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# Palynostratigraphic and palynofacies interpretations of the Muller–1 Well, Niger Delta

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## ABSTRACT

The sedimentary intervals of Muller-1 Well, located in the Greater Ughelli Depobelt, Niger Delta Basin, Nigeria, have been subjected to palynological and sedimentological studies, to biozonation and paleoenvironmental results. Ten (10) samples from 8920-9054 ft have been analyzed. There were a few common occurrences of pollen and spores with other organic-walled microfossils such as *Botryococcus braunii*, fungal spores, and diatom frustules. The sedimentological characteristics include shale intercalations with coarse-to-medium to fine-grained sandstones, indicating energy conditions that are typical of deltaic systems. The entire intervals belong to the Agbada Formation. One palynostratigraphic zone of *Cyathidites* sp. was established for the studied intervals using the International Stratigraphic Guide. The zone is an assemblage biozone, and a Paleocene (Thanetian) age was assigned to the interval based on the stratigraphic age range of diagnostic markers such as *Longerapertites* sp., *Cyathidites minor*, *Tricolporopollenites* sp., and *Monocolpites marginatus*. Hydrocarbon potential is suggested by deltaic deposits with terrestrial pollen/spores (likely gas-prone) and shale interbeds, consistent with the Agbada Formation's proven gas reservoirs in the Niger Delta Basin.

## Highlights

- Paleocene (Thanetian) age assigned using key palynomorphs like *Cyathidites minor* and *Monocolpites marginatus*.
- Deltaic deposits, with shale-sandstone interbeds, suggest hydrocarbon (gas-prone) potential.
- Agbada Formation confirmed via palynology and sedimentology, aligning with Niger Delta's proven gas reservoirs.

## 1. Introduction

The Niger Delta Basin, located in the South Atlantic Ocean and the West African craton, is one of the world's most productive hydrocarbon-producing areas. The complex depositional environment of the Cenozoic sedimentary basin was developed over millions of years as a result of tectonic activity, eustatic sea-level shifts, and climate oscillations (Nwajide, 2013). With a size of roughly 75,000 square kilometers, the basin contains enormous quantities of gas and oil that have been used for business purposes since the 1950s (Doust & Omatsola, 1990). The hydrocarbon potential of the basin is important, but so are its distinct stratigraphic and paleoenvironmental features,

which shed light on the basin's geological past. A complex succession of paralic and marine facies was created by the formation of deltaic depositional systems as a result of sediment movement from the Niger River, as highlighted by several studies (Short & Stauble, 1967; Evamy et al., 1978). The Akata, Agbada, and Benin Formations are the three main lithostratigraphic formations in the Niger Delta Basin, and they are well known for their importance in the search for hydrocarbons. The main source rock is thought to be the Akata Formation, which is mostly made up of marine shales. The main reservoir rock is thought to be the Agbada Formation, which is made up of sandstones and shales that alternate (Weber & Daukoru, 1975). In sedimentary basins, the study of preserved pollen and spores is a crucial technique for determining age

(Morley, 1995). The abundance of palynomorphs in the Niger Delta Basin, including spores, pollen, and dinoflagellate cysts, provides useful biostratigraphic markers that help in determining the age of sedimentary sequences (Germeraad et al., 1968). Pollen, spores, and organic microfossils provide insight into the geological history of the Niger Delta. *Retidiporites magdalenensis*, *Longapertites* sp., and *Monocolpites marginatus* are notable biozone indicators that have been found in earlier studies. Several other important palynomorphs have also been identified, including *Magnastriatites* (tropical forests/coastal ecosystems), *Psilatricolporites* (tropical forests), *Inaperturopollenites* (freshwater settings), and *Spinizonocolpites* (mangrove/coastal environments). *Proxapertites* (Miocene-Pliocene), *Psilamonocolpites* (Pliocene-Pleistocene), *Foveotrilletes* (Pleistocene-Holocene), *Echitricolporites* (Eocene-Oligocene), and *Cingulatzonocolpites* (Oligocene-Miocene) are some more noteworthy palynomorphs. By using these microfossils, researchers can create biostratigraphical frameworks, reconstruct paleoenvironments and paleoclimates, and connect Niger Delta strata to major geological events worldwide. In the oil and gas sector, this data influences exploration and production plans. Studies by Jan du Chêne et al. (1978) and Jaramillo and Dilcher (2001) offer important new perspectives on the palynological record of the Niger Delta. Scientists can better comprehend the geological evolution of the area and its implications for natural resource management by examining these important palynomorphs. Some researchers in the Niger Delta basin have established biozones using the alpha-numeric method (Evamy et al., 1978; Morley, 1995; Ajaegwu et al., 2012; Olayiwola and Bamford, 2016; Efemena et al., 2021). A Standard biozonation scheme that aligns with the International Stratigraphic Guide for the establishment of biozones is necessary.

Analyzing paleoenvironments entails examining different forms of organic matter and the habitats in which they were deposited. This information is crucial for understanding the paleoenvironmental circumstances at the time of sediment deposition (Tyson, 1995). Amorphous organic matter (AOM), phytoclasts, and palynomorphs are the three main categories of organic matter found in sedimentary rocks. These elements show a variety of depositional habitats, from sea to land (Tyson, 2012). When sea level is low, the predominance of phytoclasts produced from land indicates fluvial-deltaic conditions, but the presence of marine palynomorphs, such as dinoflagellate cysts, indicates periods of marine incursion (Omietimi, 2025). The results align with other paleoenvironmental reconstructions of the Niger Delta Basin, which show cyclical fluctuations between deltaic and marine conditions caused by eustatic sea-level fluctuations (Petters, 1984). The Niger Delta Basin's paleoenvironmental conditions have been reconstructed in some studies using palynofacies analysis, revealing important trends in sedimentation patterns and the preservation of organic matter (Adebayo et al., 2018).

Hydrocarbon exploration relies heavily on lithostratigraphy, the study of the physical properties of rock units, to locate reservoir, source, and seal rocks. The Akata, Agbada, and Benin Formations comprise the lithostratigraphic framework of the Niger Delta Basin, which is essential to comprehending the petroleum system in the basin (Doust & Omatsola, 1990). The main reservoir unit in the Niger Delta is the Agbada Formation, which is distinguished by its alternating layers of sandstone and shale. These sandstones are perfect for the buildup of hydrocarbons since they are extremely permeable and porous (Alao et al., 2013). Conversely, the interbedded shales trap hydrocarbons inside the sandstone layers by serving as both source and seal rocks.

Owing to its stratigraphic significance and function in evaluating the hydrocarbon potential of the area, the Muller-1 Well, situated in the Greater Ughelli depobelt of the Niger Delta Basin, has drawn notice. A valuable stratigraphic record spanning multiple geological epochs is provided by the well, which was drilled in the mid-20th century (Doust, 1989). Exploring the age and depositional environment of sedimentary units is a valuable opportunity as it provides insight into the Niger Delta's larger geologic evolution. It has the potential for more hydrocarbon exploration and development because of its location in an area well-known for producing gas and oil. Using lithostratigraphic, palynological, and palynofacies analyses on the Muller-1, this study sheds light on the hydrocarbon potential, depositional environment, and age of the area. Important paleoenvironmental markers and biostratigraphic zones will be established via palynological examination of core materials. The results will promote reservoir correlation throughout the basin, evaluate the age and richness of possible source rocks, and aid in the reconstruction of the stratigraphic framework. In both the mature and frontier portions of the basin, such an integrated approach is essential for improving hydrocarbon prospectivity and lowering exploration risk.

