PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 28 (12) 4073-4082 Dec. 2024

Diagenetic Quality, Extent of Alteration and Preservation of Organic Matter of Wells A and B in Niger Delta Basin, Nigeria

***IGILI, CO; NDUBUEZE, OV**

Department of Energy and Petroleum Studies, Novena University, Ogume, Delta State, Nigeria

**Corresponding Author Email: chiigili@yahoo.com*
ORCID: https://orcid.org/0009-0007-7730-5012
Tel: +234-8036933480

Co-Author Email: nduvino@gmail.com

ABSTRACT: This study investigates the application of palynofacies and calcareous nannofossils in determining the diagenetic qualities of Wells A and B in the Niger Delta Basin. The objective is to evaluate the diagenetic quality, extent of alteration and preservation of organic matter. The acid method for samples preparation was employed for the recovery of biofacies assemblages present in the two wells. The assemblages were dominated by moderate records of terrestrial sporomorphs such as *Retitricolporites irregularis*, *Monocolpites* sp., *Laevigatosporites* sp., *Verrucatosporites* sp., *Acrostichum aureum*, *Psilatricolporites crassus* and nannofossils such as *Discoaster bollii*, *Discoaster*, *Catinaster coalitus*, *Reticulofenestra pseudoumbilicus*, *Sphenolithus moriformis*, *Coccolithus pelagicus* and *Helicosphaera carteri.* Occurrence of *Verrucatosporites sp.*, *Acrostichum aureum,* and *Psilatricolporites crassus* may indicate some degree of degradation or oxidation, suggesting fair preservation quality. These palynomorphs are more susceptible to degradation. Abundance of *Botryococcus braunii*, *Echiperiporites estelae*, and fungal spores could indicate shallow water environment with potential degradation or contamination, suggesting poor preservation quality. Presence of *Reticulofenestra pseudoumbilicus* and *Sphenolithus moriformis* may indicate some degree of dissolution, potentially related to changes in pH or oxygen levels. Abundance of *Sphenolithus moriformis* could suggest overcompaction, leading to deformation or fragmentation of nannofossils. Occurrence of *Catinaster coalitus* and *Coccolithus pelagicus* may indicate some degree of reworking, potentially due to changes in sediment supply or winnowing. In conclusion, the wells has experienced varying degrees of diagenetic alteration. While some intervals show good preservation quality, others have undergone oxidation, degradation, or contamination, resulting in fair to poor preservation quality. Also there is no significance difference between the two wells.

DOI: https://dx.doi.org/10.4314/jasem.v28i12.17

Cite this Article as: IGILI, C.O.; NDUBUEZE, O.V. (2024). Diagenetic Quality, Extent of Alteration and Preservation of Organic Matter of Wells A and B in Niger Delta Basin, Nigeria. *J. Appl. Sci. Environ. Manage.* 28 (12) 4073-4082

Dates: Received: 22 October 2024; Revised: 20 November 2024; Accepted: 08 December 2024; Published: 18 December 2024

Keywords: Calcareous nannofossils; Palynomorphs; Early Miocene; Diagenesis; Paleoenvironment

Palynology biostratigraphy is a branch of paleontology that combines the study of pollens, spores and other microscopic organic particles referred to collectively as "palynomorphs" with stratigraphic principles to establish the ages of rocks, paleoenvironmental interpretation and sedimentary layers (Adegoke, 2002; Fadiya *et al.*, 2020). Combaz (1964) used palynofacies to distinguish organic petrology from coral petrology and represent the total organic content of palynological assemblage. Palynofacies therefore, refers to the study of distribution, composition and preservation of palynomorphs which are microscopic organic particles derived from plants, algae, fungi and certain bacteria (Odedede, 2012). Palynomorphs are the individual organic particles that make up

