Bima Journal of Science and Technology, Vol. 8(4B) Jan, 2025 ISSN: 2536-6041

DOI: 10.56892/bima.v8i4B.1209

Palynostratigraphc, Paleoenvironmental and Paleoclimatic Analysis of the Tertiary Strata of the Niger Delta: an insight from palynological analysis

Igili Chinedu O.[1], Ndubueze O. Vin[2]

[1]Department of Energy and Petroleum Studies, Novena University, Ogume, Nigeria
[2]Department of Energy and Petroleum Studies, Novena University, Ogume, Nigeria

Corresponding Author: chiigili@yahoo.com

ABSTRACT

Paleodepositional and paleoclimatic studies were carried out on ditch cutting samples retrieved from wells A & B at depth between 11,140 to 12,580 ft. and 11,620 to 13,570 ft. respectively within the marginal offshore Niger Delta. The study aimed at identification, description and classification of palynofacies assemblages and paleoenvironment under which they were deposited. The acid method for samples preparation were employed for the recovery of palynofacies assemblages present in the two wells. The assemblages were dominated by dominated by moderate records of terrestrial sporomorphs such as *Retitricolporites irregularis*, *Monocolpites* sp., *Laevigatosporites* sp., *Verrucatosporites* sp., *Acrostichum aureum* and *Psilatricolporites crassus*. Relatively common occurrence of fresh water algae *Botryococcus braunii*. Both wells are characterized with same palynomorphs and as such are treated as one. Based on the stratigraphic occurrence of marker species such as *Verrutricolporites rotundiporus* and *Echiperiporites estelae*, three informal biozones were recognized namely A-2, A-3 and A-4 for well A while well B recorded four biozones A-1, A-2, A3 and A-4. The presence of *Borryococcus* braunii, which is indicative of a wet climate and also utilizing various climate proxy indicators, like temperature-sensitive species or plant functional types, to reconstruct past climate conditions. The presence of tropical and subtropical elements, such as *Acrostichum* (a mangrove fern) and *Psilatricolporites crassus*, suggests a warm and humid paleoclimatic setting. The occurrence of *Botryococcus braunii* further supports the inference of a tropical to subtropical climate with sufficient freshwater input.

Keywords: Palynostratigraphc, Paleoenvironmental, Paleoclimatic, Niger Delta.

INTRODUCTION

The Niger Delta, one of the world's most prolific hydrocarbon provinces, is characterized by a complex interplay of geological and ecological processes (Adegoke, 2002; Atta-Peters, 2013). As a critical region for both petroleum exploration and environmental studies, understanding its biostratigraphy and paleoenvironments is essential for resource management and ecological conservation (Ekweozor, and Dankoru,1994). This research focuses on wells A and B, located in the marginal offshore Niger Delta, to explore biostratigraphic zonation, paleodepositional environments, and paleoclimatic conditions through the analysis of palynofacies. Biostratigraphy, the branch of stratigraphy that uses fossil organisms to date and correlate rock layers, provides vital insights into the geological history of an area (Anyiam, et. al., 2019; Adegoke, 2002). In the context of the Niger Delta, biostratigraphic zonation is particularly significant due to the region's rich fossil record, which reflects past ecological dynamics and sedimentary processes. By identifying and classifying palynological (pollen and spore) assemblages, we can delineate distinct biostratigraphic zones that correlate with specific depositional environments and time intervals (Combaz 1964).

Paleodepositional studies further enhance our understanding of the geological history of the wells. The Niger Delta is marked by

DOI: 10.56892/bima.v8i4B.1209

intricate depositional patterns influenced by factors such as sea-level fluctuations, tectonic activity, and sediment supply dynamics (Igili et al. 2024). Through the examination of palynofacies microfossil assemblages that encapsulate organic material and its depositional context we can reconstruct the ancient environments that shaped the formation (Batten & Stead (2005) . This investigation not only aids in hydrocarbon exploration but also provides a framework for understanding the ecological responses to past environmental changes. Climate is a driving force in shaping sedimentary processes and biotic communities (Batten, 1982). Paleoclimatic studies allow us to infer the climatic conditions that prevailed during the deposition of sediments in wells (Batten, 1982; Combaz). By analyzing palynofacies, we can draw correlations between fossil assemblages and past climate regimes, shedding light on how climatic shifts influenced both sedimentation patterns and biological diversity in the region. Understanding these relationships is critical for predicting how contemporary climate change may impact the Niger Delta's ecology and geology.

This research aim to synthesize findings from biostratigraphic zonation, paleodepositional, and paleoclimatic studies of the wells, using palynomorphs as a key analytical tool. Through a comprehensive examination of these aspects, we seek to contribute to the broader understanding of the Niger Delta's geological evolution and its implications for resource management and environmental stewardship. By integrating these various dimensions of study, we hope to provide a holistic view of the interplay between geological history, climate, and biodiversity in one of the world's most dynamic geological settings.

Geology

Niger Delta is located on the continental margin of Southern Nigeria and covers an area of 70km. It lies between longitude 5^0E and 8^0E and latitudes 30^0 and 60^0 Short and Stable (1997). Stable mega tectonic framework such as the Benin and Calabar flank mark the northewest and eastern boundaries. The Anambra basin and the Abakaliki high mark the northern boundary and it is bounded to the south by the west of guinea. The stratigraphic fill of the Niger Delta basin is composed primarily of three lithostratigraphic units that extend across the whole delta (Obafemi et al. 2020). These include basal marine pro-delta Akata Formation, the middle shallow-marine delta-front Agbada Formation and, the overlying youngest continental, delta plain Benin Formation (Doust and Omatsola 1990; Adojoh et al. 2020). The Akata Formation, a prodeltaic lithofacies of Paleocene to Recent in age is composed primarily of marine shales with turbidite sands and continental slope channel fills (Doust and Omatsola 1990). It is estimated to be up to 7 km thick and generally considered as the source rock of the Niger Delta. The middle paralic Agbada Formation, estimated to be over 3.7km thick and ranges in age from Eocene to Recent (Tuttle et.al., 1999; Avbovbo, 1978) is primarily composed of delta-front lithofacies and characterized by intercalations of sand and shale. The sandstone reservoirs facies within this formation are mostly shoreface and channel sands with minor shales in the upper part, and alternation of sands and shales in the lower part (Doust and Omatsola 1990). This unit serves as the hydrocarbon reservoir within the basin with sand percentage ranging from 30 to 70% (Doust and Omatsola 1990). The deltaic sequence is capped by the topmost Benin Formation that is Oligocene to Recent in age, about 2km thick and is made up of continental fluvial sands (Avbovbo 1978; Doust and Omatsola 1990; Owolabi et al. 2019). Adegoke et al. (2017) described the formation as friable, white, fine to coarse and pebbly, poorly sorted sands, with lignites occurring as thin streaks or as finely dispersed fragments.

