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SEDIMENTOLOGICAL AND PALYNOLOGICAL EVIDENCE FOR PALEOENVIRONMENTAL EVOLUTION OF PALEOCENE-EOCENE DEPOSITS IN THE VF WELL, NIGER DELTA BASIN, NIGERIA

By

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ABSTRACT

This research combines sedimentological and palynological datasets from VF well in the Niger Delta Basin, Nigeria, to delineate its vegetation dynamics and infer ancient environmental setting. Fifteen (15) ditch-cutting samples underwent detailed lithologic analysis to determine their lithology, color, and textural characteristics (grain size, sorting, and grain morphology), as well as the occurrence of accessory minerals. Palynological analysis was carried out using standard maceration techniques to isolate acid-insoluble, organic-walled microfossils from sediment samples. Sedimentologic result shows that the succession is dominated by shale with subordinate clay-rich shale. The sediments are non-calcareous and devoid of accessory mineral constituents. Seven lithozones were delineated, reflecting deposition under predominantly low-energy conditions. Palynological result shows abundance of spore over pollen, though the pollen has higher diversity with low abundance of dinoflagellate cyst. The accessory microfossils include abundant botryococcus braunii, diatom frustules, rare fungal spores, and charred plant debris. key diagnostic taxa including Longapertites sp., Proxapertites cursus, Verrucatosporites usmensis, Palaeocystodinium australinum, Echitriporites triguliformis, Psilamonocolpites marginatus, and Operculodinium centrocarpum, were utilized to established the age of the succession as Danian-Ypresian (Early Paleocene-Early Eocene). The synthesized analysis of both sedimentological and palynological findings suggest deposition in a low-energy, freshwater-dominated lacustrine to swamp setting with minor intermittent brackish influence and strong terrestrial input. The finding is consistent with previous palynological records from many Paleocene-Eocene successions which indicate shifts in vegetation patterns, including the increase of thermophilic and moisture-loving plant taxa associated with possible PETM event during the Paleocene-Eocene Epoch. This study provides additional evidence of integrating sedimentological and palynological data records in optimizing resolution of re-evaluating paleoenvironmental conditions in basin assessment.

Keywords: Niger Delta Basin, Danian-Ypresian, Paleoenvironment, Pollen, Spore.

1.0 INTRODUCTION

The Niger Delta Basin is considered one of the most profitable hydrocarbon provinces in West Africa, characterized by a complex geological history and a significant Cenozoic sedimentary sequence that has been widely studied for petroleum potential (Doust & Omatsola, 1990; Reijers et al, 1997). Biostratigraphy, which uses fossil associations for the dating and correlation of stratigraphic sequences, is an important technique for understanding basin evolution and defining subsurface stratigraphic outlines in hydrocarbon provinces (Adegoke, 2012; Traverse, 2007). Palynomorphs, consisting of pollen, spores, and dinoflagellate cysts are particularly important due to their high proliferation, wide geographic spreading, and availability to paleoenvironmental variations (Muller, 1968; Tschudy & Scott, 1969; Williams et al., 2017). Their utility has been extensively indicated in refining stratigraphic boundaries, developing chronological outlines, and reinterpreting paleoenvironments in Basin depositional settings. In the Niger Delta Basin, palynological research has acted a vital function in recognizing stratigraphic boundaries, and recreating settings of sediment accumulation, thereby assisting both hydrocarbon exploration and broader basin evaluation (Adeonipekun et al., 2016; Olayiwola & Bamford, 2016).

The Paleocene–Eocene succession constitutes an important stratigraphic interval in the basin's evolution, recording significant tectonic reorganization, oscillations in relative sea level, and preserved sedimentary progradation, all of which contributed to a vital role in modifying the current stratigraphic framework (Burke, 1972; Knox & Omatsola, 1989).

The Paleocene–Eocene Thermal Maximum (PETM; ~56 Ma) was a significant planetary warming event triggered by a swift release of carbon into the ocean–atmosphere environment. It induced marked environmental variations, characterized by increased temperatures, intensified hydrological cycling, accelerated weathering and sediment supply, ocean acidification, and changes in terrestrial and marine ecological communities. Previous palynological records from many Paleocene–Eocene successions indicate shifts in vegetation patterns, including the increase of thermophilic and moisture-loving plant taxa in adjusting to warmer and wetter climatic conditions. (McInerney & Wing, 2011; Sluijs et al., 2007; Chen et al., 2023).

