Scientia Africana, Vol. 23 (No. 2), April, 2024. Pp 77-84
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

HYDROCARBON PRODUCTION POTENTIAL OF PARALIC RESERVOIRS FROM THE NIGER DELTA BASIN: EVIDENCE FROM ICHNOLOGICAL STUDIES

Efemena, O. O.,[1] and Ugwueze, C. U.[2]
[1]Department of Geological Sciences, Achievers University, Owo, Nigeria
[2]Department of Geology, University of Port Harcourt, Choba, Nigeria
Corresponding authors Email: onomeefe1@yahoo.com; charles.ugwueze@uniport.edu.ng

Received: 21-02-2024
Accepted: 12-03-2024

https://dx.doi.org/10.4314/sa.v23i2.8

Journal Homepage: http://www.scientia-african.uniportjournal.info
Publisher: *Faculty of Science, University of Port Harcourt.*

ABSTRACT

Reservoir ichnological study was employed to improve on the inconsistencies and poor interpretation of hydrocarbon-bearing strata within the multipartite maturing terrain of the onshore Niger Delta basin. Ichnofacies characterization revealed two distinctive trace fossil suites that both reflected different feeding behaviours and responses to substrate consistency, which assisted in the high-resolution assessment of facies constituting the paralic reservoirs. Fifteen potential reservoir intervals were subdivided into productive and non-productive as revealed on core slabs as well as well log signatures. Fluctuating river sediment influx has been considered to be detrimental to the colonization of the channel deposits and barrier bars, which resulted in excellent hydrocarbon reservoirs in the study area. The sandstone facies, characterized by sparse bioturbation and extensive bedding, displays imprints of Ophiomorpha, Thalassinoides, and Palaeophycus. The removal of these imprints has minimized subtle heterogeneities, resulting in more uniform reservoir characteristics. This uniformity has favored the accumulation of hydrocarbons within the point bars.Biogenicchurning of bedded sediment generated a poorer sorting index thereby reducing the reservoir quality at 9866-9840ft, 9154-9120ft, and 9090-9060ft depth intervals, which has been interpreted to represent poor reservoir potentials. However, it is advised that future investigations should focus on the forced regressive shoreface and delta front reservoirs of the studied interval for its internal continuity that may contain maximum production potential.

Keywords: Bioturbation; Paralic Reservoirs; Hydrocarbon; Ichnofacies; Niger Delta Basin

INTRODUCTION

The play in the onshore Niger Delta sedimentary basin (**Fig. 1a**) has been reported by workers to be well-developed and most prolific in terms of petroleum exploration and exploitation. From the Eocene to the Recent, the delta has prograded south-westward forming depositional belts that represent the most active portion of the delta at each stage of its development (Doust &Omatsola, 1990). Pemberton and Gingras (2005), noted that the three diachronous formations (Akata, Agbada, and Benin) in the Niger Delta were deposited in each of the five depositional belts shown in Fig. 1a. The depositional belts are 30–60km wide with the oldest northward while progradation is 250km south-westward over oceanic crust into the Gulf of Guinea. Nichols (2009) used wireline log correlations and several features from core studies to interpret some activities in the Greater Ughelli depositional belt. Avbovbo (1978) applied ichnological analysis while examining ichnofacies and reservoir properties of shoreline deposits in the Coastal Swamp depositional belt. Consequently, Droser and Bottjer (1986) and Ugwueze*et al*., (2019) integrated gamma-ray logs, described sedimentological cores showing sedimentary features, and used ichnological characteristics to define the depositional settings within the depositional belts.

The science of ichnology unfolded the different behavioral patterns of an organism that lived in a particular environment during a particular time interval. Therefore, trace fossil analysis in reservoir description has generated great interest among petroleum geoscientists. Recently, an increased importance has been attached to trace fossils in interpreting depositional environments because organisms of one sort or another inhabit the entire sedimentary environment on Earth. The rate of sedimentation, degree of oxygenation, and salinity levels control the degree and diversity of bioturbation which changes porosity and permeability trends in hydrocarbon-bearing strata thereby altering their quality assessment.