Bima Journal of Science and Technology, Vol. 8(4B) Jan, 2025 ISSN: 2536-6041

DOI: 10.56892/bima.v8i4B.1209

MATERIALS AND METHODS

A total number of 40 ditch cuttings from intervals 11140 – 12580 ft of well A and 11620 – 13570 ft of well B drilled in the Niger Delta were utilized for this study. Other materials used includes: charts, microscope and camera, and computer software (Stratabug, Corel draw, Surfer and Microsoft Excel). Laboratory analysis was carried out in Crystal Age Laboratory Lagos and Novena University Ogume. The Niger Delta where the studied wells were located is shown in Fig.1: as the actual locations of the wells were not made available for proprietary reasons.

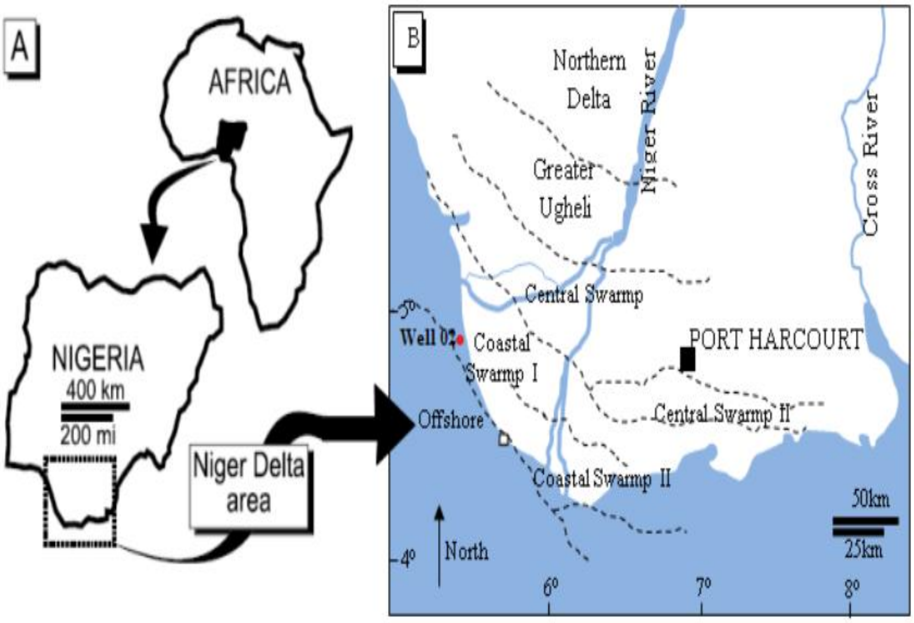

Figure 1: Location of the study area. Simplified regional geological setting map of the Niger Delta basin, showing the different depobelts (Modified from Suyi 2014).

Palynological Sample Preparation and Procedure

25g of each sample were treated to standard palynological maceration procedures of acid dissolution before the addition of concentrated 36% hydrochloric acid (HCl) for 20-30mins to remove carbonates while the silicate content was removed with 40% hydrofluoric acid (HF). Zinc bromide (ZnBr) solution was added following 2Faegri and Iversen (1989) method to aid separation of the organic content. The oxidized organic matter was removed with nitric acid (HNO) through 5mm sieve. Thorough mixture of the samples with the chemicals was ensured at critical maceration stages by centrifugation at high speed. However, unoxidized residue for palynofacies was separated prior to sieving and oxidation. Final residue was mixed thoroughly with 100% glycerin and put in a labelled vial. About 20 ml of the mixture was mount strewn on a 32 mm x 22 mm cover slip and mounted on a 72 x 22 mm glass slide using Norland Optical adhesive mounting medium under the UV light. The same mounting process was adopted for the unoxidized palynofacies slide preparation.

Palynological analysis of the prepared slides was carried out with the aid of a Leitz Ortholux II transmitted light microscope with a x25 objective lens as well as x100 objective lens for detailed identification of palynomorphs. The unoxidized slides were also scanned for the particulate organic matter. Relevant bibliographic references consulted include Germeeraad *et al.* (1968) and Evamy *et al.* (1978).

RESULTS AND DISCUSSION

Palynostratigraphic Wells A and B

Palynological processing and analysis were carried out on eighteen (18) ditch cuttings retrieved from well A as shown in Fig. 2 below and twenty two (22) ditch cutting samples from well B as shown in Fig. 4. below. The were processed and analysed for their palynomorph contents for both wells. The studied section was dominated by moderate records of terrestrial sporomorphs such as *Retitricolporites irregularis*, *Monocolpites* sp., *Laevigatosporites* sp., *Verrucatosporites* sp., *Acrostichum aureum* and *Psilatricolporites crassus*. Relatively common occurrence of fresh water algae *Botryococcus braunii* and fungal spore were also identified. The studied section Fig. 4. for well B was dominated by low to moderate records of terrestrial species such as *Retitricolporites irregularis*, *Psilatricolporites crassus*, *Laevigatosporites* sp., *Verrucatosporites* sp., *Acrostichum aureum* and *Polypodiaceoisporites* sp. Rare occurrence of *Leoisphaeridia* sp. and *Lejeunecysta* sp. with relatively common occurrence of fresh water algae *Botryococcus braunii* were also identified. The results were used to decipher the age of sedimentary succession and possible paleoenvironment of deposition for the wells.