In the Niger Delta basin, prior research work on Paleocene–Eocene deposits implies that palynological data are consistently utilized in palynostratigraphic correlation, paleoecological interpretation, and paleoenvironmental interpretation. Regional studies within the basin and connecting basins also demonstrate that distinctive palynomorph associations are efficient for

interpreting depositional environments. (Germeraad et al., 1968; Evamy et al., 1978; Adeonipekun et al., 2016).

Researches from individual well sections further demonstrate the usefulness of palynology in paleoenvironmental reconstruction. This includes the work of Asadu et al., 2015; Adeniran. 2015; Ikegwuonu & Umeji 2016; Okeke & Umeji, 2016; Ukpong & Ikediasor, 2018; Awad & Oboh-Ikuenobe, 2019; Owoeye, 2022 and Ocheli et al., 2023. They have consistently demonstrated the value of palynological data in interpreting depositional settings across the Niger Delta Basin. Notwithstanding these progressions, detailed integration of paleoenvironmental datasets at high resolution within specific well intervals, especially across the Paleocene–Eocene succession, remains insufficiently developed in certain sectors of the basin. Therefore, a clear understanding of the basin's biostratigraphic and paleoenvironmental evolution is critical to hydrocarbon exploration, as it supports the delineation of reservoir-bearing intervals and enhances regional stratigraphic correlation (Doust & Omatsola, 1990; Reijers et al, 1997).

Accordingly, this study aim to combine sedimentological and palynological datasets as an effective tool of reinterpreting the paleoenvironmental evolution of Paleocene-Eocene deposits in VF Well, Niger Delta Basin, Nigeria, with the following objectives: to carry out a detailed sedimentological study and build a lithologic model, reconstruct depositional environment using palynomorph assemblages, characterize vegetation communities, and evaluating the effect of planetary environmental variation on regional sedimentary systems. The red partial circle in fig. 1 indicates the location of the VF well with geographical location $N6^0$ 28' 45'' and $E6^0$ 43' 38.