## 2. The Study Area

The Muller-1 Well (Figure 1) is situated in Nigeria's Niger Delta Basin, in the Greater Ughelli depobelt, an area well-known for its hydrocarbon deposits. This region, which is roughly located at latitude 5°30'N and longitude 6°00'E, is distinguished by a dynamic deltaic environment with alternating marine impacts. The well's strategic location adds to its importance in comprehending the Niger Delta Basin's geology and petroleum potential.

### 2.1 The Geologic and Tectonic History of the Niger Delta

One of the most prolific hydrocarbon provinces in the world, the Niger Delta Basin, which spans around 75,000 km<sup>2</sup>, is situated in southern Nigeria (Doust & Omatsola, 1990; Short & Stauble, 1967). Due to the opening of the South Atlantic Ocean, the tectonic plates of Africa and South America started to split apart during the Cretaceous period, which is when their geological history began (Evamy et al., 1978). After undergoing complex tectonic and sedimentary processes, the proto-Niger Delta was formed as a result of this rifting and developed into the current deltaic system that we see today (Doust, 1989). Acknowledged as a failed arm of the triple junction that developed during the separation of the two continents in the Late Jurassic to Early Cretaceous periods, the Benue Trough and the ensuing basin formation are directly related to the early rifting (Weber & Daukoru, 1975). Because of the region's major influence from extensional tectonics, the nascent basin developed. Thick sedimentary layers were easier to deposit in the Benue Trough due to subsidence that was visible by the mid-Cretaceous (Short & Stauble, 1967). In the Late Cretaceous, the first delta started to form when rivers carried continental materials into the Basin (Reijers, 2011). The Niger Delta is a passive margin basin with crustal extension and sedimentation processes that further characterize its geologic structure. In the early stages of the sedimentary basin's formation, marine transgressions predominated and marine shales were deposited; however, as the basin matured, the substantial sediment input from rivers draining the continental interior caused it to change into a primarily deltaic system

(Doust & Omatsola, 1990; Reijers, 2011). The Paleocene is when the contemporary Niger Delta originated, and it has continued to change throughout the Eocene, Oligocene, Miocene, and Pliocene periods (Evamy et al., 1978; Doust, 1989). Significant volumes of sediments from inland regions have been brought into the basin by several fluvial systems since the Eocene, causing the Delta to prograde continuously (Short & Stauble, 1967). The existing structure of the delta has been greatly influenced by the continuous processes of subsidence, sediment loading, and compaction of deltaic sediments (Reijers, 2011). Three primary lithostratigraphic units—the Agbada, Benin, and Akata formations—are identified within this complicated sedimentary environment. Every formation is representative of a different depositional environment and is essential to the accumulation of hydrocarbons (Weber & Daukoru, 1975). The Agbada Formation's sandstone reservoirs function as an efficient environment for trapping hydrocarbons, whereas the Akata Formation, which is mainly composed of marine shales, is an essential source rock. With its continental sands, the Benin Formation serves as a major aquifer, facilitating groundwater flow in the region. Collectively, these stratigraphic units illustrate the Niger Delta's importance in regional geology and energy resources while also illuminating the complex interactions between geological

processes that have turned it into a major hydrocarbon province in the international arena.

2.2 Stratigraphy of the Niger Delta

The Niger Delta's stratigraphy is separated into three main formations: Akata, Agbada, and Benin Formations (Table 1). Different depositional conditions are represented by these strata, which regulate the distribution and accumulation of hydrocarbons throughout the basin. As the principal source rock for hydrocarbons, the organic-rich sediments of the Akata Formation, which were deposited between the Paleocene and the present, are primarily marine shales with sporadic turbidite sands and clays (Doust & Omatsola, 1990; Reijers, 2011). As the major reservoir, alternating sandstones and shales make up the Agbada Formation, which spans from the Eocene to the present and represents the transition from deep marine to deltaic settings (Agyingi, 2013). The Benin Formation was deposited between the Oligocene and the present and is made up of continental sandstones has freshwater aquifers. It represents a fluvial-deltaic depositional environment, characterized by predominantly coarse-grained, porous, and unconsolidated sands interbedded with minor shales and clay lenses (Weber & Daukoru, 1975).