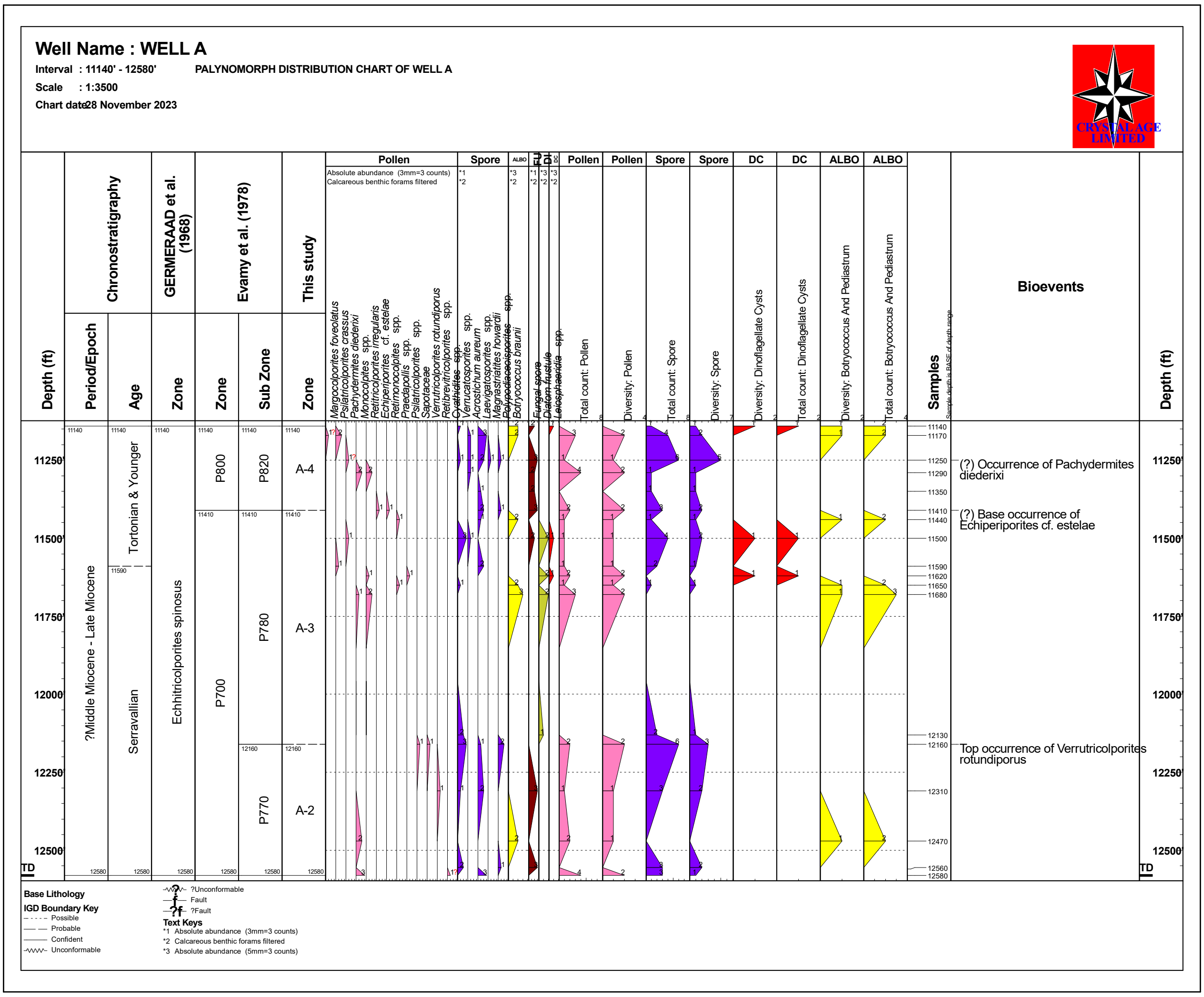

Figure 2: Distribution chart showing abundance and diversity plots of palynomorphs in well A

DOI: 10.56892/bima.v8i4B.1209

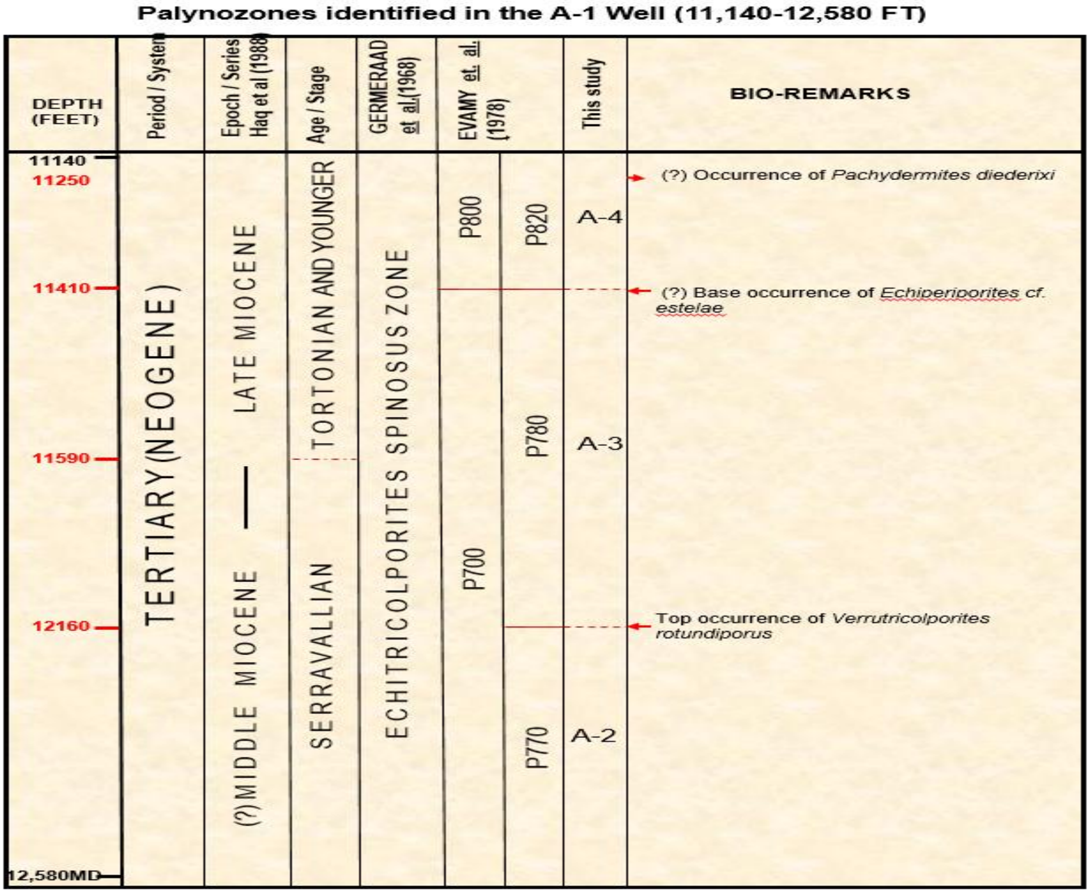

Figure 3: Showing the palynozones in well A.