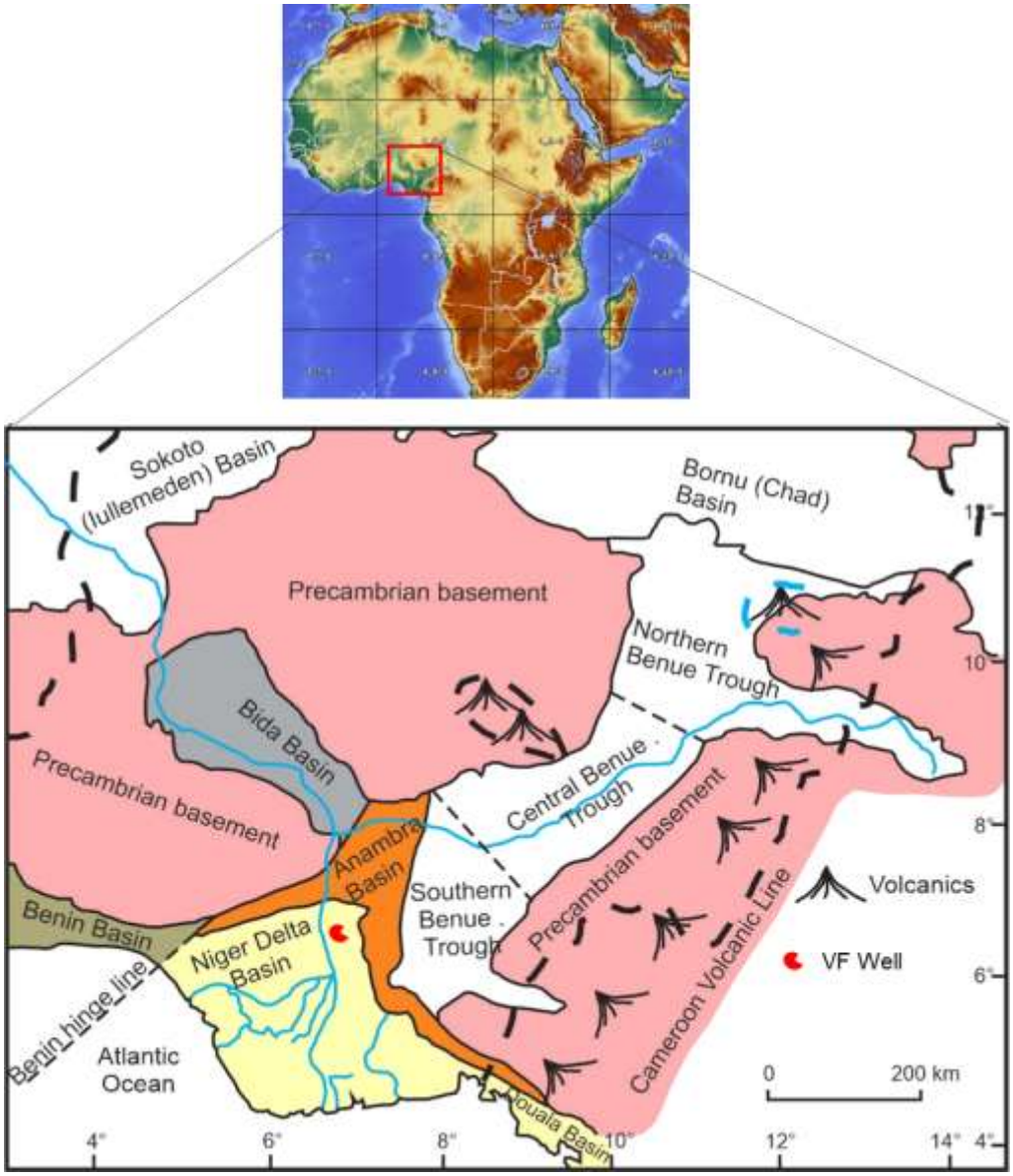


Fig.1a: Map of Africa (the red box represents the location of Nigeria); **b:** Map of Nigeria showing the areas underlain by basement complex rock and sedimentary basins, red partial circle indicates the location of the VF well (adapted from Edegbai et al., 2019).

2.0. TECTONIC EVOLUTION OF THE NIGER DELTA BASIN

The Niger Delta Basin represents the last stage of the Benue Trough's tectonostratigraphic cycle. The Benue Trough was formed during the Late Jurassic–Mid Cretaceous rifting of West Gondwana, which resulted in the separation of South American and African plates (Fairhead 1988; Moulin et al., 2010). The Benue Trough is polycyclic, with its complex tectonic history comprising of several rift, sag, transpression, and passive margin stages. The Niger Delta Basin thus represents a passive-margin phase that developed during the Paleogene (Kulke, 1995; Reijers et al., 1997;

Doust & Omatsola, 1990). This phase is characterized by sediment progradation, which has resulted in a deltaic system characterized by faulting, subsidence, and extensive sediment deposition.

Notably, the Paleocene–Eocene transition interval represents a significant interval in the early evolution of the Niger Delta, associated to the onset of important deltaic progradation following regional tectonic post-rift stability and lithospheric cooling-induced subsidence of the passive margin (Doust & Omatsola, 1990; Kulke, 1995; Reijers et al., 1997). This interval is related with enhanced sediment supply from the tectonically active continental hinterland, inducing the growth of the proto-Niger Delta system and creating the fundamental depositional framework of the Akata to Agbada sedimentary system (Short & Stauble, 1967; Evamy et al., 1978). Progressive subsidence and sediment supply during this period strengthened the growth faulting and basin ward development of deltaic depocenters, laying the groundwork for later Neogene progradation and structural segmentation of the basin (Weber, 1971; Stacher, 1995; Reijers, 2011).