**Corresponding Author Email: chiigili@yahoo.com*
ORCID: https://orcid.org/0009-0007-7730-5012
Tel: +234-8036933480

palynofacies (Combaz, 1964). They can be classified into several categories such as pollen and spores that is single-celled structures produced by fungi, ferns which are resistant to decay and can provide insights into past vegetation and environmental conditions (Fadiya *et al.,* 2020). Dinoflagelate cysts are marine organism that produce cyst as part of their life cycle which are resistant to decay and can be found in marine sediments, providing information about past marine environments and sea-level changes (Tyson *et al.,* 1993). Palynofacies analysis involves the identification of palynomorphs, plant debris and amorphous particles, their absolute and relative proportion, size and state of preservation (Combaz 1964). The analysis has assumed greater significance in oil exploration by virtue of its contributions to reconstruction of depositional environments which aid in the general evaluation of the hydrocarbon potential of sedimentary basin (Btten, 1982).

Nannofossil biostrtigraphy is a branch of paleontology that focuses on the study of microfossils called nannofossils which are remains or impressions of tiny marine algae known as coccoloithophores (Brown, 2005; Dairo, *et al.,* 2016). These organisms have distinct calcium carbonate shells called coccoliths which are composed of intricate plates arranged in various patterns (Dairo and Oladiran, 2016). The principle behind nannofossil biostrtigraphy is that different species of nannofossil evolved and became extinct at different times throughout Earth's history (Bown, 2010). By comparing the fossil assemblages found in different rock layers, we can identify specific nannofossil zones which corresponds to a particular time intervals (Fadiya *et al.,* 2020). Calcareous nannofossils are tiny (1-25µm) remains of golden brown single-celled algae subdivided into coccoliths and nannoliths (Perch-Nielsen, 1985). Coccoliths are the minute calcite plates produced by unicellular marine algae, the coccolithophorides (Olajide *et al.,* 2016). Coccoliths together with small calcite bodies called nanoliths by different school of thoughts, constitute the calcareous nannofossil group. Several authors (Olajide and Ekaete, 2016; Odedede, *et al.,* 2012; Fadiya, *et. al.,* 2020) studied palynomorphs and calcareous nannofossils within Niger Delta Basin and conclude that they represents a major tool used by biostratigrapher in the characterization of the reservoir strata and correlation in well site operation. It is also important in the accurate reconstruction of time of deposition during basin analysis. Knowledge of living coccolithophores have infact demonstrated that a precise recognition of biodiversity is necessary for paleoenvironmental study since even different morphotypes of a species complex may diverse ecological preference and biogeography. Calcareous nannofossils are particularly relevant when trying to reconstruct paleooceanographic and paleoenvironmental conditions (Raffi *et al.,* 2006).

Diagenesis, the physiochemical changes occurring in sediments post-deposition can significantly impact porosity, permeability and overall reservoir quality (Lai and Wang 2018). Joseph, *et al.,* (2021) studied Sedimentary facies and petrographic analyses of Miocene nearshore deposits, Central Swamp Depobelt, onshore Niger Delta Basin: implications for reservoir quality and concluded that petrophysical attributes are infuenced by depositional fabric, degree of diagenesis and matrix/cement proportions. He also said that bioturbation intensity may also play a crucial role in affecting these attributes. Considering these implications becomes a critical factor when modelling the petrophysical properties and estimating performance for marginal marine reservoir intervals, within the Niger Delta Basin. By analyzing fossil content and distribution, biostratigraphy can provide insights into the depositional environment and subsequent diagenetic alterations. In Niger Delta where varying sedimentary environments have led to diverse diagenetic pathways, integrating biostratigraphic data with diagenetic studies allows for a more comprehensive assessment of well quality. It will unravel the geological history of the formation. The objective of this paper is to evaluating the diagenetic quality and extent of alteration and preservation of organic matter of Wells A and B in the Niger Delta Basin, Nigeria

MATERIALS AND METHOD

An aggregate total number of sixty (60) 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.

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.