Biostratigraphy of Well A

Based on the stratigraphic occurrence of marker species such as *Verrutricolporites rotundiporus* and *Echiperiporites estelae*, as shown in Fig. 3 above, three informal biozones were recognized namely A-2, A-3 and A-4 This biozones fall within the *Echitricolporites spinosus* zone of Germeraad et al. (1968) and correlates with the P770, P780 and P820 subzones of Evamy et al. (1978). Thus, middle Miocene (Serravallian) to late Miocene (Tortonian and younger) age is interpreted for the studied interval. Details of the palynological results are discussed below.

Zone A-4

Depth: 11,140-11,410 ft.

Age: Late Miocene (Tortonian and younger)

The base of this biozone is defined by the base occurrence of associate marker species *Echiperiporites estelae* at 11,410 feet, the top coincides with the first sample analysed. This relatively thin interval is further characterized by occurrence of *Pachydermites diederixi* and *Magnastriatites howardi*. The biozone correlates with the *Echitricolporites spinosus* Germeraad et al. (1968) and the P820 subzone Evamy et al. (1978).

Zone A-3

Depth: 11,410-12,160 ft.

Age: Middle Miocene (Serravallian) - Late Miocene (Tortonian)

The base of this biozone is defined by the top occurrence of *Verrutricolporites rotundiporus* at 12,160 feet while the top is marked by the base occurrence of *Echiperiporites estelae* at 11,410 feet. This thick interval is further characterized the occurrence of *Retitricolporites irregularis*

Bima Journal of Science and Technology, Vol. 8(4B) Jan, 2025 ISSN: 2536-6041

DOI: 10.56892/bima.v8i4B.1209

and *Praedapollis* sp. This interval correlates with the *Echitricolporites estelae* of Germeraad et al (1968) and the P780 subzone of Evamy et al. (1978).

Zone A-2

Depth: 12,160-12,580 ft.

Age: Middle Miocene (Serravallian)

The base of this biozone coincides with the last sample analysed at 12,580 feet while the top is defined by the top occurrence of *Verrutricolporites rotundiporus* at 12,160 feet. Few records of *Monocolpites* sp., *Retibrevitricolporites* sp., *Acrostichum aureum* and *Laevigatosporites* sp. *Polypodiaceoisporites* sp. and *Sapotaceae* were identified this biozone.

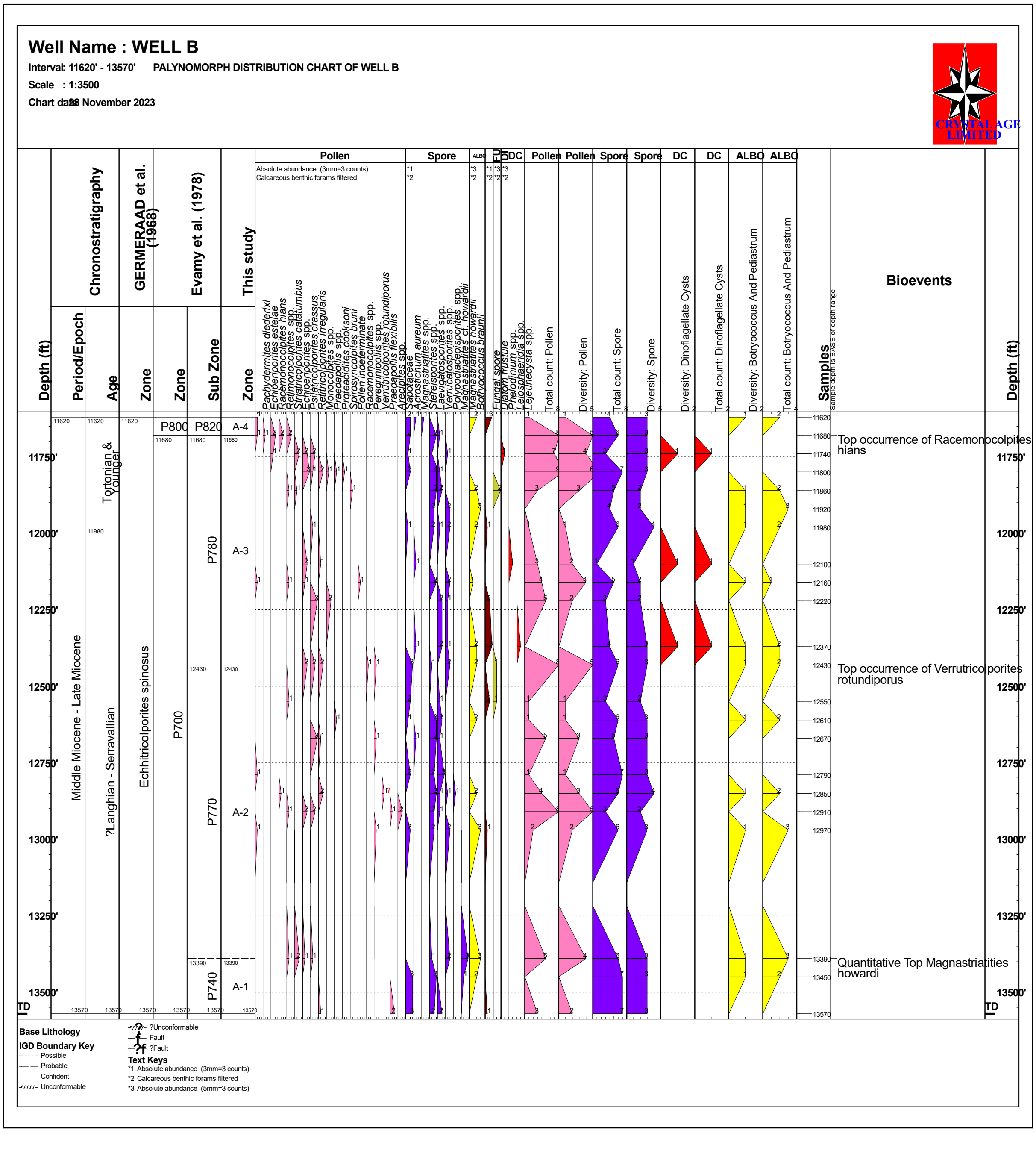

Figure 4: Distribution chart showing abundance and diversity plots of palynomorphs in well B.