2.1 STRATIGRAPHY OF THE NIGER DELTA BASIN

The stratigraphy of the Niger Delta Basin is divided into three diachronous formations (Figure 2). The Akata Formation is the oldest and deepest lithostratigraphic unit of the Niger Delta Basin. It consists primarily of deep-marine shales, and subordinate limestone and sandstones deposited from the Paleocene-Recent in a prodelta marine setting (Reijers et al., 1997; Short & Stauble, 1967). It is a major hydrocarbon source rock, that is coeval with the Imo Formation as its onshore equivalent. (Nwajide, 2013; Ekweozor & Okoye, 1980; Nwachukwu & Chukwura, 1986), with thicknesses exceeding 7,000 m in some areas (Avbovbo, 1978). The overlying Agbada Formation was deposited during deltaic progradation from the Eocene-Recent. It consists of alternating sandstones and shales deposited under delta-front, distributary-channel, and deltaic-plain environments (Reijers et al., 1997; Short & Stauble, 1967). It is coeval with the Ogwashi-Asaba Formation with thicknesses exceeding 4,000 m (Avbovbo, 1978). Additionally, it contains shaly and sandy intervals which have been proven to be hydrocarbon source and reservoir rocks (Ekweozor & Okoye, 1980; Nwachukwu & Chukwura, 1986; Reijers et al., 1997). The Benin Formation overlies it as the youngest lithostratigraphic unit within the Niger Delta Basin. The Benin Formation consists of continental sandstones, gravels, and clays deposited in fluvial environments from the Oligocene-Recent (Reijers et al., 1997; Short & Stauble, 1967). With

thicknesses up to 2,100 m (Avbovbo, 1978), it serves as a major aquifer and source of construction materials (Etu-Efeotor, 1994; Akpokodje, 1987).

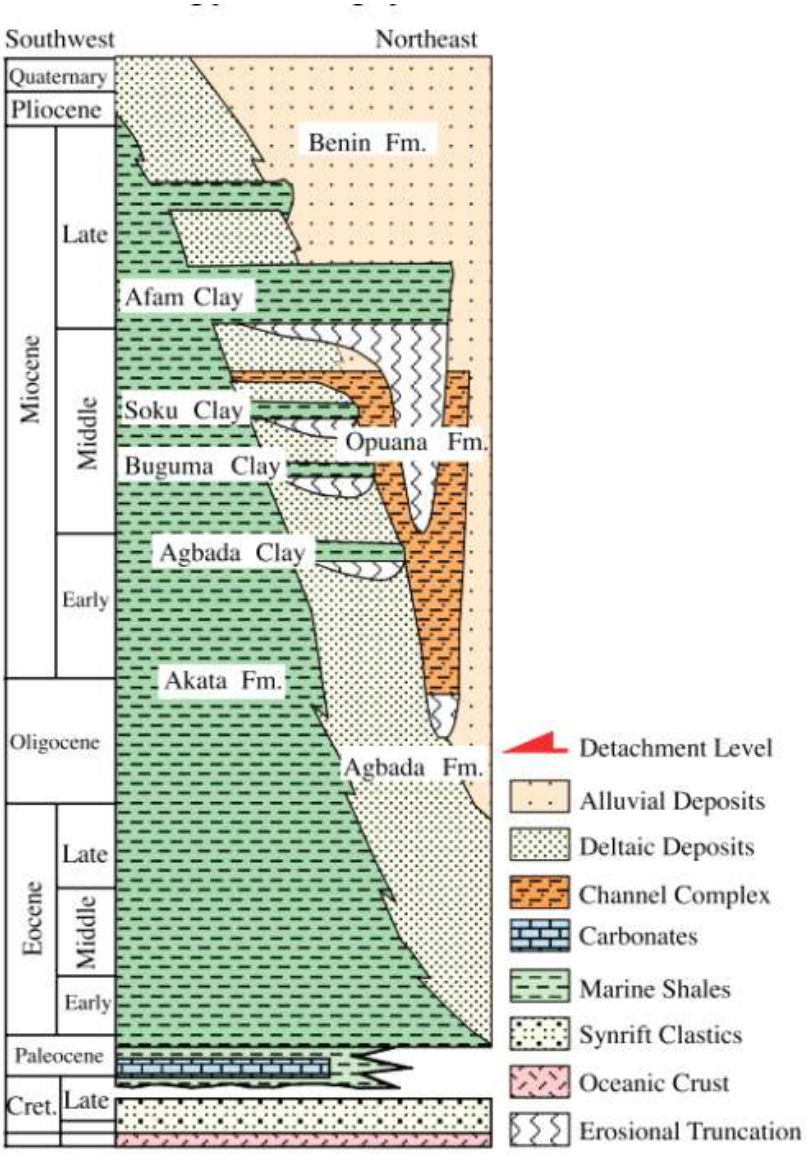


Fig. 2: Schematic representation of the diachronous nature of major lithofacies units, and the stratigraphic relationships of clay-filled channels on the delta flanks. Modified after Doust and Omatsola (1990) and Lawrence et al. (2002).