In the present paper, nine (9) core-runs of E-GU1 well, wireline logs of E-GU1 and A-GU2 from the Greater Ughelli depositional belt of the Niger Delta were examined using ichnology to assess the effect of bioturbation on reservoir quality of the shoreline sediments to achieve a full understanding of the potential reservoirs in this basin.

The Niger Delta's Geological Background

The Niger Delta Basin is an extensional rift basin positioned within the Niger Delta and the Gulf of Guinea on the passive continental margin adjacent to Nigeria's western coast, between longitude 5–8°E and latitudes 3–6°N (Michele *et al.,* 1999). It is surrounded by nine coastal states in the southern Nigerian including all six states in the South-South geopolitical zone: one state (Ondo), two states (Abia and Imo) in the South East geopolitical zone, and one state (South West).

The Niger Delta is one of the largest regressive sequences in the world, with a central thickness of approximately 12,000 m. According to Avbovbo (1978), Doust &Omatsola (1990) and Kulke (1995), the delta is separated into three diachronous formations that reflect prograding depositional facies that are primarily characterized by sand-shale ratios. The first is the Akata Formation, the oldest unit consisting primarily of prodelta shale with sporadic turbidite sands. The Akata Formation was created during lowstands (Ugwueze and Woken, 2023) that lasted from the Paleocene to the Holocene and involved the movement of clays and terrestrial organic matter to deep-water environments with low oxygen and energy levels (Stacher, 1995). According to Doust &Omatsola (1990), the structure could be up to 7,000 meters thick. It is the foundation of the entire delta and is frequently under pressure. The likely source is thick shale from the Akata Formation and shale from the Agbada Formation. The second is the paralitic Agbada Formation, consisting primarily of shelf deposits with alternating sand and shale. This is the delta's main petroleum-bearing unit. Its formation started in the Eocene and is still growing stronger. The youngest unit, the Benin Formation, is a continental uppermost Eocene to Recent deposit of alluvial and upper coastal plain sands that are up to 2,000m thick (Avbovbo, 1978). Shale and sandstone beds coexist in equal amounts in the lower portion, whereas the upper portion is mostly made up of sand with only minor shale inter-beds (Michele *et al.,* 1999). The Agbada Formation is Eocene in age. It is a marine facies that combines traits from freshwater and the deep sea. This facies dominates the basin in terms of oil and natural gas production. When this rock layer became subaerial and was surrounded by an organically rich marshy environment, the hydrocarbons in this layer developed. It has

Scientia Africana, Vol. 23 (No. 2), April, 2024. Pp 77-84
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

an estimated thickness of 3,700m (Tuttle *et al.*, 2015).

In the Niger Delta Basin, paralic reservoirs have a substantial economicimportant. With the presence of hydrocarbons and a complex and varied sedimentary architecture, the area has become a significant player in the world's oil and gas business.Despite the basin's complexity, it has considerable economic value because it is home to a very prolific petroleum system. Knowing where reservoir rocks are located and what makes them unique is essential for hydrocarbon exploration. Paralic reservoirs in the Niger Delta Basin include various types of reservoir rocks, such as sandstones and siltstones. Sandstones are particularly common due to their high porosity and permeability, which are essential properties for the storage and flow of hydrocarbons (Reijers, 2011).

Study Location

The study was carried out on two different oilfields located within the onshore Greater Ughelli depositional belt, Niger Delta basin. The distance between the two wells is approximately 133,023ft (436745m) (**Fig.1b**).