Bima Journal of Science and Technology, Vol. 8(4B) Jan, 2025 ISSN: 2536-6041

DOI: 10.56892/bima.v8i4B.1209

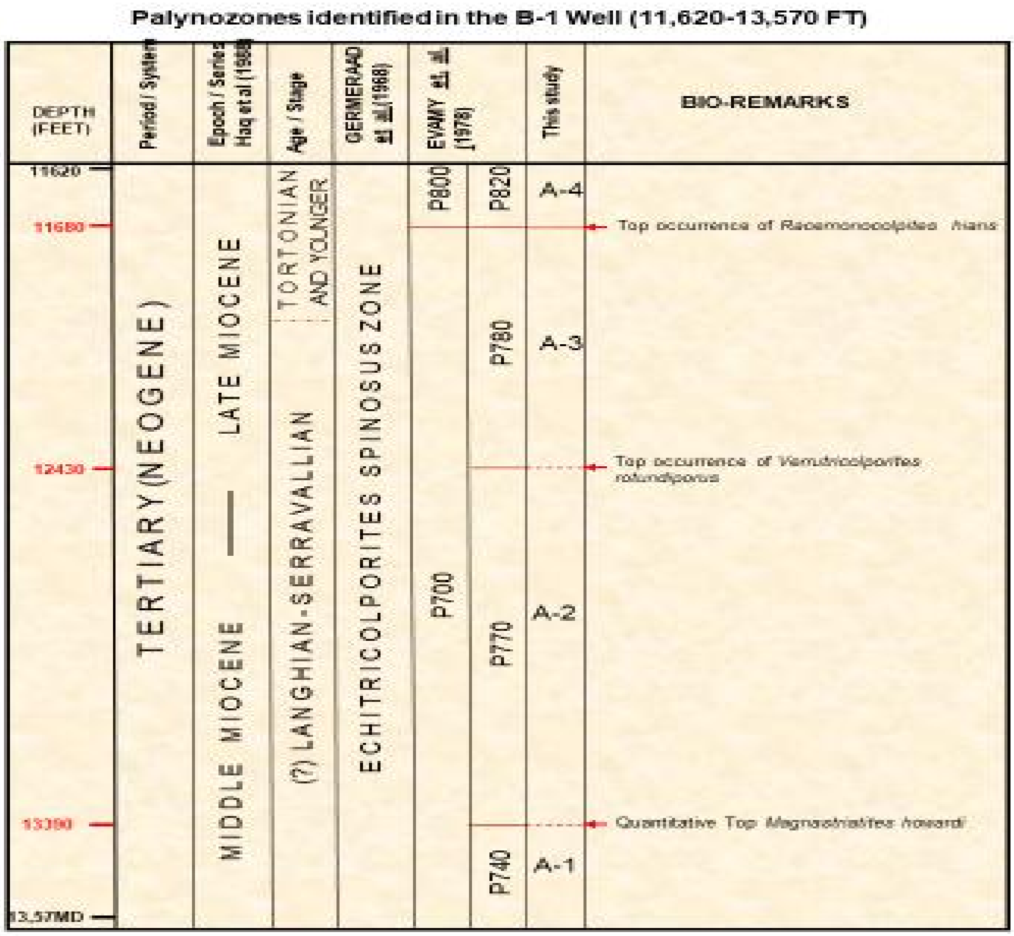

Figure 5: Showing the palynozones in well.

Biostratigraphy for well B

Based on the stratigraphic occurrence of marker species such as *Racemonocolpites hians*, *Verrutricolporites rotundiporus* and *Magnastriatites howardi* as shown in fig. 5, four informal biozones were recognized namely A-1, A-2, A-3 and A-4.This biozones correlates with the *Echitricolporites spinosus* zone of Germeraad et al. (1968) and the P740, P770, P780 and P820 subzones of Evamy et al. (1978). Thus, middle Miocene to late Miocene (Tortonian and younger) age is interpreted for the studied interval. Details of the palynological results are discussed below.

Zone A-4

Depth: 11,620-11,680 ft.

Age: Late Miocene (Tortonian and younger)

The base of this biozone is defined by the top occurrence of marker species *Racemonocolpites hians* at 11,680 feet while the top coincides with the first sample analysed. Palynoflora assemblage made up of *Echiperiporites estelae*, *Pachydermites diederixi, Acrostichum aureum* and *Retimonocolpites* sp. were recorded within this interval. The biozone correlates with the *Echitricolporites spinosus* Germeraad et al.

DOI: 10.56892/bima.v8i4B.1209

(1968) and the P820 subzone Evamy et al. (1978).

Zone A-3

Depth: 11,680-12,430 ft.

Age: Middle Miocene (Langhian-Serravallian) - Late Miocene (Tortonian)

Discussion: The base of this biozone is defined by the top occurrence of *Verrutricolporites rotundiporus* at 12,430 feet while the top is marked by the top occurrence of *Racemonocolpites hians* at 11,680 feet. Additional palynoflora that characterized this interval include *Proteacidites cooksonii, Spirosyncolpites brunii, Striatricolporites catatumbus* and *Retitricolporites irregularis*. Rare records of *Leoisphaeridia* sp. and *Lejeunecysta* sp. were recognized which suggest a probable period of marine incursion. This interval correlates with the *Echitricolporites estelae* of Germeraad et al. (1968) and the P780 subzone of Evamy et al. (1978).

Zone A-2

Depth: 12,430-13,390 ft.

Age: Middle Miocene (Langhian - Serravallian)

The base of this biozone is defined by the quantitative top occurrence of *Magnastriatites howardi* at 13390 feet while the top is defined by the defined by the top occurrence of *Verrutricolporites rotundiporus* at 12,430 feet. The occurrence of *Praedapollis flexibilis* and *Polypodiaceoisporites* sp. further characterized this interval. This biozone correlates with the *Echitricolporites estelae* of Germeraad et al. (1968) and the P770 subzone of Evamy et al. (1978).

Zone A-1

Depth: 13,390-13,570 ft.