3.0 MATERIALS AND METHODS

3.1 Materials

Fifteen (15) ditch cutting sample from Nigerian Geological Survey, Kaduna, Nigeria, reflected and transmitted light binocular microscope, hand lens, hydrochloric acid, hydrofluoric acid, nitric acid (HNO_3), zinc bromide, KOH, weighing scale, palynological photo album and web-based album, Niger Delta Cenozoic Geological Data Table and StrataBug 2.0 software, Tilia software 3.0.3 version.

3.2 Methods

3.2.1 Sedimentologic Description

Fifteen (15) Ditch cutting samples from the VF well were obtained from the Nigerian Geological Survey Agency, Kaduna, Nigeria. The samples were first described under reflected light microscope, and hand lens by considering the textural attributes such as: colour, grain size, degree of sorting, and roundness, sand-shale percentage, and documenting the mineralogy. Diluted Hydrochloric Acid was used to test for the presence of carbonate. Effervescence depicts the presence of carbonate in the sediment (Tucker, 2011).

3.2.2 Palynological Preparation

The ditch cutting samples were processed using standard palynological preparation techniques for recovering acid insoluble organic-walled microfossils from sediment. (Wood *et al.* (1996); Lucas and Balogun (2015). Restricting all operations to highly efficient fume chamber and ensuring cleanliness, orderliness and accurate observations throughout procedures. The standard palynological techniques include the following steps: Samples were sequentially treated to isolate palynomorphs: carbonates were removed with HCl acid, silicates with HF acid, and residues washed repeatedly. Organic matter was separated using zinc bromide and centrifugation, followed by oxidation with HNO_3 for palynomorph cleaning, while a portion was left unoxidized for palynofacies analysis. Humic acids were excluded during sediment processing with the use of KOH, and the resulting residues were then processed through sieving to enhance palynomorph concentration for microscopic examination. Residues were mounted on glass slides using glycerin, labeled, and examined under a transmitted light binocular microscope. Photographs of key markers and other species were captured. Palynomorphs were identified using morphological features, aperture types, and reference palynological atlases. Palynological counts were digitized and analyzed with StrataBug 2.0 software and Tilia software 3.0 version.

3.2.3 Paleoenvironmental reconstruction

Paleoenvironmental reconstruction of the VF well was achieved through integration of sedimentological and palynological datasets. Main palynomorph assemblages, including spores, pollen and dinoflagellate cysts were quantitatively analyzed across stratigraphic intervals. The abundance of accessory microfossils such as botryococcus braunii, fungal spores, diatom frustules, and charred graminae cuticles were also considered. Their relative abundance, diversity, and assemblage composition across stratigraphic intervals were used to infer depositional environments, following established approaches in Niger Delta studies (Ekom et al., (2024); Alege and Joseph (2024); Joseph et al. (2025); Abdullahi et al. (2024); Ihunda and Ihunda (2025).

3.2.4 Quantitative paleoenvironmental analysis

This was achieved by calculating the abundance of major palynomorph groups including terrestrial (spores and pollen) and marine components (dinoflagellate cysts) taken for 100%. Percentages of different groups in composition of palynomorphs were used to assess changes in terrestrial input, marine influence, and depositional environments following standard palynological procedures (Faegri et al., 1989; Traverse, 2007). For spore and pollen percentage are illustrated below in Equation I and II.

Spore / Pollen Percentage

$$\% \text{ spore} = \frac{\sum \text{Spore}}{\sum (\text{spore} + \text{pollen} + \text{Dinoflagellate cysts})} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

(Modified after Faegri et al., 1989; Smol et al., 2001).

$$\% \text{ pollen} = \frac{\sum \text{Pollen}}{\sum (\text{spore} + \text{pollen} + \text{Dinoflagellate cysts})} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots (II)$$

(Modified after Faegri et al., 1989; Smol et al., 2001).

Dinoflagellate cysts Percentage

This percentage value is calculated from equation III and it can provide information about the movement of the shoreline to evaluate the effect of marine environment for the period of sedimentation.

$$\% \text{ a taxa} = \frac{\sum \text{Dinoflagellate cyst}}{\sum (\text{Marine Taxa} + \text{Non-Marine Taxa})} \times 100\% \quad \ldots\ldots\ldots\ldots (III)$$

(Modified after Jansonius & McGregor, 1996; Sluijs et al., 2005).

