Selected chapters in Geology, sedimentary geology and sequence stratigraphy of the Anambra Basin* edited by T.J.A. Reijers (SPDC publication) 133–148.
16. Obi, G.C. (2000). Depositional Model for the Campanian-Maastrichtian Anambra Basin, Southern Nigeria. Unpublished Ph.D. Thesis, University of Nigeria, Nsukka, 291 pp.
17. Obi G. C., and Okogbue, C. O. (2004). Sedimentary response to tectonism in the Campanian Maastrichtian succession, Anambra Basin, South-eastern Nigeria. Journal of African Earth Sciences, 38, 99- 108.
18. Obi G. C., Okogbue, C.O. and Nwajide, C.S. (2001). Evolution of the Enugu Cuesta: A tectonically driven erosional process. Global Journal Pure Applied Sciences, 7/2, pp 321-330.
19. Ojoh, K. A. (1992). The southern part of the Benue Trough, (Nigeria); Cretaceous stratigraphy, basin analysis, palaeoceanography and geodynamic evolution in theequatorial domain of the south Atlantic. NAPE Bulletin 7 / 2, 131-152.
20. Pemberton, S. G., and Frey, R. W. (1982). Trace Fossil Nomenclature and Planolites, Paleophycus Dilemma. Journal of Paleontology 56, pp.843-881.
21. Pemberton, S.G., (ed.) (1992). Applications of Ichnology to Petroleum Exploration: Society of Economic Paleontologists and Mineralogists Core Workshop 17, Society of Economic Paleontologists and Mineralogists, Tulsa, pp.429.

22. Popoff, M. (1990). Deformation Intracontinental Gondwanienne–Rifting Mesozoique En Afrique (Evolution Meso-Cenozoique Du Fosse De La Benue, Nigeria) -Relations ’ocean Atlantique Sud. These De Etat, University Aix-Marseillea III.
23. Prothero, D.R. and Schwab, F. (1996). Sedimentary Geology. New York, W.H. Freeman and Company, 575p.
24. Reyment RA (1965). *Aspects of the Geology of Nigeria*. University of Ibadan Press, Nigeria, 145.
25. Seilacher, A. 1964. Biogenic sedimentary structures. *In* Imbrie, J. and Newell, N. (eds) *Approaches to Paleoecology*. Wiley, New York, pp. 296-316.
26. Walker RG and Plint AG (1992). Wave & storm – dominated shallow marine systems. In: *Facies models: Response to Sea level change* edited by Walker, R.G. and James, N.P. (Geological Association of Canada) 219 – 238.