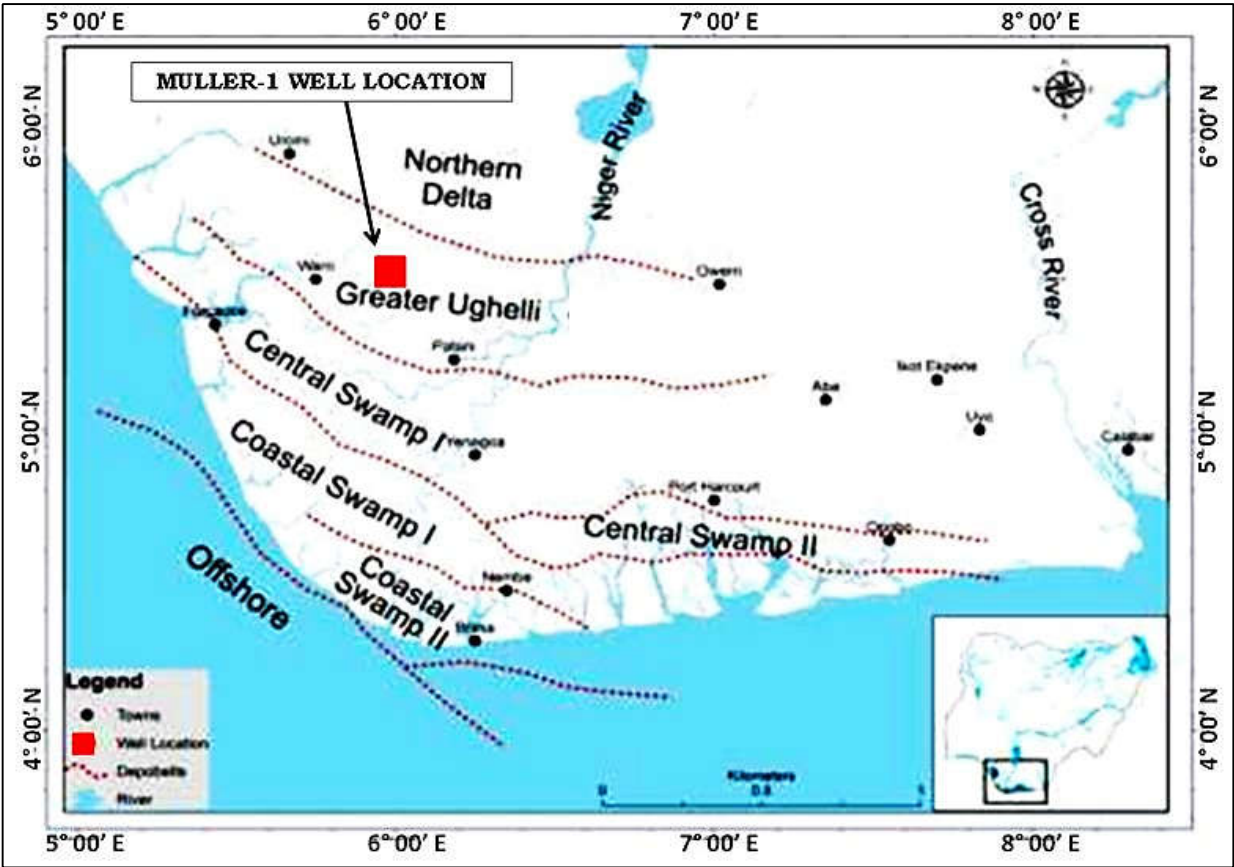


Figure 1: Geological maps of the Niger Delta basin. Study location in red rectangle (modified after Aladeitan et al., 2024).

Table 1: The stratigraphic framework of the Niger Delta (Reijers, 2011).

Formation	Age	Lithology	Depositional Environment	Significance
Benin	Oligocene to Recent	Coarse-grained sandstones, minor clay lenses	Continental (fluvial, floodplain)	Cap rock, freshwater aquifers
Agbada	Eocene to Recent	Alternating sandstones and shales	Delta-front, delta-plain, fluvial	Primary hydrocarbon reservoirs
Akata	Paleocene to Recent	Marine shales, minor turbidite sands, and clays	Deep marine (slope, basin floor)	Hydrocarbon source rock

### 2.3 Tectonic Evolution, Subsidence, and Hydrocarbon Potential

Extensional faulting brought on by the movement of the African plate with the South American plate has affected the tectonic history of the Niger Delta. Normal faults that resulted from rifting during the Cretaceous period shaped patterns of sediment deposition (Doust & Omatsola, 1990; Short & Stauble, 1967). Growth faults and rollover anticlines became more prevalent when sedimentary loads rose and subsidence persisted; these features are essential for capturing hydrocarbons (Weber & Daukoru, 1975). Hydrocarbons migrate across important listric faults from source rocks into reservoir rocks, which run from the Agbada Formation into the Akata Formation (Evamy et al., 1978; Reijers, 2011). The Niger Delta is now a well-known hydrocarbon region as a result of structural and stratigraphic traps in the Agbada Formation. According to Ekweozor and Daukoru (1994), hydrocarbon traps are further formed by shale diapirism, which is brought on by overpressured shales in the Akata Formation.

Since the 1956 discovery of the Oloibiri field, the Niger Delta Basin has played a significant role in the world's oil production. The intricate stratigraphy, tectonic environment, and depositional history of the delta are all strongly related to its hydrocarbon potential (Doust, 1989; Weber & Daukoru, 1975). An optimal environment for hydrocarbon formation, migration, and accumulation is created by the combination of high-quality reservoir rocks in the Agbada Formation, organic-rich source rocks in the Akata Formation, and efficient sealing units in the Benin Formation (Diab et al., 2023). The main locations of hydrocarbons in the Niger Delta are stratigraphic traps created by deltaic depositional

processes and rollover anticlines connected to growth faults (Oyanyan & Oshinowo, 2020). The primary hydrocarbon reservoir is the Agbada Formation, where productive zones are composed of stacked sandstones. The Delta is a crucial area for the production of both oil and gas since it has a predominantly oil-based hydrocarbon system, but it also contains sizable amounts of natural gas (Ite et al., 2013).

### 3. Materials and Methods

Systematic sampling methods were adopted, and ten (10) core samples were collected to obtain valuable initial data and assess subsurface stratigraphy and paleoenvironmental conditions. A hammer, chisel, and sample bags were used for sampling. The materials were examined in a sedimentological laboratory using the AmScope SM-2T Trinocular Stereo Microscope. To detect carbonate content, 10% HCl was used. The sediment texture was evaluated using a comparative chart (Efemena and Maju-Oyovwikowhe, 2022). The sedimentological analysis of the shale samples involved a detailed microscopic examination of their grain size, shape, mineral content, and fossil remains. Fossil remains, including microfossils and organic matter, were identified, providing crucial insights into the paleoenvironmental conditions at the time of shale formation. For palynological analysis, 15 grams of dry sample was crushed to a particle size between 0.25mm and 2.5mm, and the mineral matrix was disintegrated using dilute HCl to remove carbonates (Faegri et al., 1989). The samples were then washed and neutralized before being treated with concentrated HF for silicate digestion over 15 hours, followed by the removal of fluoride gel with hot

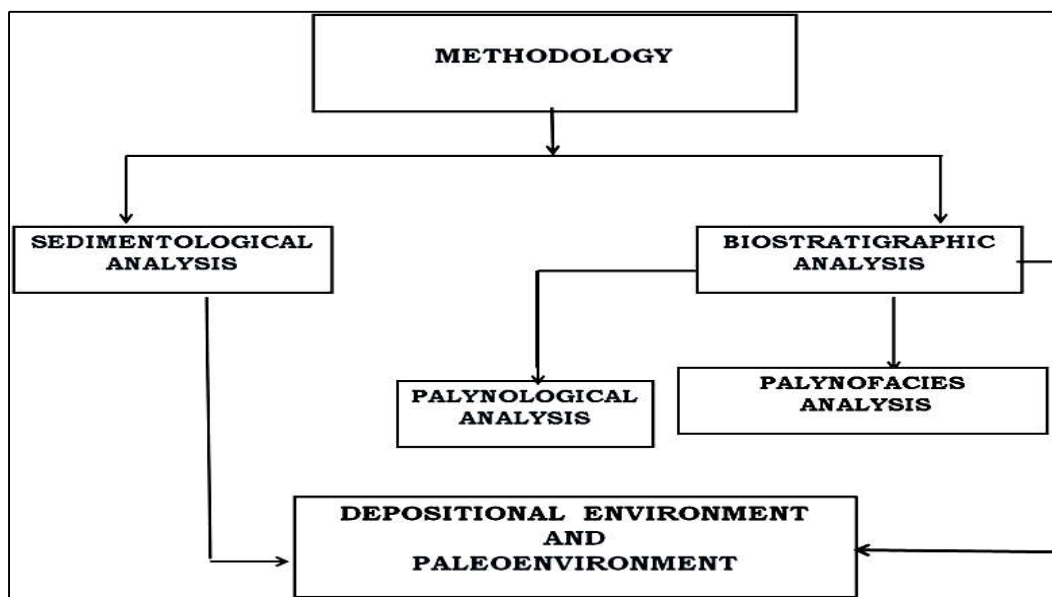


Figure 2: Methodology flow chart for this study.