Age: Middle Miocene (Langhian - Serravallian)

The base of this biozone coincided with the last sample analysed while the top is defined at 12,430 feet by the quantitative top occurrence of *Magnastriatites howardi*. The occurrence of *Laevigatosporites* sp., *Monocolpites* sp., *Verrucatosporites* sp., *Magnastriatites howardi* and *Acrostichum aureum* were additional palynoflora events recorded within this interval.

Paleodepositional Environment

From the palynomorph chart in Fig. 2 and Fig.5, they both have similar palynomorphs as shown in Plate 1. and fall within the same biozone, both wells A and B will be treated together as one. The common occurrence of land derived palynomorphs such as *Verrucatosporites* sp., *Polypodiaceoisporites* sp., *Acrostichum aureum*, *Retitricolporites irregularis* and *Monocolpites* sp., with fresh water algae *Botryococcus braunii* suggest deposition of sediments in terrestrial (Rainforest vegetation) paleoenvironment.

The presence of taxa such as Verrucatoaporites sp., Acrostichum, and Psilatricolporites crassus suggests a coastal or transitional environment, possibly a mangrove or estuarine setting. Mangroves are typically found in tropical to subtropical regions, thriving in areas with a mix of fresh and saline water (Odedede, et. al., 2016).

The occurrence of Botryococcus braunii, a freshwater green algae, indicates the presence of standing or slow-moving freshwater bodies within the depositional system (Fadiya, et. al., 2020). This could be associated with fluvial or lacustrine environments (Kholeif & Ibrahim 2010).

DOI: 10.56892/bima.v8i4B.1209

PALYNOMORPHS AND PALYNOFACIES PHOTOGRAPHS FOR WELL A AND B

Plate 1. Palynomorph recovery, photomicrographs of palynomorph from well A and B

The diverse assemblage of pollen and spores, including *Retricolporites irregularis, Monocolpites sp., and Verrutricolporites rotundiporus*, suggests a mixed vegetation community, possibly representing a transitional zone between terrestrial and aquatic environments (Fadiya, et. al., 2020; Itiowe, & Lucas 2020).

Paleoclimatic Conditions

Considering the overall palynoflora composition, diversity, and abundance Fig. 2 and Fig.4 using specific climatic indicators within the assemblage, such as the presence of *Borryococcus* braunii, which is indicative of a wet climate (Itiowe & Lucas 2020), and also utilizing various climate proxy indicators, like temperature-sensitive species or plant functional types, to reconstruct past climate conditions (Abdel, et. al,. 2013).

The presence of tropical and subtropical elements, such as *Acrostichum* (a mangrove fern) and *Psilatricolporites crassus*, *Retitricolporites irregularis* a pollen type associated with the family *Annonaceae*, which comprises tropical trees and shrubs suggests a warm and humid paleoclimatic setting (Oboh, 1992; Odedede, 2016). The occurrence of *Botryococcus braunii* further supports the inference of a tropical to subtropical climate with sufficient freshwater input (Itiowe & Lucas 2020).

DOI: 10.56892/bima.v8i4B.1209

The diversity of the palynological assemblage, including both terrestrial and aquatic taxa, indicates a relatively stable and well-established ecosystem, with a balance between freshwater and marine/estuarine influences. The combination of the palynological data suggests a paleodepositional environment characterized by a coastal or transitional setting, with a mix of freshwater and saline water conditions, and a warm and humid paleoclimatic regime (Odedede, et. al., 2016; Igili, et. al, 2024).

CONCLUSION

A comprehensive analysis of the ditch-cutting samples from wells A and B in Niger Delta Basin was conducted using palynological methods. The two wells showed no much significance differences hence was interpreted generally. The studied section was dominated by moderate records of terrestrial sporomorphs such as *Retitricolporites irregularis*, *Monocolpites* sp., *Laevigatosporites* sp., *Verrucatosporites* sp., *Acrostichum aureum* and *Psilatricolporites crassus*. Relatively common occurrence of fresh water algae *Botryococcus braunii*. Based on the stratigraphic occurrence of marker species such as *Verrutricolporites rotundiporus* and *Echiperiporites estelae*, three informal biozones were recognized namely A-2, A-3 and A-4. This biozones fall within the *Echitricolporites spinosus* zone of Germeraad et al. (1968) and correlates with the P770, P780 and P820 subzones of Evamy et al. (1978). Thus, middle Miocene (Serravallian) to late Miocene (Tortonian and younger) age is interpreted for the studied interval. The occurrence of land derived sporomorphs such as *Laevigatosporites* sp., *Acrostichum aureum*, *Verrucatosporites* sp., *Polypodiaceoisporites* sp., *Retitricolporites irregularis* amongst others suggest deposition of sediments in terrestrial (Rainforest vegetation) paleoenvironment. The presence of *Borryococcus* braunii, which is indicative of a wet climate and also utilizing various climate proxy indicators, like temperature-sensitive species or plant functional types, to reconstruct past climate conditions. The presence of tropical and subtropical elements, such as *Acrostichum* (a mangrove fern) and *Psilatricolporites crassus*, suggests a warm and humid paleoclimatic setting. The occurrence of *Botryococcus braunii* further supports the inference of a tropical to subtropical climate with sufficient freshwater input.

REFERENCES

Abdel, G. H., Sherif, F. & Hatham, A., (2013). Paleoclimatic Analysis of the Late Oligocene/Middle Miocene Planktonic fauna of west central Siani, Egypt. *Egypt Journal of Paleontology.* 13, 29-48.

Adegoke, O. S. (2002). High Resolution Biostratigraphy, Sequence Stratigraphy and 3-D Modelling: Indispensable Tools for E & P Activities in the New Millenium. *Nigerian Association of Petroleum Explorationists Bulletin* 16(1), 46-65.

Akinwumi, F. V., Arochukwu, E. C., and Abdul-Kareem, A. S**.** (2004). “Managing Uncertainties in Hydrocarbon-in-place Volumes in a Northern Depobelt Field, Niger Delta, Nigeria” paper SPE 88880, presented at the 28th Annual SPE International Technical Conference and Exhibition in Abuja, Nigeria.