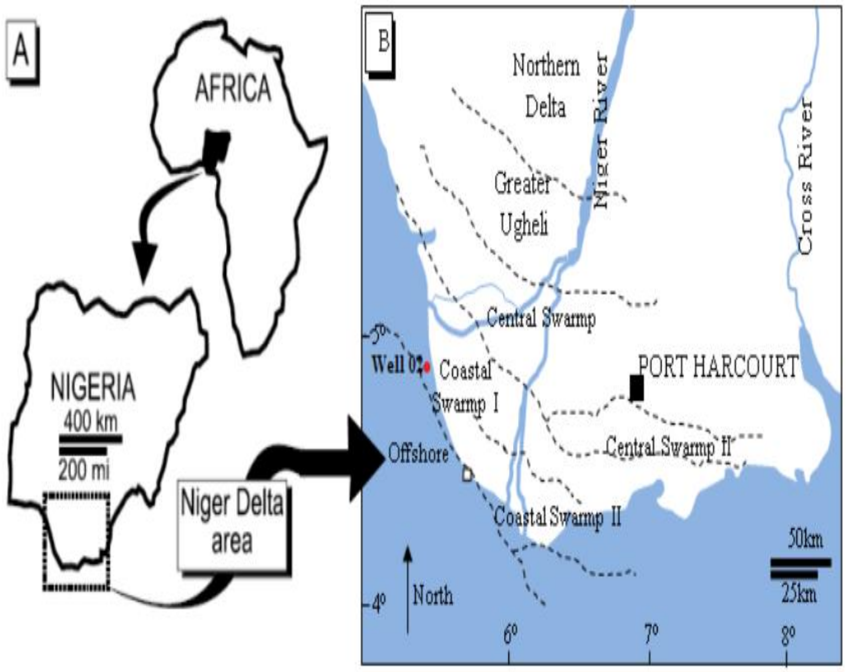

Fig. 1: Location of the study area. Simplified regional geological setting map of the Niger Delta basin, showing the different depobelts (Modified from Suyi 2014).

Palynological 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).

Calcareous Nannofossils Sample Preparation Procedures: Sample Preparation: A slight modification of the standard smear slide preparation was employed. About 5 gm of cuttings was measured and dried, the material was gently crushed using mortal and pestle (for shaly samples). The samples were treated with hydrogen peroxide to remove organic matter, washed with distilled water and dried again.

*Slide Preparation:*Small amount of the processed sample with distilled water. Crushed material was dispersed in distilled water in a tube. Pipette a few drops of the mixture onto a glass slide. A disposable glass pipette was employed to pipette the suspension for final slide making. The pipetted solvent was dried on a 22 x 40mm cover slip at a slightly hot temperature normally 40° - 50°C. Allow the mixture to dry completely.

Fix the sample with a few drops of Canada balsam or equivalent. The dried cover slip was then mounted on a glass slide using the Norland adhesive mounting medium and cured under the UV-light. For Data Interpretation Standard nannofossil zonation for all samples making use of the schemes of Martini (1971), Okada and Bukry (1980) and nannotax.org website was employed.

RESULT AND DISCUSSION

Calcareous Nannofossils Biostratigraphy of Well A: A total of eighteen (18) ditch cuttings from interval 11140 – 12580 m of well A were prepared and analysed for nannofossils at various interval. The analysis revealed a fair to common distribution of calcareous nannofossils over the upper interval 11140 – 11680 ft while interval 11680 – 12580 ft is characterized by rare and scattered distribution of non-age and –zonal diagnostic taxa as shown in Fig. 2. The occurrence of characteristic index markers within sample 11250 ft upper analysed section of the well facilitated the zonal delineation of the studied section using the zonation scheme of Martini (1971). The well section (Interval 11140 – 12580 ft) has been dated Late Miocene (NN9 and Older zones). Well B is barren of Calcareous nannofossils shown in Fig. 3.