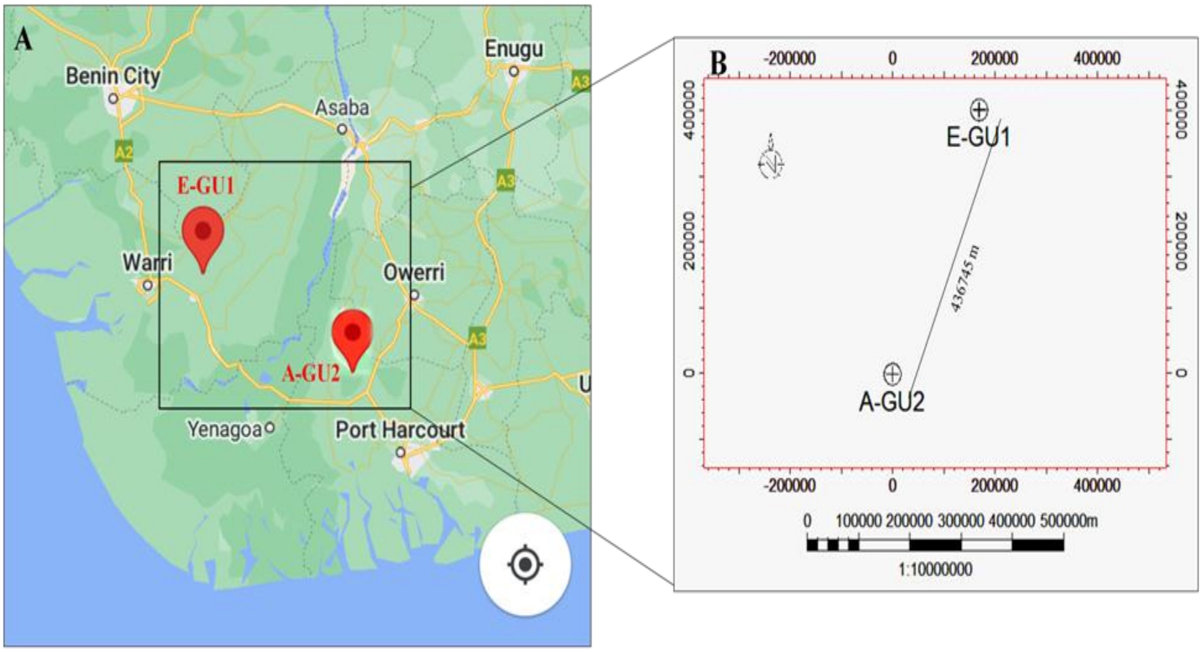

Figure 1. (a) Satellite Image of the Niger Delta, showing the studied wells, (b) Base Map of the studied fields, showing well positions in time and space

METHODOLOGY

A total of 738.50ft (223.78m) length core barrels containing 251 core slabs of 4.0cm in diameter and about 3ft (0.3m) long covering 6963-9866ft depth intervals were ichnologically studied. Digital core photographs were also critically examined (Efemena and Maju-Oyovwikowhe, 2022) to boost the visualization of ichnological features. Ichnofacies categorization was based on Seilacher's model modified by Michele *et al.*, (1999) and the degree of bioturbation (ichnofabric index) was based on a modified Egbu*et al.*, 2009. Facies encountered (ichnological and sedimentary characteristics) were used to interpret the depositional environments. The core samples were also calibrated to the wireline logs to establish characteristic wireline log signatures. Recognition of petroleum systems within the paralic settings presented a justification for considerable potential reservoirs and their productivity.

RESULTS AND DISCUSSION

Ichnodiversity and Ichnoabundance

This interval revealed diverse ichnofossil assemblages composed mainly of

Palaeophycus, Planolites, Skolithos, Teichichnus, Arenicolites, Asterosoma, Chondrites, Ophiomorpha, Thalassinoides, and *Diplocraterion. Ophiomorpha, Planolites,*and *Thalassinoides*ichnospecies burrows were < 0.5 – 2.0cm in diameter and typically occurred at the sandstone interface. *Palaeophycus, Teichichnus, and Chondrites* ichnospecies burrows were < 0.5cm in diameter, and typically occurred at shale or muddy interfaces. Less common trace fossils included *Arenicolites* and *Asterosoma*. Robust to most abundant branching dwelling burrows with pelleted walls were from *Ophiomorpha* trace maker.