4.0 RESULT AND DISCUSSION

4.1 RESULT OF SEDIMENTOLOGIC ANALYSIS

The sedimentological analysis of the ditch-cutting samples was used to establish seven (7) lithologic zones based on the sedimentological properties observed. The lithofacies encountered were mainly dominated by shale, followed by clayey shale and shaly clay. The sedimentologic description and the lithologic zones delineated are shown in Table 1.

Table 1: Shows the sedimentological Description of VF well. (4340 - 9780 ft.)

Lithozone 1: (8090 - 9780 ft.) (1690 ft. thick) is dominated by dark grey, moderately hard, fissile, non-calcareous shale. Lithozone 2: (7560 - 8090 ft.) (530 ft. thick) consists of clayey shale, with dark grey fissile shale and milky, moderately hard, non-calcareous clay. Lithozone 3: (7310 - 7560ft.) (250 ft. thick) is composed mainly of dark grey, moderately hard, fissile, non-calcareous shale. Lithozone 4: (7010 - 7310 ft.) (300 ft. thick) contains clayey shale with dark grey fissile shale and milky, moderately hard, non-calcareous clay. Lithozone 5: (5960 - 7010 ft.) (1050 ft. thick) is dominated by milky, moderately hard clay with minor dark grey shale. Lithozone 6: (4720 - 5960 ft.) (1240 ft. thick) comprises clayey shale, with dark grey fissile shale and milky, moderately hard, non-calcareous clay. Lithozone 7: (4340 - 4720 ft.) (380 ft. thick) consists mainly of dark grey, moderately hard, fissile, non-calcareous shale.

The dominance of shale, clayey shale, and shaly clay lithofacies indicates deposition under low-energy conditions characterized by suspension settling of fine-grained sediments. The absence of accessory minerals suggests a relatively mature, clay-dominated system with limited proximal detrital input, while the non-calcareous nature reflects a siliciclastic-dominated environment with negligible carbonate contribution. Collectively, these features are consistent with deposition in a distal, low-energy setting such as a pro-delta to offshore marine environment, where fine sediments accumulate under quiet water conditions. (Guo et al., 2024).

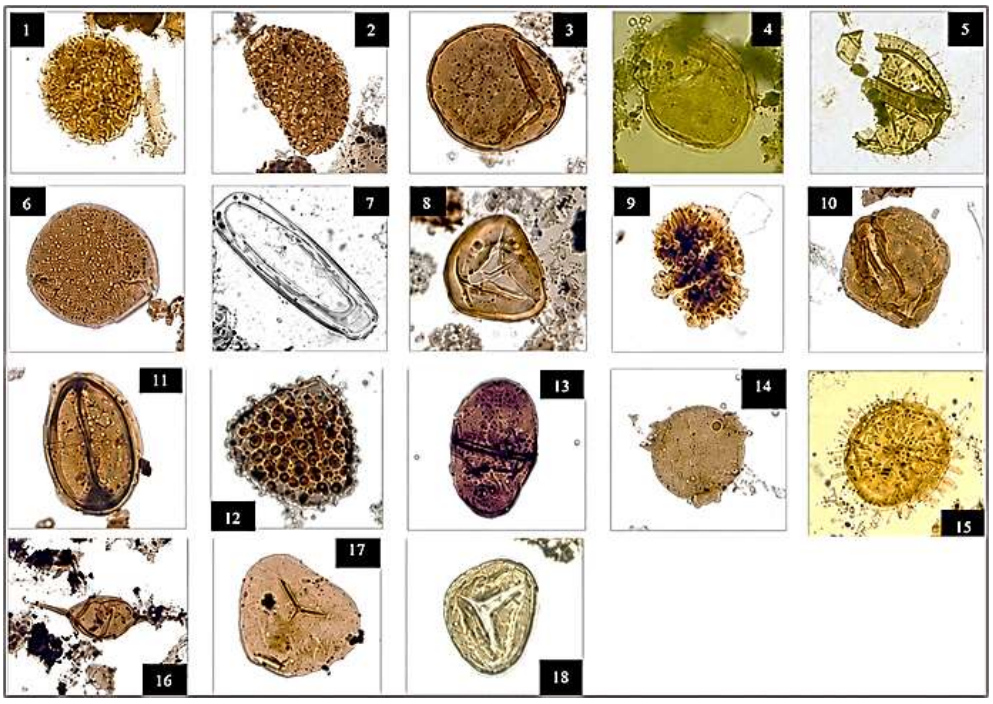
Overall, the analyzed section strongly supports a quiet-water, distal depositional system, which fits perfectly with the Akata Formation environment that is widely recognized as a major

hydrocarbon source rock in the Niger Delta Basin (Ekweozor and Okoye, 1980; Nwachukwu and Chukwura, 1986).