Anyiam, O. A., Eradiri, J. N., Mode, A. W., Okeugo, C. G., Okwara, I. C., & Ibemesi, P. O. (2019). Sequence stratigraphic analysis and reservoir quality assessment of an onshore feld, Central Swamp Depobelt, Niger Delta Basin Nigeria. *Arabian Journal of Geosciences*, 12(24), 791.

Atta-Peters, D., Agama, C. I., Asiedu, D.K. and Apesegah, E. (2013). Palynology, palynofacies and paleoenvironments of sedimentary organic matter from Bonyere – Well, Tano basin, Western Ghana. International Letters of Natural Sciences 5, 27- 45.

Batten, D. J. and Stead, D. T. (2005). Palynofacies analysis and its stratigraphic application. In: Koutsoukos, E. A. M. (Ed.), Applied Stratigraphy. Springer Dordrecht, Netherlands. 203–226.

Batten, D.J (1982). Palynofacies, palaeoenvironments and petroleum. *Journal of Micropalaeontology* 1, 107-114.

Boboye, E.A. and Adeleye, A.M. (2009). High resolution biostratigraphy of Early Pliocene to Late Miocene calcareous Nannoplankton and foraminifera, deep offshore, Niger Delta, Nigeria. *European Journal of Scientific Research*, 34: 308 – 325

Bown, P. R. (2005). Calcareous nannoplankton evolution: A tale of two oceans. Micropaleontology, 51(4), 299-308. https://doi.org/10.2113/gsmicropal.51.4.299

Bown, P.R (2010). Calcareous nannofossils fom the Paleocene/Eocene Thermal Maximum interval of southern Tanzania (TDP Site 14). Journal of Nannoplankton Research. 31 (1), 11-38.

Bown, P.R. & Dunkley Jones, T. (2012). Calcareous nannofossils from the Paleogene equatorial Pacific (IODP Expedition 320 Sites U1331-1334). *Journal of Nannoplankton Research*. 32 (2), 3-51.

Bown, P.R. & Newsam, C. (2017). Calcareous nannofossils from the Eocene North Atlantic Ocean (IODP Expedition 342 Sites U1403–1411). *Journal of Nannoplankton Research*, 37(1), 25 60

Bridge, J. S., and I. A. Lunt (2006). Depositional models of braided rivers, in Braided Rivers, edited by G. S. Sambrook Smith et al., Spec. Publ. Int. Assoc. Sedimentol., 36, 11 – 50

Carvalho, M. A., Filho, J. G. M. and Menezes, T. R. (2006). Palynofacies and sequence stratigraphy of the Aptian-Albian of the Sergipe Basin, Brazil. Sedimentary Geology 192 (5), 57-74.

Christopher, R. A. and Goodman, D. K. (1996). Introduction to biostratigraphy and time scales. In: Jansonius, J. and McGregor, D. C. (Ed.), Palynology: principles and applications; American Association of Stratigraphic Palynologists Foundation 2, 463- 492.

Combaz, A. 1980. Les kerogenes vus au microscope. In: Durand, B. (Ed.), Kerogen - insoluble organic matter from sedimentary rocks, Paris, Editions

Dairo, V.A. & Oladiran, M.A. (2016). Biozonation and correlation of two wells in Niger Delta using calcareous nannofossils. Acta Palaentologia Romaniae 12(1), 43-45.

Doust, H. and Omatsola, E. (1990). Niger Delta. In: Edwards, J. D. and Santogrossi, P. A. (Eds.), Divergent /Passive Margin Basins. AAPG Memoir 48, 201-238.

DOI: 10.56892/bima.v8i4B.1209

Ejedawe, J. E. (1981). Patterns of incidence of oil reserves in Niger delta basin. American Association of Petroleum Geologists Bulletin 65:1574–1585.

Ekweozor, C.M. and Dankoru, E.M., (1994): North Delta depobelt portion of the Akata – Agbada (1) Petroleum System , Niger Delta, Nigeria, in Magon, L.B., and Dow, W.G., eds. The petroleum system from source to trap, American Association of Petroleum Geologist, memoir 60; Tulsa. 599 -614

Emery, D & Myers, KJ; (1996): Sequence stratigraphy. Blackwell Science Limited, 297

Evamy B. D., Haremboure J., Kamerling P., Knaap W. A., Molloy F. A. and Rowlands P. H. (1978). Hydrocarbon habitat of Tertiary Niger Delta. American Association Petroleum Geologist, Bulletin. 62: 1-39.

Ezekwe, J. N., and Filler, S. L. (2005). "Modeling Deep water Reservoirs," paper SPE 95066 presented at the 2005 SPE Annual Technical Conference and Exhibition held in Dallas, Texas, U.S.A. delta: AAPG Memoir 48:201-238.

Fadiya, S. L., Ogunleye, S. O., Oyelami, A.B., & Aroyewun, F.R., (2020). Palynostratigraphic and Palynofacies Analysis of X and Y Wells, Offshore Niger Delta, Nigeria. *Ife Journal of Science.* 22(3)

Faegri, K. and Iversen, J. (1989). Pollen Analysis. In: Faegri, K., Kaland, P. E., Krzywinski, K, (Eds). New York: John Wiley & Sons, New York. 328

Frankl, E. J. and Cordry, E. A. (1967). The Niger delta oil province: Recent developments onshore and offshore. Seventh World Petroleum Congress Proceedings, Mexico 2, 195 – 209.

Germeraad, J. H., Hopping, C. A. and Muller, J. (1968). Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6, 189-348.

Germeraad, J. H., Hopping, C. A., & Muller, J. (1968). Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology, 6, 189–348.

Howard, H.A. & Braiser, M.D., (2004) Microfossils, Second Edition. Blackwell Publishing, Maden, Massachusetts, USA, 16-23. 55

Igili, C.O. and Ndubueze, O.V. (2024). Diagenetic Quality, Extent of Altration and Preservation of Organic Matter of Wells A and B in Niger Delta Basin, Nigeria. *J. Appl. Sci. Environ. Manage.* 28 (11) 3513-3518

Itiowe K. 1 , Omontese S. O , Adiela U. P. (2016) Paleo-environmental Reconstruction of 't' Well in the Niger-Delta Basin, South-South Nigeria *Journal of Scientific and Engineering Research*, 3(6):352-355

Itiowe, K. and Lucas, F.A. (2020). Palynological Zonation and Paleoclimatic condition of the Sediments penetrated by ash-3 well in the greater Ughelli Depobelt, Niger Delta Basin *Scientia Africana*, 19 (1), 37-48.