Distribution of Ichnofacies

Trace fossil assemblages, commonly referred to as ichnofacies, represent distinctive associations of traces left by ancient organisms.However, there was a noticeable preference for specific types of trace fossils, facilitating the approximation of lithofacies,and thereby reflecting progressive changes in depositional conditions (Michele *et al.*, 1999). Two principal marine soft-ground types were present: *Cruziana*and *Skolithos.* They both reflected different feeding behaviours and responses to substrate consistency.

*Cruziana*ichnofacies were represented by deposit-feeding to sediment grazing. The *Cruziana* facies contained muddy silt, clean silt, and sand. Depositional conditions characteristic of the trace fossils observed were *Asterosoma, Thalassinodes, Chondrites, Teichichnus, Zoophyco, Phycosiphon, Palaeophycus, Planolite, Macaronichnus and Rhizocorallium* (**Fig. 2a**). *Skolithos*ichnofacies containing scavenging and filter-feeding/ suspension-feeding traces occurring in cross-bedded sands of tidal-fluvial estuarine channels, tidal inlets and tidal channels, shoreline, swaley cross-stratified (SCS) and hummocky cross-stratified (HCS) was indicative of high levels of wave or current energy, and was typically well developed in clean, well sorted, lose or shifting substrates. Characteristic trace fossils observed were *Ar: Arenicolites; C: Conichnus; Dp: Diplocraterion; fu: fugichnia; Macaronichnus; O: Ophiomorpha; Pa: Palaeophycus; and Sk: Skolithos* (**Fig. 2b**).

Index and intensity of bioturbation were not recorded in environments associated with the fluctuating fluvial influx, river-sediment input, and other dynamic processes prevalent in the coastal zone that made it stressful, and not habitable for animals. Potential reservoirs have excellent (Rev 6, Rev 7, Rev 8, Rev 12 and Rev 13) to very good (Rev 3) hydrocarbon production due to favourable sorting and increased permeability. On the other hand, intense bioturbation of cross-stratified sandstones was interpreted as being detrimental to reservoir quality in Rev 1, Rev 4, Rev 5 and Rev14 (James and Dalrymple, 2010; Ørjan, 2016). Biogenic churning of bedded sediment typically generated poorer sorting and thereby reduced permeability and those intervals were non-productive (Kulke, 1995). The dominance of *Ophiomorpha* burrows was indicative of a stressed environment associated with high energy and a high rate of sediment supply. *Ophiomorpha* burrows are elements of *Skolithos*ichnofacies, while others are common elements of change in energy and oxygen levels.

Qualitative Interpretation of Wireline Log

The examination of the wireline logs revealed that the reservoir bodies in the well were cyclically inter-bedded with shales (clays/siltstones) of varying thicknesses. Gamma-ray logs (API) often showed three basic curve shapes; bell, funnel, and cylindrical normally used to interpret sandstone body types and depositional environments. Spontaneous Potential (mV) log was used to distinguish between reservoirs and non-reservoirs indicative of hydrocarbon-bearing zones. It was also used to detect permeable beds and their boundaries. Deep resistivity (Res_Dep.Ohmm) curves correlated with Total Hydrocarbon Saturation (SH.v/v) while Total water Saturation (Sw.v/v) curves were

Scientia Africana, Vol. 23 (No. 2), April, 2024. Pp 77-84
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

contrary, thereby establishing its usage as a hydrocarbon indicator.

Depositional Environments

Vertical facies relationships and their depositional processes derived from the integrated ichnological-sedimentological facies model (**Fig. 3**) greatly strengthened the environmental interpretation in this study. Interpreted depositional environments in E-GU1 Well included prograding wave-dominated delta under the influence of fluvial, tidal, and marine systems (Ezeh *et al.*, 2016) (**Table 1**).

Petroleum System of the Studied Area

The studied field is considered a petroleum-bearing field with all the petroleum system elements displayed. The following are the major fundamentals of hydrocarbon entrapment in sedimentary basins including the Niger Delta: source rocks, reservoir rocks, traps, and seals (cap rocks). Fifteen (15) potential hydrocarbon reservoir units were discovered; Rsv-1 – Rsv-15 (**Fig. 3**).