4.2 RESULT OF PALYNOLOGIC ANALYSIS

Palynological analysis of the slides identified twenty-five palynomorph species, comprising twenty (21) miospores (8 spores – 32% and 13 pollen – 52%) and four (4) dinoflagellate cysts – 16%. The palynomorph range chart was developed based on the first appearance datum (last downhole occurrence) and last appearance datum (first downhole occurrence) of miospore (pollen, spores) and dinoflagellate cysts species identified in the well section. A few of the recovered palynomorphs are long ranging, such as *Polypodiaceoisporites sp.*, *Verrucatosporites sp.*, *Laevigatosporites sp.*, and *Monocolpites sp.*, and a few forms were restricted to their stratigraphic ranges. From the recovered palynomorphs, pollen have higher diversity while the spore abundance was higher in most of the depths analyzed. The dinoflagellate cysts were few in abundance. Fig. 3. The accessory palynomorphs recovered were: Abundant botryococcus braunii and diatom frustules, while charred graminae cuticle and fungal spores were rare. Photomicrographs of some of the microfossils and ancillary microfossils recovered from the VF well are shown in plate I.

PLATE 1: Photomicrographs of some palynomorphs recovered from VF well.



4.3 Biostratigraphy (Age)

The age of the sediments penetrated by the VF well was determined using key marker species. Early Paleocene indicators include *Longapertites sp., Proxapertites cursus, Verrucatosporites usmensis,* and *Palaeocystodinium australinum,* which occur alongside Early Eocene diagnostic species such as *Echitriporites triguliformis, Psilamonocolpites marginatus,* and *Operculodinium centrocarpum.* These taxa are widely recognized and stratigraphically significant elements of Paleogene tropical palynofloras in West African basins, where their co-occurrence is routinely applied for Paleocene–Eocene age determinations and regional correlation (Germeraad et al., 1968; Atta-Peters and Salami, 2004). Based on these correlations and established regional palynological frameworks, the studied section of the well is interpreted to range in age from Early Paleocene (Danian) to the Early Eocene (Ypresian). Figure 3 and table 2.