HCl in 40 minutes. After neutralization, the dark particles were removed via oxidation using concentrated  $\text{HNO}_3$ , leaving behind only the palynomorphs. Organic matter was separated from inorganic matter by adding zinc bromide ( $\text{ZnBr}_2$ ) solution (S.G. 2.2 to 2.4), allowing the organic matter to float to the surface, which was then collected for analysis. The recovered palynomorphs were mounted onto slides and accurately labeled with their name, number, and depth interval for

further examination. For palynofacies (kerogen) analysis, similar sample preparation techniques were used, including treatment with HCl and HF to isolate the organic fraction. Density separation using heavy liquid separation was also employed to isolate different fractions of organic matter based on density. Palynomaceral evaluation and microscopic identification of micro-plant materials were carried out. The palynomaceral types (PM-1, PM-2, PM-3, and PM-4), their

abundance and sizes, as well as Structureless Organic Matter (SOM), were recorded and characterized in more detail using specialized software (Figure 2).

4. Results and Discussion

4.1 Lithostratigraphic Units

The lithologies of the studied interval are mainly sandstone, shale, clayey sand, and coal. The thickness of the analyzed interval is 120 ft

(Figure 3). This analysis revealed a fine-grained texture, predominantly composed of clay minerals with occasional silt-sized grains, indicating deposition in low-energy environments (Nichols, 2009). Fossil remains, including microfossils and organic matter, were identified, providing crucial insights into the paleoenvironmental conditions at the time of shale formation. These lithologies represent alternating high- and low-energy depositional environments typical of deltaic settings within the Niger Delta Basin.

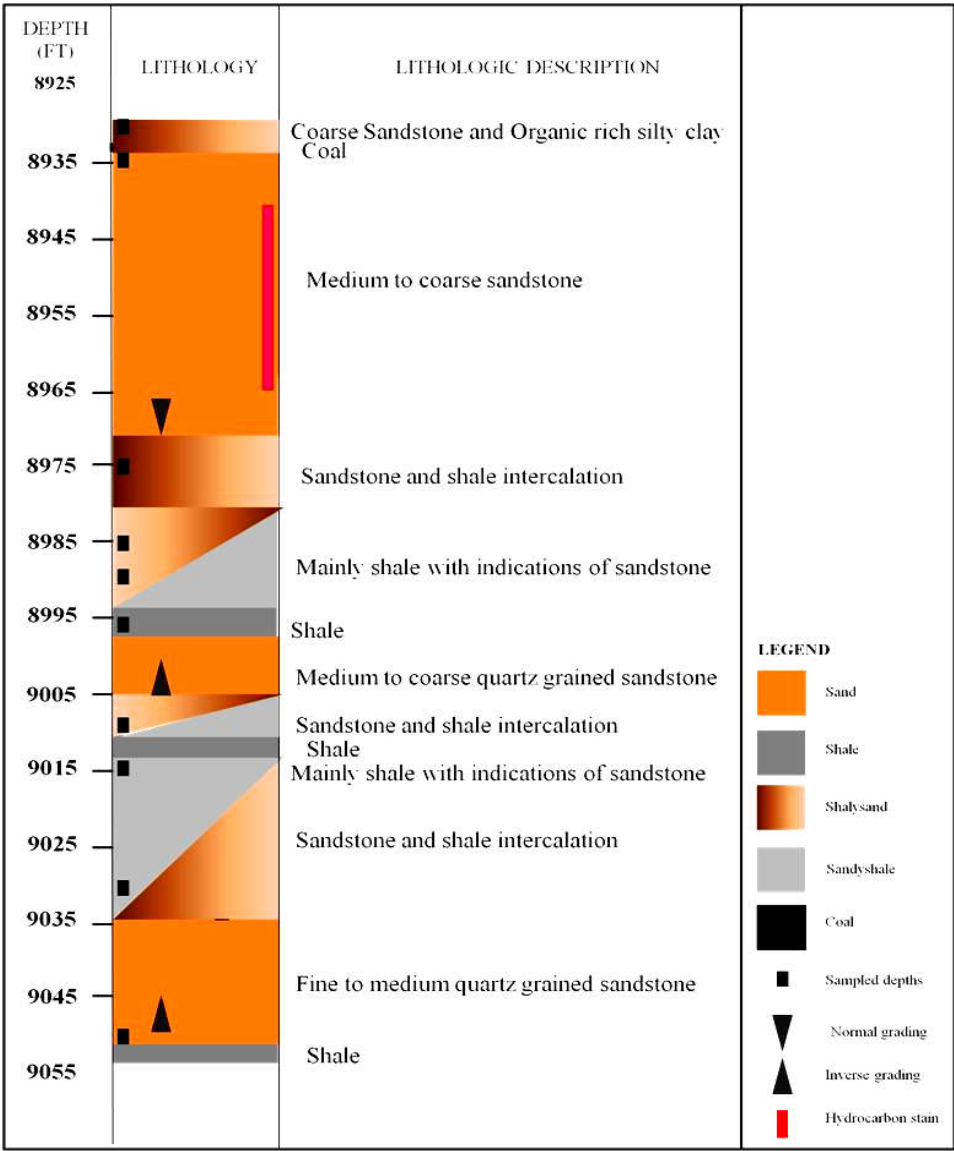


Figure 3: Lithostratigraphic log of Muller-1 Well.

4.2 Lithological Description:

- a. **Sandstone:** Smokey white to orange in color, fine to coarse-grained, sub-angular to sub-rounded, and well sorted. The occasional presence of ferruginization, plant materials, muscovite flakes, and carbonaceous fragments suggest deposition under varying energy conditions, with intermittent terrestrial input. The good sorting and rounding indicate prolonged transport, likely in fluvial to distributary channel systems.
- b. **Shale:** Brown to grey, occasionally black, fissile, moderately hard, and sometimes carbonaceous. These characteristics point to low-energy environments, such as floodplains, lagoonal, or prodelta settings, with possible anoxic conditions indicated by the dark coloration and carbonaceous content.
- c. **Clayey Sand:** Milkish to light brown, medium to coarse-grained, poorly sorted, and rich in plant debris. These features indicate deposition in transitional zones such as levees or



crevasse splays, where sediments were deposited rapidly with limited sorting.

- d. **Coal:** Black with vitreous luster and containing fine particles. Its presence confirms the development of peat-forming swamps, indicative of continental to paralic depositional environments, often formed during periods of low clastic influx.