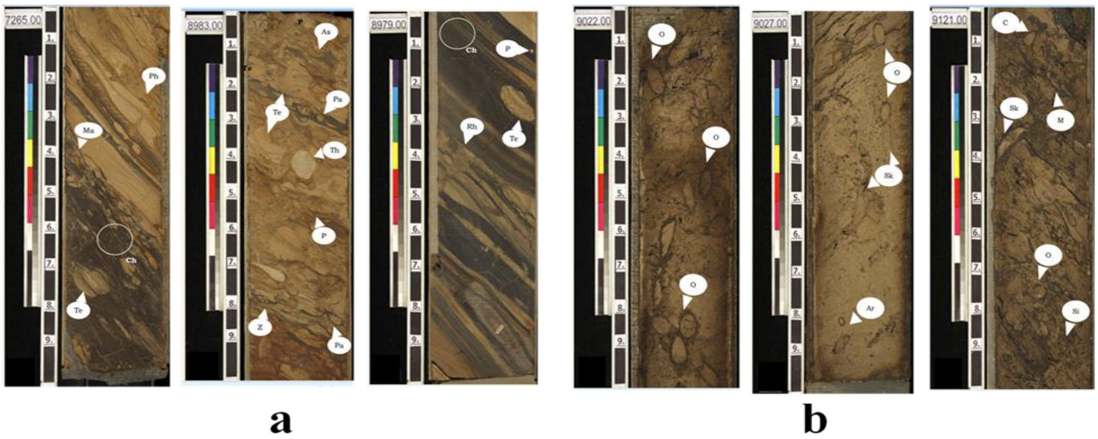

Figure 2. (a) Core photographs of the *Cruziana*Ichnofacies. Trace-fossil abbreviations are as follows: *As: Asterosoma; Ch: Chondrites;* M: *Macaronichnus; P: Planolites; Pa: Palaeophycus; Ph: Phycosiphon; Rh: Rhizocorallium; Te:* Teichichnus; *Th: Thalassinoides;* and Z: *Zoophycos;* (b) Core photographs of the *Skolithos*ichnofacies. Tracefossils abbreviations are as follows: Ar: *Arenicolites*; C: *Conichnus*; *Macaronichnus*; O: *Ophiomorpha*; Pa: *Palaeophycus*; and Sk: *Skolithos*.

Table 1: Interpreted depositional environments, the processes operating in them, and the available Cores in E-GU1 Well

Depositional environment	Successive environment	Major depositional processes	Core
Deltaic-Fluvial	Fluvial Channel Fluvial Point bar Levee Floodplain	River currents	#5, #4. #3 and #2
Barrier Island	Barrier Bar Beach Shoreface Crevasse splays	Waves	#4, #2 and #1
Tidal Flat	Supratidal Intertidal Subtidal	Tidal currents	#8, #7 and #2
Estuary	Estuary Complex Estuary Mouth	River currents, waves, tidal currents	#8
Continental shelf	River Mouth bar	Waves, tidal currents	#9 and #8