Palynostratigraphic of Well A: Fig. 4 showed the palynological analysis carried on eighteen (18) ditch cuttings retrieved from well A. The results were used to decipher the age and possible diagenetic processes of the formation.

Microflora characterization: The studied section as shown in fig. 4 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.

Biostratigraphy: 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.

Palynostratigraphic of Well B: Twenty two (22) ditch cutting samples from the well B were processed and analysed for their palynomorph contents fig. 4. The results were used to decipher the age and possible diagenetic processes of the formation.

Microflora characterization: The studied section Fig. 4: 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.

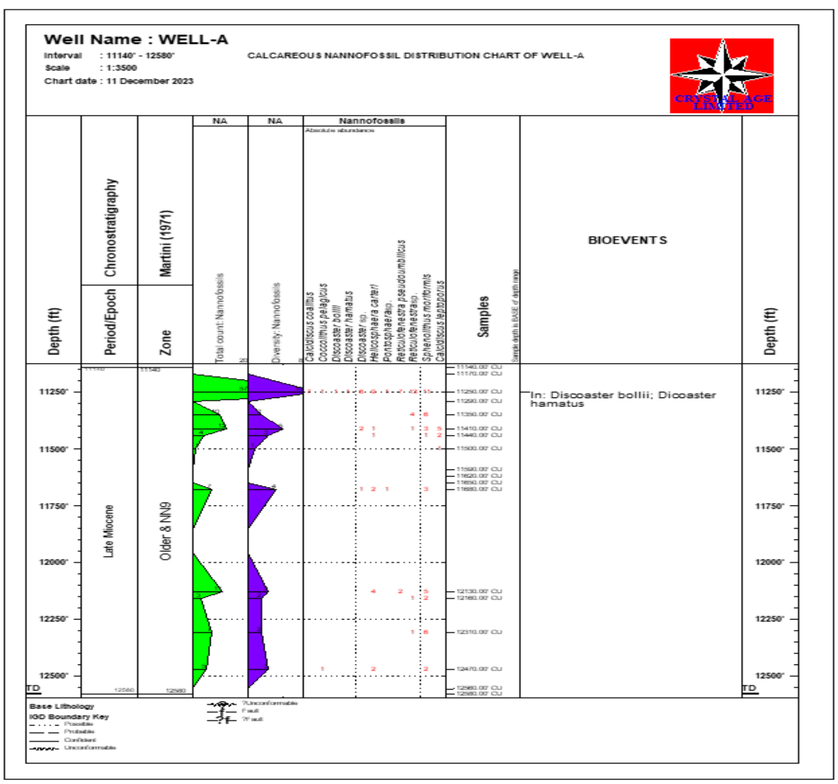

Fig. 2: Calcareous Nannofossil Distribution chart of Well A

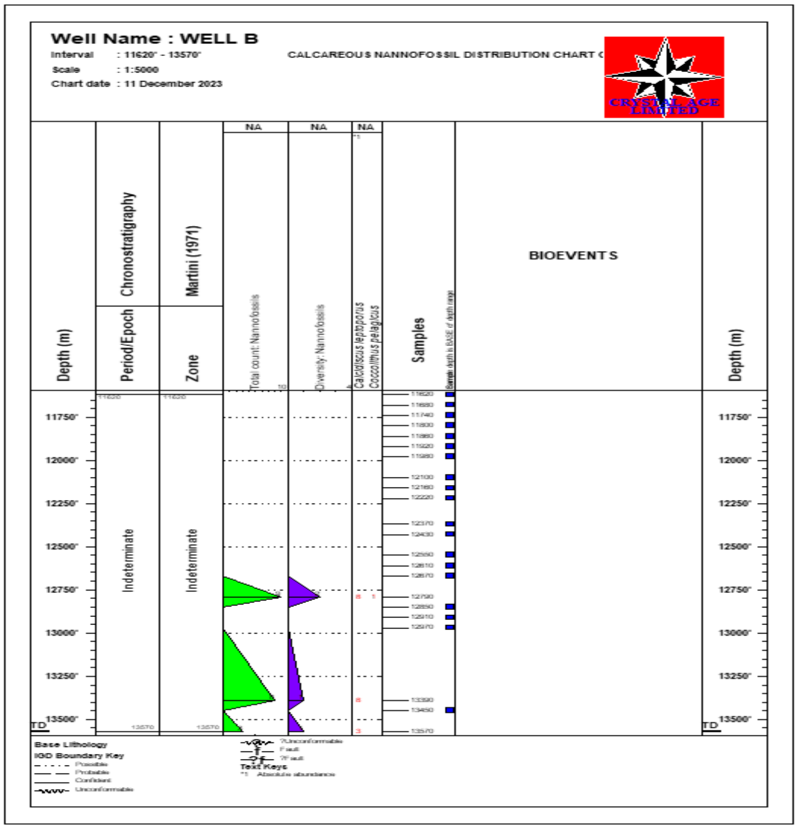

Fig. 3: Calcareous Nannofossil Distribution chart of Well B

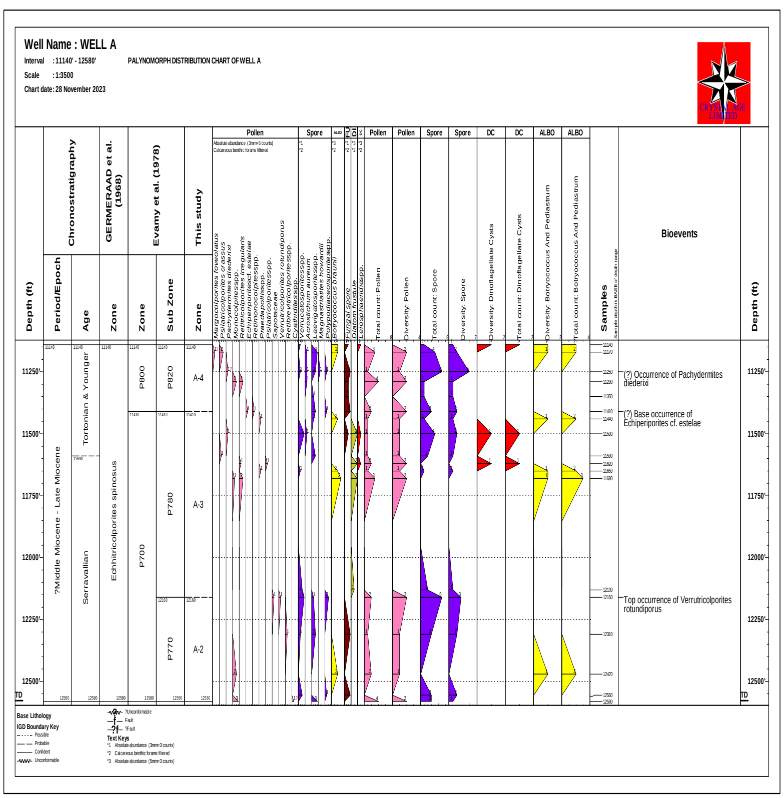

Fig. 4: Palynomorph distribution chart of Well A

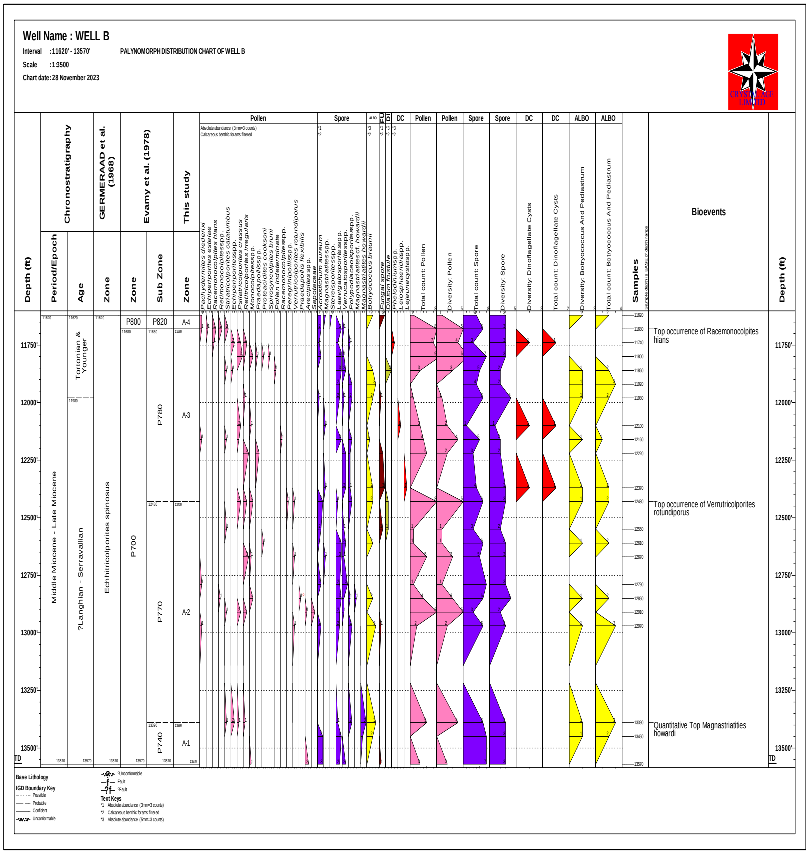

Fig. 5: Showing the palynomorph chart of Well B