### 4.3 Facies and Stratigraphic Interpretation

The section reveals 13 lithostratigraphic units, grouped into seven distinct Lithofacies (Figure 3) based on texture, composition, and vertical arrangement:

1. **Unit 1 (8929.00–8934.00 ft):** Coarse sandstone and organic-rich silty clay suggest channel fill overlain by overbank or floodplain deposits.
2. **Unit 2 (8934.00–8935.00 ft):** A thin coal seam indicates brief swamp development, potentially during a pause in clastic deposition.
3. **Unit 3 (8935.00–8972.00 ft):** Thick, medium to coarse sandstone represents a dominant channel sand body, suggesting a high-energy fluvial or distributary channel.
4. **Unit 4–5 (8972.00–8994.00 ft):** Interbedded sandstone and shale, then predominantly shale, imply decreasing energy, marking a shift to lower-energy floodplain or prodelta conditions.
5. **Units 6–10 (8994.00–9016.00 ft):** Recurrent alternations of shale and sandstone suggest cyclical changes in energy conditions, perhaps driven by fluctuating sea levels or avulsion processes in a delta-front environment.
6. **Unit 11 (9016.00–9035.00 ft):** This interval is characterized by the continued interbedding of sandstone and shale, suggesting fluctuating energy conditions associated with distributary or tidal channel systems. The repeated alternation of facies indicates active sedimentation in a transitional environment between the delta front and delta plain.
7. **Unit 12–13 (9035.00–9054.00 ft):** This section consists predominantly of fine to medium-grained sandstone

transitioning into shale, indicating a shift from higher energy deposition back to lower-energy prodelta or bay fill environments. The fining-upward trend supports a waning depositional energy scenario, likely linked to marine influence or deltaic abandonment phases.

The lithostratigraphic analysis of the Muller–1 Well reveals a complex vertical succession of sandstone, shale, clayey sand, and coal units, typical of a deltaic depositional system. The identified lithofacies indicate repeated shifts between high-energy fluvial or distributary channel environments and low-energy floodplain, swamp, and prodelta settings. These alternations reflect dynamic sedimentary processes such as channel migration, avulsion, and relative sea-level changes within the Greater Ughelli Depobelt. These detailed facies interpretation provides a foundational framework for understanding the stratigraphic architecture and enhances reservoir characterization, ultimately supporting more effective hydrocarbon exploration and development in the basin.

### 4.4 Palynomorph Distribution

The microscopic examination of particulate organic matter (POM) revealed the presence of amorphous organic matter (AOM), phytoclasts, and palynomorphs, providing a comprehensive understanding of the overall organic composition. Table 2 provides palynomorph counts at different depths, reflecting changes in vegetation, climate, and depositional environment over time. The dominant palynomorphs identified across the samples include fungal spores, which are consistently present, suggesting humid conditions with abundant decaying organic matter. Diatom frustules are also abundant, indicating deposition in aquatic or wetland environments. *Laevigatosporites* sp., likely representing fern spores, recur in several intervals reflecting persistently moist conditions. *Monocolpites marginatus* and *Monocolpites* sp., associated with monocotyledonous plants like palms and grasses, appear frequently, suggesting open vegetation or marshy habitats. *Verrucatosporites* sp., occurring in moderate counts, points to fungal or algal input into the depositional environment.

**Table 2:** Recovered palynomorphs for MULLER-1 Well samples.

S/No.	Depth	Palynomorphs	Counts
1	8933	<i>Laevigatosporites</i> sp., <i>Diatom frustules</i> , <i>Psilatricolporites</i> sp.	2, 5, 1
2	8935	Fungal spores, <i>Monocolpites marginatus</i> , <i>Tricolporopollenites</i> sp., <i>Sapotaceae</i> , <i>Laevigatosporites</i> sp., <i>Verrucatosporites</i> sp., <i>Leiosphaeridia</i> sp., <i>Monoporites annulatus</i> , <i>Diatom frustules</i> , <i>Verrutricolporites</i> sp.	13, 2, 2, 1, 5, 12, 1, 1, 18, 1
3	8975	<i>Laevigatosporites</i> sp., <i>Retitricolporites irregularis</i> , <i>Leiosphaeridia</i> sp., <i>Diatom frustules</i>	1, 1, 1, 4
4	8985	<i>Phelodinium</i> sp., <i>Diatom frustules</i> , Fungal spores, <i>Tricolporopollenites</i> sp., <i>Monocolpites</i> sp., <i>Canthiumidites</i> sp., <i>Brevicolporites guinetii</i> , <i>Verrucatosporites</i> sp., <i>Inaperturopollenites</i> sp., <i>Retitricolporites irregularis</i> , <i>Cyathidites</i> sp.	1, 18, 15, 2, 2, 1, 2, 3, 1, 2, 1
5	8990	<i>Laevigatosporites</i> sp., <i>Monocolpites</i> sp., <i>Peregrinipollis nigericus</i> , <i>Psilatricolporites</i> sp., <i>Leiosphaeridia</i> sp., <i>Monoporites annulatus</i> , <i>Tricolporopollenites</i> sp., <i>Cyathidites</i> sp., Fungal spores, <i>Polypodiaceoisporites</i> sp., <i>Racemonocolpites</i> sp., <i>Striatricolporites catatumbus</i> , <i>Canthiumidites</i> sp., <i>Sapotaceae</i>	6, 3, 1, 1, 7, 1, 2, 1, 12, 1, 1, 1, 1, 1
6	8996	<i>Monocolpites marginatus</i> , <i>Verrucatosporites</i> sp., Fungal spores, <i>Cyathidites minor</i> , <i>Laevigatosporites</i> sp., <i>Monoporites annulatus</i> , <i>Adenanthites simplex</i> , <i>Diatom frustules</i> , <i>Tricolporopollenites</i> sp., <i>Monocolpites</i> sp.	1, 2, 5, 2, 3, 1, 1, 5, 1, 1
7	9013	<i>Diatom frustules</i> , <i>Monocolpites</i> sp., <i>Cyathidites</i> sp., Fungal spores, <i>Verrucatosporites</i> sp., <i>? Retibrevitricolporites obodoensis</i>	3, 1, 2, 1, 2, 1
8	9015	Fungal spores, <i>Psilatricolporites</i> sp., <i>Monocolpites</i> sp., <i>Inaperturate pollen</i> , <i>Acrostichum aureum</i> , <i>Polypodiaceoisporites</i> sp., <i>Brevicolporites guinetii</i> , <i>Longapertites</i> sp., <i>Botryococcus braunii</i> , <i>Tricolporopollenites</i> sp., <i>Monocolpites marginatus</i> , <i>Diatom frustules</i> , <i>Laevigatosporites</i> sp., <i>Psilatricolporites crassus</i> , <i>Proxapertites curcus</i> , <i>?Striamonocolpites rectostriatus</i>	5, 1, 2, 3, 2, 1, 1, 1, 2, 3, 1, 6, 2, 1, 1, 1
9	9031	Fungal spores, <i>Charred gramineae cuticle</i> , <i>Polypodiaceoisporites</i> sp., <i>Verrucatosporites</i> sp., <i>Tricolporopollenites</i> ssp., <i>Botryococcus braunii</i> , <i>Diatom frustules</i>	3, 1, 1, 2, 1, 1, 21
10	9052	<i>Verrutricolporites</i> sp., <i>Diatom frustules</i> , <i>Verrucatosporites</i> sp., <i>Charred gramineae cuticle</i> , <i>Botryococcus braunii</i> ,	1, 16, 2, 2, 3

The analyzed samples are quantitatively dominated by terrestrially derived palynomorphs, particularly *Monocolpites* sp., *Tricolporopollenites* sp., *Monocolpites marginatus*, *Cyathidites* sp., *Verrucatosporites* sp., and *Laevigatosporites* sp. These species exhibit high abundance across multiple intervals, indicating significant input from nearby vegetated landmasses. Sporadic to common occurrences of aquatic palynomorphs such as diatom frustules and *Botryococcus braunii* suggest intermittent freshwater influence. Marine indicators, including sparse *Phelodinium* sp. and *Leiosphaeridia* sp. dinoflagellate cysts, reflect brackish to marginal marine conditions in certain intervals.