under Delta influence	Delta front platform Pro Delta Open Shelf Shelf sand

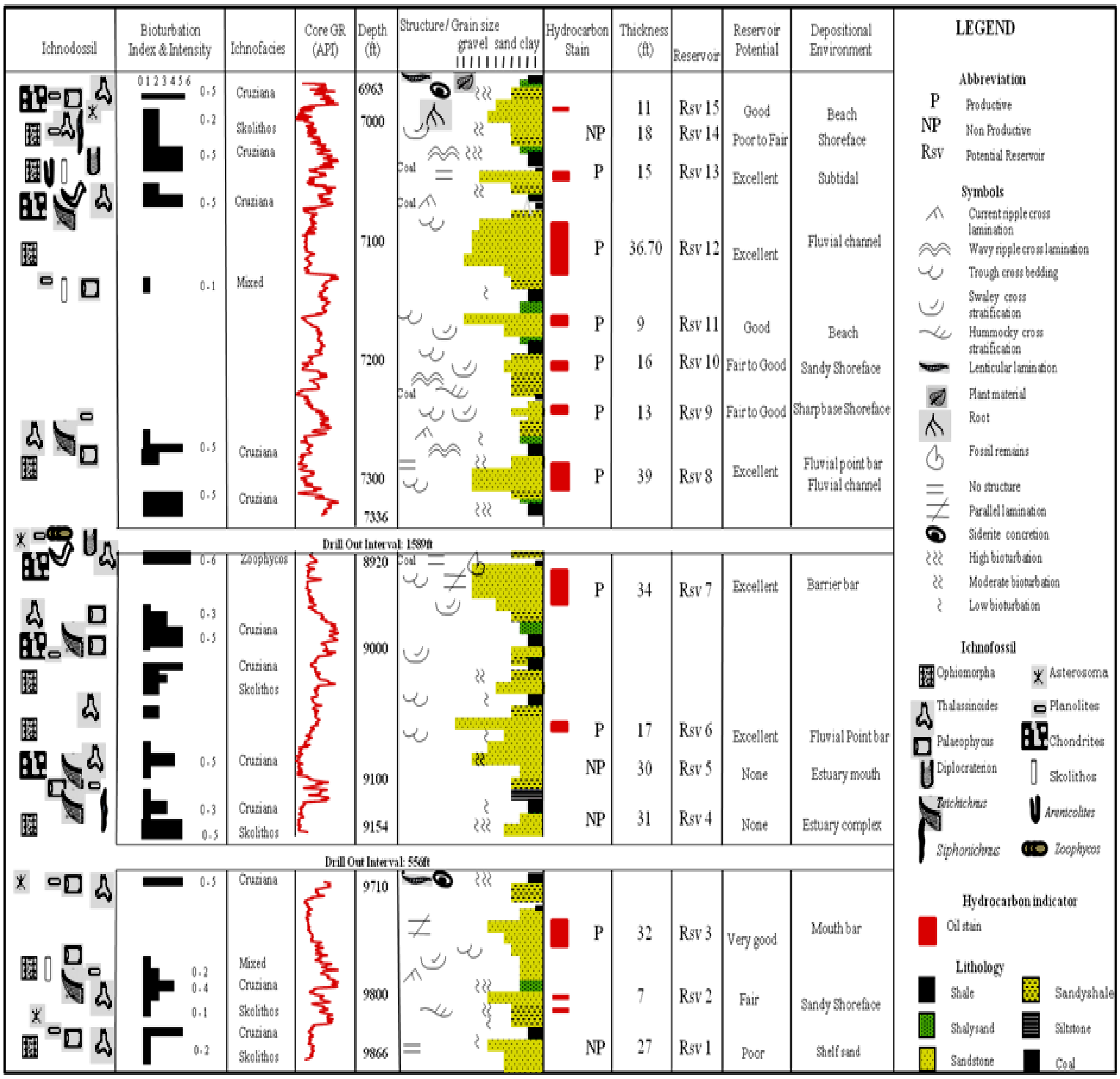

Figure 3. Model of ichnofacies and their colonization as it influences reservoir quality in E-GU1 Well

CONCLUSION

Ichnofacies characterization has increased high-resolution evaluation and contributes meaningfully to the understanding of reservoirs in paralic successions in the studied area. Hydrocarbon-bearing strata were inferred to be productive with low or no trace fossil activities while non-productive with highly intensified activities of animals that inhabited them. Reservoir Ichnology is highly effective in helping to discern animal responses to the relative importance of waves, storms, tides, river-sediment input, and fluvial discharge in the terrain of the onshore Niger

Scientia Africana, Vol. 23 (No. 2), April, 2024. Pp 77-84
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

Delta basin. Future investigation is recommended to focus on more wells from the forced regressive shoreface and delta front reservoirs of the studied interval for its internal continuity that may contain maximum production potential.

Acknowledgement

The authors wish to appreciate N P D C, Benin City for the permission given to access the data used for this study.

REFERENCES

Avbovbo, A.A., (1978). Tertiary lithostratigraphy of Niger Delta. *American Association of Petroleum Geologists Bulletin* 62, 295–300.