Biostratigraphy: Based on the stratigraphic occurrence of marker species such as *Racemonocolpites hians*, *Verrutricolporites rotundiporus* and *Magnastriatites howardi*, 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. The studied sections was dominated by low to moderate records of terrestrial species such as *Retitiricolporites irregularis*, *Monocolpites sp.*, *Laevigatosporites* sp., *Verrcucatosporites* sp., *Acrostichum aureum*, *Psilatricolporites crassus*. Relatively common occurrence of fresh water algae *Botryococcus braunii* and fungal spore were also identified which are correlateable and similar with well be having *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*. With this, a general interpretation of the diagenetic history can be made.

Diagenetic history using calcareous nannofossil: Calcareous nannofossils are excellent indicators of diagenetic quality due to their sensitivity to changes in the sedimentary environment.

Preservation Quality: Presence of *Discoaster hamatus*, *Discoaster bollii*, and *Helicosphaera carteri* indicates a relatively stable and oxygenated environment, suggesting good preservation quality. Occurrence of *Catinaster coalitus* and *Coccolithus pelagicus* may indicate some degree of dissolution or reworking, suggesting fair preservation quality (Joseph *et al.*, 2022). Abundance of *Reticulofenestra pseudoumbilicus* and *Sphenolithus moriformis* could indicate a more stressful environment with potential dissolution or overcompaction, suggesting poor preservation quality (Joseph *et al.*, 2022).

Diagenetic Processes: Presence of *Reticulofenestra pseudoumbilicus* and *Sphenolithus moriformis* may indicate some degree of dissolution, potentially related to changes in pH or oxygen levels (Bown, and Newsam, 2017).

Abundance of *Sphenolithus moriformis* could suggest overcompaction, leading to deformation or fragmentation of nannofossils. Occurrence of *Catinaster coalitus* and *Coccolithus pelagicus* may indicate some degree of reworking, potentially due to changes in sediment supply or winnowing (Varol, 1992; Watkins and Bergen, 2003).

This suggest that both wells has experienced varying degrees of diagenetic alteration. While some intervals show good preservation quality, others have undergone dissolution, over-compaction, or reworking, resulting in fair to poor preservation quality.