The variation in palynomorph assemblage reflects fluctuating depositional environments ranging from terrestrial to marginal marine settings. By alternating between terrestrial/forest-marsh phases (fungal spores, *Monocolpites*, Sapotaceae) and wetland/aquatic-dominated phases (high diatoms, *Botryococcus*), the palynological distribution displays dynamic environmental changes. Charred gramineae cuticles are a sign of recurring fire incidents, which may be caused by human activity or arid climate conditions. While variations in tricolpate pollen and monocolpate indicate transitions between forested and open vegetation, the recurrent *Laevigatosporites* and diatoms indicate

ongoing dampness. All things considered, the series shows a paleoenvironment shifting from freshwater-dominated marshy wetlands to drier, fire-prone grasslands, most likely as a result of climatic variability. The stratigraphic distribution of key taxa is illustrated in Figure 4, and representative microphotographs are shown in Figure 5.

#### 4.5 Palynofacies characterization

A total of 200 counts were made per type of palynomaceral (PM) per slide to determine for abundance of various size fractions of each PM group. The percentage of the counts is computed to determine the percentage dominance of the palynomaceral type. Large, angular, opaque woody fragments with high reflectivity and minimal internal structure make up Palynomaceral 1 (PM1), which is a sign of oxidized, high-energy deltaic or river environments. They reflect oxidized terrestrial input and are high in inertinite; they are frequently linked to Type III kerogen. With its light-colored, structured woody tissues like cuticles and broken-down lignocellulosic fragments, palynomaceral 2 (PM2) preserves anatomical traits and suggests intermediate preservation in suboxic to dysoxic environments.

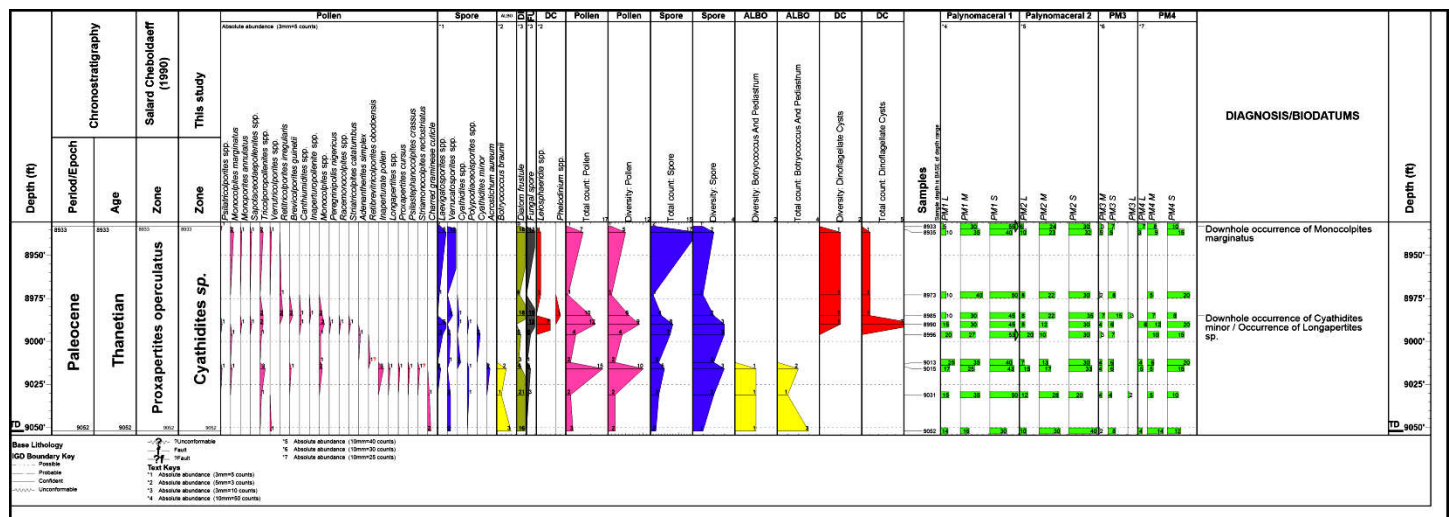


Figure 4: Palynomorphs distribution chart and palynofacies characterization of Muller-1 Well.

The presence of coarsely granular, amorphous, or gel-like organic matter with spongy textures, known as Palynomaceral 3 (PM3), is indicative of more reducing circumstances, potentially brackish or marine, and is frequently associated with damaged phytoplankton or components generated from microorganisms. The elongated, dark-colored, filamentous, or homogenous pieces with inadequate internal structures make up Palynomaceral 4 (PM4) (Figure 6). These fragments are usually fungal remnants or disintegrated spores, indicating low-energy, anoxic conditions with the capacity to generate hydrocarbons. With its emphasis on rather coarse and diverse textures, the image scale (600  $\mu$ m) supports the notion of a mixed terrestrial source with varying redox conditions (Tyson, 1995). The palynofacies analysis showed the predominance of medium and small-sized palynomaceral 1 and 2, with common small and medium-sized palynomaceral 3 and 4 (Figures 4 and 6).

PM1 consistently shows the highest abundance, especially in the large size fraction (L), with values reaching 50% at multiple depths (e.g.,

8996 ft, 9013 ft). This suggests a dominance of robust and possibly terrestrial-derived palynomorphs such as monocolpate grains, retitricolporoids, and spinose pollen types (Germeraad et al., 1968; Evamy et al., 1978). The variation in L (large), M (medium), and S (small) fractions across different depths reveals a distinct trend: at shallower depths (8933–8973 ft), the proportions are more balanced with greater variability, while deeper intervals (8990–9052 ft) show increasing dominance of L and S fractions. This shift suggests that the prevalence of larger palynomorphs in deeper sections may reflect better preservation, whereas the rise in smaller fractions could be linked to diagenetic processes or thermal maturity. Batten (1996) highlights that such size distributions in palynofacies serve as key indicators of depositional energy and oxidation conditions. The structured organic matter (SOM) percentages in the studied interval range from 2.5% to 12.5%, with the highest value recorded at 9031 ft (12.5%). Elevated SOM levels correspond with increased PM4 (phytoclasts) and medium-to-small-sized fractions, indicating greater terrestrial input or oxidative

conditions. These moderate SOM values suggest deposition in a marginal marine environment, likely deltaic or nearshore settings, aligning with established Niger Delta depositional models. This

interpretation is supported by Adebayo and Oboh-Ikuenobe (2004), who similarly used SOM variations in palynofacies to identify nearshore deltaic environments in the Niger Delta.