Jones, R., (2006). Aplied Paleontology. Cambridge University. Cambridge, UK. 48-67. Pleistocene climates and the Plio-Pleistocene Boundary in New Zealand. Science, 171, 276 279.

Joseph, N., E., Ehimare, E., O., Ikenna C., O., Ayonma, W., M., Okwudiri, A., A.,

DOI: 10.56892/bima.v8i4B.1209

Ngozi, A., U. & Maryanna I., U. (2021). Sedimentary facies and petrographic analyses of Miocene nearshore deposits, Central Swamp Depobelt, onshore Niger Delta Basin: implications for reservoir quality. Journal of Sedimentary Environments https://doi.org/10.1007/s43217-021-00076-1

Kholeif, S. H. E. and Ibrahim, M. I. (2010). Palynofacies Analysis of Inner Continental Shelf and Middle Slope Sediments offshore Egypt, South-eastern Mediterranean. Geobios 43, 333-347.

Kulke H. (2013): Regional Petroleum Geology of the World. Part II: Africa, America, Australia and Antarctica (2nd) edition, Gebrüder Borntraeger, Berlin, Germany. 143-172.

Lai, J., & Wang, G. (2018). Deep burial diagenesis and reservoir quality evolution of high-temperature. High-Pressure Sandstones.

Martinez, M. A., Pramparo, M. B., Quattrocchio, M. E. and Zavala, C. A. (2008). De positiona l env ironment and hydrocarbon potential of the Middle Jurassic Los Molles Formation, Neuquen Basin, Argentina: palynofacies and organic geochemical data. Revista Geologica de Chile 35(2), 279 – 305.

Martini, E. (1971). Standard Tertiary and Quaternary calcareous nannoplankton zonation, in: Proceedings of the 2nd Planktonic Conference, 2, Tecnoscienza, Roma, 739–785.

Mathew, U.A., Paul, A.U., Thomas, A.H., Monday U.U. and Athanasius, G.U. (2020). Seismic Stratigraphy and Reservoir Characterization of ‘E’ Field Sediments: Inferences from South-Eastern Late Miocene – Pliocene Records, Offshore Niger Delta. *Journal of Natural Sciences Research ISSN 2224-3186* 11:14.

Michele L. W. T., Ronald R. C., and Michael E.B. (1999). The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa. United State Geological Survey. Denver Colorado: 4 - 70

Obafemi, S., Oyedele, K. F., Omeru, T., and Bankole, S. 2020. Characterization of deep water turbidite channels and submarine fan lobes using artificial intelligence; Case study of Frem field deep offshore Niger Delta. J Afr Earth Sci. 4 213-224

Oboh, F. E. (1995). Sedimentological and palynological characteristics of E2.0 reservoir (Middle Miocene) in the Kolo Creek Field, Niger Delta. In: Oti, M.N. and Postuma, G. (Eds.), Geology of Deltas,

Oboh, F. E., Salami, M. B. and Chapman, J. L. (1992). Palynological interpretation of the palaeoenvironments of Miocene strata of the well Igbomoturu-1, Niger Delta. *Journal of Micropalaeontology* 11, 1-6.

Odedede, O., Lucas, F. A. and Asuen, G. O. (2012). Sequence Stratigraphy and Palaeoenvironmental Studies of Palynoflora from E-12 Well, Offshore Niger Delta. *Journal of Mining and Geology* 48(2), 185-198.

Odedede, O., Ogala, J. E. & Ugbeh, F. C. (2016). Palynological Zonations and Sequence Stratigraphic Analysis of Sediments in Benin West-1, Anambra Basin, Nigeria. *Journal of Scientific Research.* 8 (2), 171-179

DOI: 10.56892/bima.v8i4B.1209

Olajide, J.A. & Ekaete, E. U., (2016). Occurrence and Environmental Implications of Calcareous Nannofossils in Surface Sediments of Western Gulf of Guinea: off Lagos Coast, South-Western Nigeria. *Journal of Envi. & Earth Science*. 6, 42-50.

Postuma, G. (Eds.), Geology of Deltas, Rotterdam/Brookfield, A. A. Balkema, 243-256.

Powell, A. J., Dodge, J. D. and Lewis, J. (1990). Late Neogene to Plesitocene palynological facies of Peruvian continental margin upwelling, Leg 112. In: Suess, E., Von Huene, R. (Eds.), Proceedings of the Ocean Drilling Project, Scientific Results, College Station, Texas, 112, 297-321.

Raffi, I., Backman, J., Fornaciari, E., Palike, H., Rio, D., Lourens, L.J. & Hilgen, F.J., (2006). A review of calcareous nannofossil astrobiochronology encompassing the past 25 million years. Quaternary Science Reviews, 25: 3113-3137.

Reijers, TR (2011): Stratigraphy and sedimentology of the Niger Delta. Geologist, 17(3), 133-162.

Rider, MH (1990): Gamma Ray log shape used as a facies indicator. London: Geological Society of London Special Publication Classics. 67-83.

Rocanglia, L. and Kuijpers, A. (2006). Revision of the palynofacies model of Tyson (1993) based on recent high-latitude sediments from the North Atlantic. Facies 52, 19-39).

Soronnadi-Ononiwu, G.C., Omoboriowo, A.O., Yikareboga, Y., and Madu, V.C., (2013). Paleoenvironmental and sequence stratigraphic studies of the D7000 sand, 'Erne' field, Niger Delta, Nigeria. Greener Journal of Physical Sciences. 3: 6 -18.

Suyi, L. F. (2014) Impact of Well site Biostratigraphy on Drilling in deep water offshore Nigeria. *Journal of African Earth Sciences*. 100:60-69.

Tyson, R. V. (1993). Palynofacies analysis. In: Jenkins,D.G. (Ed.), Applied Micropaleontology, Kluwer Academic Publishers. The Netherlands, Amsterdam. 153–191.

Varol, O. (1992). Sullivania a new genus of Palaeogene coccoliths. Journal of Micropalaeontology, 11(2), 141-149. https://doi.org/10.1144/jm.11.2.14

Watkins, D. K., & Bergen, J. A. (2003). Late Albian adaptive radiation in the calcareous nannofossil genus Eiffellithus. Micropaleontology, 49 (3), 231-250. https://doi.org/10.2113/49.3.231