Diagenetic history using palynofacies

Preservation Quality: Presence of *Retitricolporites irregularis, Monocolpites sp.,* and *Laevigatosporites sp.* indicates a relatively stable and oxygenated environment, suggesting good preservation quality. These palynomorphs are resistant to degradation and are often found in well-preserved sediments. Occurrence of *Verrucatosporites sp., Acrostichum aureum,* and *Psilatricolporites crassus* may indicate some degree of degradation or oxidation, suggesting fair preservation quality (Anyiam *et al.,* 2019; Odedede *et al.,* 2012). These palynomorphs are more susceptible to degradation than the ones mentioned above. Abundance of *Botryococcus braunii, Echiperiporites estelae*, and fungal spores could indicate a more stressful environment with potential degradation or contamination, suggesting poor preservation quality (Odedede *et al.,* 2012). These palynomorphs are often associated with degraded or contaminated sediments.

Diagenetic Processes: Presence of *Verrucatosporites sp.* and *Acrostichum aureum* may indicate some degree of oxidation, potentially related to changes in redox conditions. Abundance of *Botryococcus braunii* and fungal spores could suggest degradation, potentially due to microbial activity or changes in sediment temperature. Also, occurrence of *Echiperiporites estelae* may indicate some degree of contamination, potentially related to sediment reworking or drilling activities. This suggest that the wells has experienced varying degrees of diagenetic alteration. While some intervals show good preservation quality, others have undergone oxidation, degradation, or contamination, resulting in fair to poor preservation quality.

Conclusion: Ditch cutting samples from wells A and B were studied based on their calcareous nannofossils and palynomorphs present to analyze palynofacies assemblages, identify calcareous nannofossil zones, assess diagenetic alterations the diagenetic quality and extent of alteration and preservation of organic matter. The assemblages were dominated by moderate records of terrestrial sporomorphs and nannofossils. The wells has experienced varying degrees of diagenetic alteration. While some intervals show good preservation quality, others have undergone oxidation, degradation, or contamination, resulting in fair to poor preservation quality.

Declaration of Conflict of Interest: Authors have declared that no competing interests exist.

Data Availability Statement: Data are available upon request from the first author

REFERENCES

Abdel, GH; Sherif, F; Hatham, A (2013). Paleoclimatic Analysis of the Late Oligocene/Middle Miocene Planktonic fauna of west central Siani, Egypt. *Egypt. J. Paleontology.* 13: 29-48.

Adegoke, OS (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, FV; Arochukwu, EC; Abdul-Kareem, AS (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, OA; Eradiri, JN; Mode, AW; Okeugo, CG; Okwara, IC; Ibemesi, PO (2019). Sequence stratigraphic analysis and reservoir quality assessment of an onshore feld, Central Swamp Depobelt, Niger Delta Basin Nigeria. *Arab. J. Geo*, 12 (24): 791 - 798.

Atta-Peters, D; Agama, CI; Asiedu, DK; 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, DJ (1982). Palynofacies, palaeoenvironments and petroleum. *J. Micropal.* 1: 107-114.

Boboye, EA; Adeleye, AM (2009). High resolution biostratigraphy of Early Pliocene to Late Miocene calcareous Nannoplankton and foraminifera, deep offshore, Niger Delta, Nigeria. *Euro. J. Sc. Research*, 34: 308 – 325

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

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

Bown, PR; Dunkley Jones, T (2012). Calcareous nannofossils from the Paleogene equatorial Pacific (IODP Expedition 320 Sites U1331-1334). *J. Nannoplankton Research*. 32 (2): 3-51.

Bown, PR; Newsam, C (2017). Calcareous nannofossils from the Eocene North Atlantic Ocean (IODP Expedition 342 Sites U1403–1411). *J. Nannoplankton Research*. 37 (1): 25 60

Bridge, JS; Lunt, IA (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, MA; Filho, JGM; Menezes, TR (2006). Palynofacies and sequence stratigraphy of the Aptian-Albian of the Sergipe Basin, Brazil. Sedimentary Geology 192 (5), 57-74.