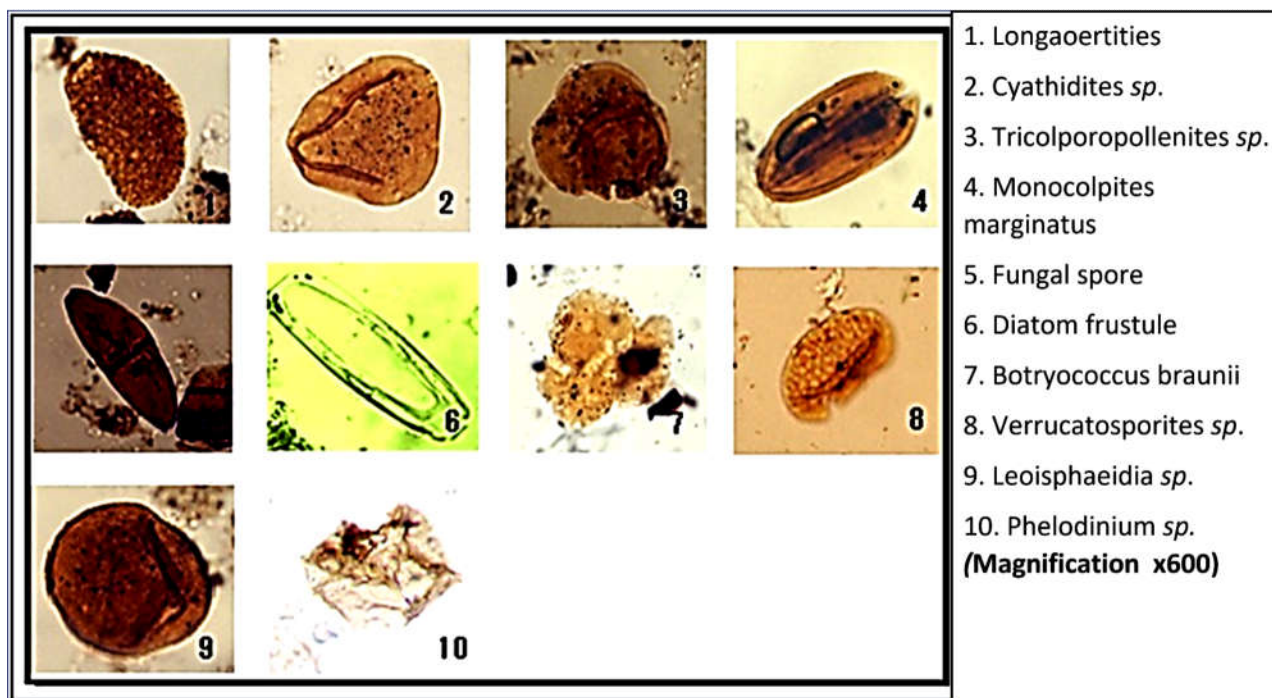


Figure 5: Photomicrographs of some selected palynomorphs from Muller-1 Well.

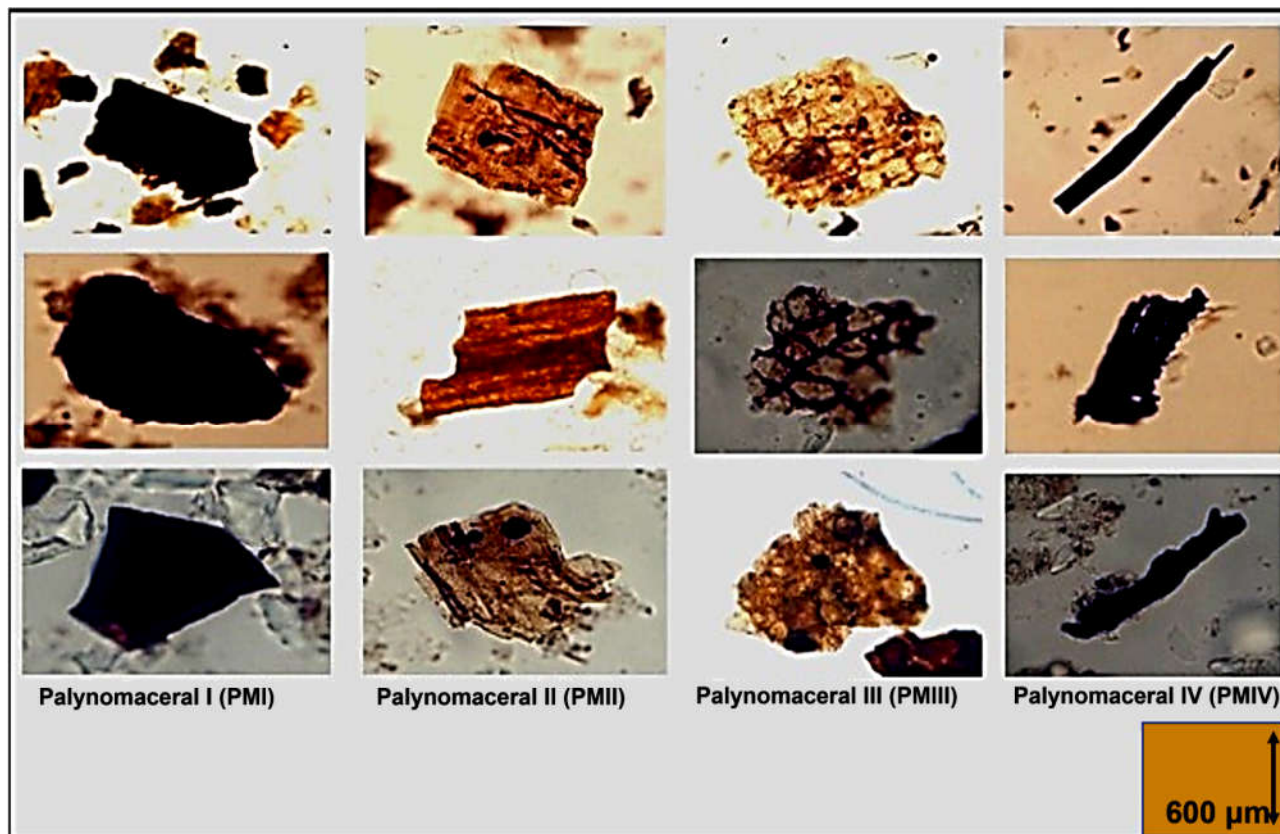


Figure 6: Photomicrographs of some palynomaceral recovered from Muller-1 Well.