Egbu, O.C., Obi, G.C., Okogbue, C.O. and Mode, A.W., (2009). Ichnofacies and reservoir properties of shoreline deposit in the coastal swamp depobelt of the Niger Delta. AAPG International Conference and Exhibition, Article, Cape Town, pp. 1–7.

Droser, M.L. and Bottjer, D.J., (1986). A semi-quantitative field classification of ichnofabric. Journal of Sedimentary Research, 56, 558–559.

Doust, H., &Omatsola, E., (1990). Niger Delta. [In:] J.D. Edwards & P.A. Santogrossi (Eds): *Divergent/passive Margin Basins*. American Association of Petroleum Geologists Memoir 48, 239–248.

Efemena O. O and Maju-Oyovwikowhe G. E., (2022). Geological description of the majuefe-01 well, Niger Delta, using cores and wireline logs data.FUW Trends in Science & Technology Journal, e-ISSN: 24085162; p-ISSN: 20485170; Vol. 7 No. 3 pp 121 – 127.

Ezeh, S.C., Mode W.A., Adejinmi, K. and Ozumba, B.M., (2016). Ichnological characteristics and variability of Miocene deposits in the Cenozoic Niger Delta: Examples from cores in the Coastal Swamp and Offshore depobelts Palaeogeography, Palaeoclimatology, Palaeoecology 454, 189–201.

James, N.P. and Dalrymple, R. W., (2010). Facies Models4Geological Association of Canada.

Kulke, H., 1995. Nigeria. [In:] H. Kulke (Ed.): *Regional Petroleum Geology of the World.* Pt II: *Africa, America, Australia and Antarctica*. GebrüderBorntraeger, Berlin, 143–172.

Michele, L.W., Tuttle, R., Charpentier, R. and Michael, E.B., (1999). *The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa*. U.S. Geologic Survey, 35 pp.

Nichols, G. (2009). Sedimentology and stratigraphy / Gary Nichols. – 2nd ed.

Ørjan, B.O., (2016). A study of the ichnology, lithology and reservoir quality of the Palaeogene Grumantbyen Formation on Svalbard Master thesis in Petroleum Geoscience, Department of Earth Science, The University of Bergen and Department of Arctic Geology, The University Centre in Svalbard.

Pemberton, S.G. and Gingras, M.K. (2005). Classification and characterizations of biogenically enhanced permeability AAPG Bulletin, v. 89, p. 1493-1517.

Pemberton, S.G., Spila, M., Pulham, A.J., Saunders, T., MacEachern, J.A., Robbins, D., and Sinclair, I.K., (2001). Ichnology and Sedimentology of Shallow to Marginal Marine Systems: Ben Nevis and Avalon Reservoirs, Jeanne d'Arcy Basin. Geological Association of Canada, Short Course Notes, Vol. 15, (343 p.).

Reijers, T.J.A., (2011). Stratigraphy and sedimentology of the Niger Delta Basin. Geologos 17, 133–162.

Stacher, P., (1995). Present understanding of the Niger Delta hydrocarbon habitat. In: Oti, M.N., Postma, G. (Eds.), Geology of Deltas. A.A. Balkema, Rotterdam, pp. 257–267.

Tuttle, M., Charpentier, R., Brownfield, M., (2015) "The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa". United States Geologic Survey.

United States Geologic Survey. Retrieved 6 March 2015.

Ugwueze, C.U. & K.O. Okengwu (2023). Textural Characteristics and Sediment Transport Dynamics of the Sandstones of the Nkporo Group, Southern Anambra Basin (Nigeria): Evidence for the Upper Cretaceous Sea-Level Lowstand. *Scientia Africana*, 22(2) 177-202

Ugwueze, C.U., Ugwu S.A.& N.E. Ajaegwu (2019). Slope fan depositional elements evaluation: Implication for reservoir depositional origin in the deep offshore Niger Delta Basin, Nigeria,*Journal of African Earth Sciences*, *Elsevier*, Amsterdam, 160 (103638) (AMSTERDAM)