Christopher, RA; Goodman, DK (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, VA; Oladiran, MA (2016). Biozonation and correlation of two wells in Niger Delta using calcareous nannofossils. Acta Palaentologia Romaniae 12 (1): 43-45.

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

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

Ekweozor, CM; Dankoru, EM (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: 599 -614

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

Evamy, BD; Haremboure, J; Kamerling, P; Knaap, WA; Molloy, FA; Rowlands, PH (1978). Hydrocarbon habitat of Tertiary Niger Delta. American Association Petroleum Geologist, Bulletin. 62: 1-39.

Ezekwe, JN; Filler, SL (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, SL; Ogunleye, SO; Oyelami, AB; Aroyewun, FR (2020). Palynostratigraphic and Palynofacies Analysis of X and Y Wells, Offshore Niger Delta, Nigeria. *Ife. J. Sci.* 22 (3):

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

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

Germeraad, JH; Hopping, CA; Muller, J (1968). Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology 6, 189-348.

Howard, HA; Braiser, MD (2004). Microfossils, Second Edition. Blackwell Publishing, Maden, Massachusetts, USA, 55: 16-23.

Itiowe K1; Omontese SO; Adiela UP (2016). Paleo-environmental Reconstruction of 't' Well in the Niger-Delta Basin, South-South Nigeria *J. Sci. Engr. Research*, 3 (6): 352-355

Jones, R (2006). Aplied Paleontology. Cambridge University. Cambridge, UK. 48-67. Pleistocene climates and the Plio-Pleistocene Boundary

Joseph, NE; Ehimare, EO; Ikenna, CO; Ayonma, WM; Okwudiri, AA; Ngozi, AU; Maryanna IU (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, SHE; Ibrahim, MI (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, P. 143-172.

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

Martinez, MA; Pramparo, MB; Quattrocchio, ME; Zavala, CA (2008). Depositional environment 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, p. 739–785.

Mathew, UA; Paul, AU; Thomas, AH; Monday, UU; Athanasius, GU (2020). Seismic Stratigraphy and Reservoir Characterization of 'E' Field Sediments: Inferences from South-Eastern Late Miocene – Pliocene Records, Offshore Niger Delta. *J. Nat. Sci. Research ISSN 2224-3186* 11:14.

Michele, LWT; Ronald, RC; Michael, EB (1999). The Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa. United State Geological Survey. Denver Colorado: p. 4 - 70

Oboh, FE (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, FE; Salami, MB; Chapman, JL (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, FA; Asuen, GO (2012). Sequence Stratigraphy and Palaeoenvironmental Studies of Palynoflora from E-12 Well, Offshore Niger Delta. *J. Min. Geol.* 48 (2), 185-198.

Odedede, O; Ogala, JE; Ugbeh, FC (2016). Palynological Zonations and Sequence Stratigraphic Analysis of Sediments in Benin West-1, Anambra Basin, Nigeria. *J. Sc. Research.* 8 (2): 171-179

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

Powell, AJ; Dodge, JD; 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, LJ; Hilgen, FJ (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. P. 67-83.

Rocanglia, L; 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, GC; Omoboriowo, AO; Yikareboga, Y; Madu, VC (2013). Paleoenvironmental and sequence stratigraphic studies of the D7000 sand, 'Erne' field, Niger Delta, Nigeria. *Greener J. Phy. Sci.* 3: 6 -18.

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

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

Varol, O (1992). Sullivania a new genus of Palaeogene coccoliths. *J. Micropalaeontology*, 11(2): 141-149.

Watkins, DK; Bergen, JA (2003). Late Albian adaptive radiation in the calcareous nannofossil genus Eiffellithus. *Micropaleontology*, 49 (3): 231-250.