4.6 Hydrocarbon Potential

Using Tyson’s (1995) guidelines, the palynofacies assemblage in the studied intervals is terrestrially dominated, consisting mainly of phytoclasts (80–90%), including cuticles, opaque woody debris, and robust pollen/spores (e.g., *Monocolpites marginatus*, *Longerapertites spp.*) (Figures 4–6). This suggests a nearby fluvial-deltaic source and high-energy deposition. The presence of Amorphous Organic Matter (AOM) in trace proportions (<10%) is indicative of inadequate preservation in oxic to suboxic environments. It is primarily composed of degraded particles and sparse algal components such as *Botryococcus braunii*. Resistance sporomorphs and fungal spores are other small liptinitic components that could be involved in gas potential. Similar Agbada Formation reservoirs show that Type III/IV kerogen, which is characteristic of terrestrial, gas-prone systems, clearly outnumbers amorphous organic matter (AOM) (Doust & Omatsola, 1990). The relationship of the palynofacies with interbedded shales and coarse-grained deltaic sandstones supports their interpretation as possible gas-prone source or reservoir facies in the Niger Delta, despite the lack of direct hydrocarbon generation studies (e.g., Rock-Eval pyrolysis) (Oboh-Ikuenobe *et al.*, 2005; Evamy *et al.*, 1978).

4.7 Biostratigraphy: Palynological Zonation

Based on the occurrence of palynomorph marker species, one palynological biozone, namely, the *Cyathidites* sp. Biozone was established and interpreted to be of Paleocene (Thanetian) age at a depth of 8933–9052 feet (Figure 7). This is based on the occurrence of Paleocene marker species such as *Longapertites* sp., *Cyathidites minor*, *Tricolporopollenites* sp., and *Monocolpites marginatus*. This assemblage biozone correlates with the P200 palynological zone of

4.8 Palynofacies Zonation

We tentatively assign the studied interval to the Paleocene–Early Eocene based on the presence of diagnostic palynomorphs such as *Longapertites spp.*, *Spinizonocolpites spp.*, and *Monocolpites spp.*, consistent with established Niger Delta biozones. The dominance of terrestrial-derived PM1 and PM2 components, along with significant size fractions, further supports this age determination, aligning with the *Spinizonocolpites baculatus* (Paleocene) and *Retidiporites magdalenensis* (Early Eocene) Zones defined by Evamy *et al.* (1978). The prevalence of terrestrial pollen (PM1 & PM2) and moderate structured organic matter (SOM) suggests deposition in a coastal plain to delta-front setting, while variations in palynomorph size fractions and palynofacies indicate fluctuating energy conditions, likely driven by transgressive-regressive cycles—a pattern also observed by Doyle and Lezine (1993) in similar marginal marine environments.

The Muller-1 Well has yielded rich palynological assemblages that provide a detailed chronostratigraphic framework. These assemblages, when correlated with established biostratigraphic zones in the Niger Delta, allow for precise age dating of the sedimentary units encountered in the well (Germeraad *et al.*, 1968). The identification of marker species from the Late Cretaceous to the Eocene suggests that the Muller-1 Well spans several key geological periods, which are critical for understanding the timing of hydrocarbon generation and accumulation (Ekweozor & Daukoru, 1994; Jan du Chene *et al.*, 1978).

Evamy *et al.* (1978) and the *Proxapertites operculatus* palynological zone of Salard Cheboldaef (1990).

Depth (Feet)	SYSTEM/ PERIOD	SERIES/ EPOCH	STAGE/AGE	Salard Cheboldaef, (1990)	This study	BIO-MARKEREVENTS
8933	PALEOGENE	PALEOCENE	DANIAN - THANETIAN	<i>Proxapertites operculatus</i> zone	<i>Cyathidites</i> sp. zone	* Downhole occurrence of <i>Monocolpites marginatus</i>
8985						* Downhole occurrence of <i>Cyathidites minor</i> / Occurrence of <i>Longapertites</i> sp.
9052						

Figure 7: Palynological interpretation of Muller-1 Well (8933–9052 ft).

The palynofacies assemblages from the Muller-1 Well reveal a complex depositional history influenced

by fluctuations in sea level and sediment supply. The presence of marine palynomorphs, such as dinoflagellate cysts, suggests periods of marine transgression, while the dominance of terrestrially derived phytoclasts points to fluvial-deltaic conditions during periods of low sea level (Okeke & Umeji, 2016). The studied interval is characterized by the abundant occurrence of medium and small-sized palynomaceral 1 and 2 in association with common small to medium-sized palynomaceral 3 and 4 (Olatunji and Oluwajana, 2022). The research period is in line with the *Cyathidites* sp. Zone, which is in line with the P200 palynozone of the Niger Delta succession, according to the interpretation in Figure 5. Biostratigraphically, this zone falls between the Paleocene's Danian and Thanetian phases. The predominance of *Cyathidites* species and related terrestrial palynomorphs indicates deposition in a low-energy, humid environment, which is usually associated with deltaic swamp or coastal plain environments.

By applying these techniques to the Muller-1 Well, this study seeks to refine our understanding of the depositional environments that controlled the formation of the basin’s hydrocarbon reservoirs. The Muller-1 Well intersects these formations, providing an opportunity to study their lithological properties in detail. Lithostratigraphic analysis of the Muller-1 Well has revealed several promising reservoir intervals characterized by clean, well-sorted sandstones with distinct cross-bedding and minimal shale intercalations indicative of high-energy fluvial-deltaic deposition (Reijers, 2011). Understanding the

lithostratigraphic succession in the Muller-1 Well is crucial for evaluating its hydrocarbon potential. This study integrated lithostratigraphic, palynological, and palynofacies analyses to provide insights into hydrocarbon generation and migration. Located in the Greater Ughelli Depobelt, a key oil and gas-producing region, the well's stratigraphic record helps in assessing the timing and conditions of hydrocarbon formation.

## 5. Conclusion

This study presents a detailed palynological and sedimentological analysis of the interval from 8929 feet to 9054 feet in the Muller-1 Well, Greater Ughelli, Niger Delta Basin, Nigeria, which enabled a comprehensive reconstruction of the paleoenvironment, revealing a dynamic depositional setting transitioning from terrestrial rainforest to brackish water swamp conditions.

Sedimentological evidence includes coal seams, shale intercalations, and coarse-to-fine sandstone layers, further confirming fluctuating energy conditions typical of deltaic systems. The palynological data suggest a Paleocene to Early Eocene age in the P200 palynozone, evidenced by characteristic pollen and spore assemblages. The researched period is in line with the *Cyathidites* sp. Zone, which is in line with the P200 palynozone of the Niger Delta succession.

In the Greater Ughelli Depobelt, the present investigation closes a significant gap in interval-specific palynological and sedimentological characterization. Prior studies have frequently lacked the detail required for accurate age identification and paleoenvironmental reconstruction. The interval improves knowledge of local depositional dynamics and offers a more comprehensive palynostratigraphic framework.

This research enhances the understanding of the Niger Delta Basin's depositional history and geological evolution through detailed palynological analysis, demonstrating its effectiveness in reconstructing paleoenvironmental conditions. The results provide crucial insights for hydrocarbon exploration and stratigraphic correlation in analogous deltaic settings.

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## Competing Interest

The author affirms that there are no identifiable conflicts of interest, either financial or personal, that could be perceived as influencing the work presented in this paper.

## Data Availability Statement

All data generated or analyzed during this study are included in this published article.

## Ethics Approval

Ethical approval was not required for this study as it did not involve human participants or animal subjects.

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