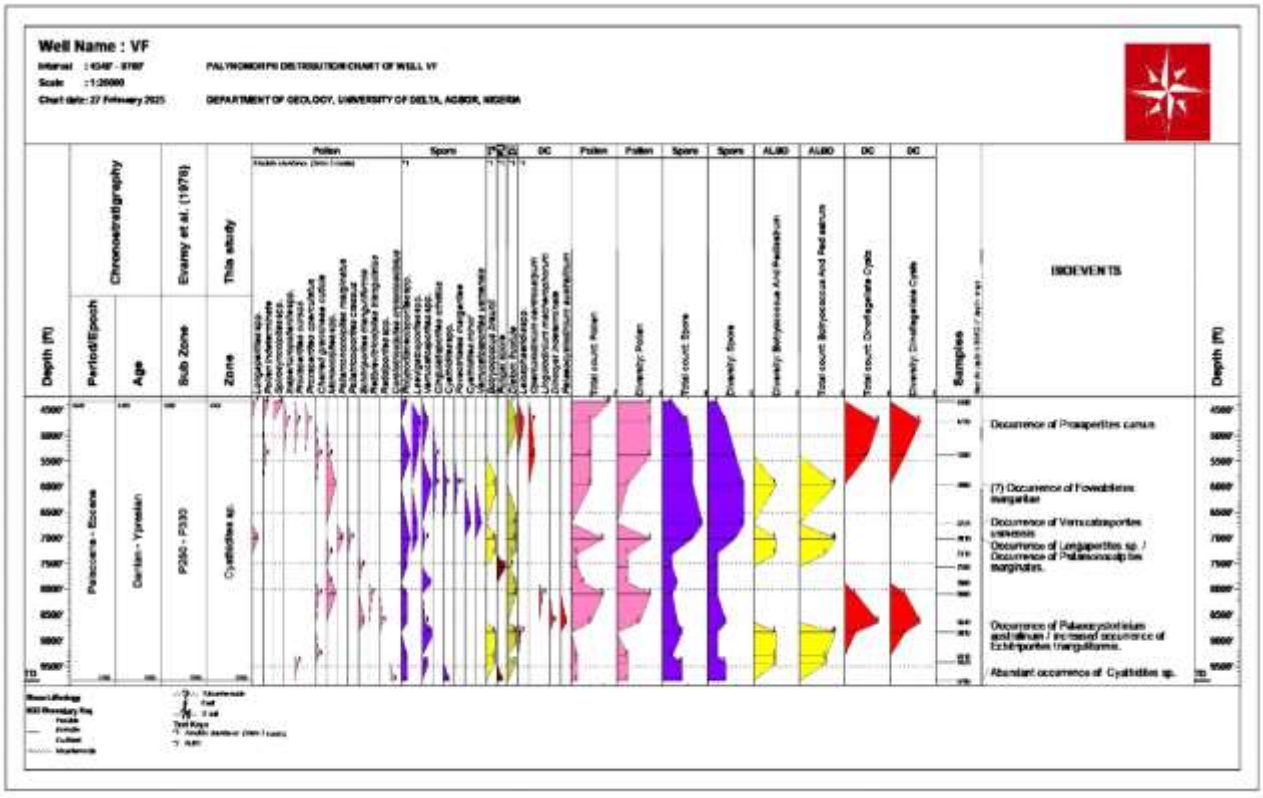


Figure 3: Graphical plot of palynomorph counts with depth in VF well.

4.4 Paleoenvironmental Reconstruction in VF well

Based on the vegetation groups recovered and their relative abundance, the paleoenvironmental reconstruction within the stratigraphic succession of the studied well is presented in Table 3.

Table 3: Vegetation group recovered and Paleoenvironment Reconstructed in VF well (4340 ft. - 9780 ft.).

Depth (ft.)	Palynomorphs	Counts	Vegetation Group	Paleoenvironment
4340	*Polypodiaceoisporites sp.*	2	Mangrove	Coastal
	Spirosyncolpites sp.	3	Lowland	Coastal/Transitional
	Longapertites sp.	1	Rainforest	Coastal
	Pollen indeterminate	2	Rain forest	?
	Diatom frustules	1	?	Coastal
			Freshwater	
4720	*Laevigatosporites sp.*	3	Mangrove	Shallow marine
	Verrucatosporites sp.	2	Rainforest	Tropical to subtropical
	Leoisphaeridia sp.	2	Shallow Marine	Shallow marine
	Inaperturopollenites sp.	1	Lowland	Transitional
	Proxapertites	1	Rainforest	Transitional
	operculatus	1	Lowland	Shallow marine
	Operculodinium	1	Rainforest	Transitional
	centrocarpum	4	Shallow Marine	Coastal
	Proxapertites cursus		Lowland	
	Diatom frustules		Rainforest	
			Freshwater	
5380	*Laevigatosporites sp.*	2	Mangrove	Shallow marine
	Cingulatisporites ornatus	1	Lowland	Tropical swamp
	Monocolpites sp.	1	Rainforest	Coastal and Deltaic
	Pollen indeterminate	1	Rainforest	?
	Operculodinium	2	?	Shallow Marine
	centrocarpum	3	Shallow Marine	Coastal
	Polypodiaceoisporites sp.	1	Mangrove	Open grassland

	Charred graminae cuticle		Savanna	
5960	*Verrucatosporites sp.*	3	Lowland	Tropical
	Monocolpites sp.	3	Rainforest	Coastal and Deltaic
	Cingulatisporites ornatus	1	Rainforest	Tropical swamp
	Botryococcus braunii	4	Rainforest	Lacustrine setting
	(?) Foveotriletes margaritae	1	Freshwater	?
		1	?	Tropical to subtropical
	Cyathidites sp.		Rainforest	
6720	*Polypodiaceoisporites sp.*	2	Mangrove	Coastal
	Diatom frustules	4	Freshwater	Coastal
	Verrucatosporites usmensis	2	Lowland	Tropical to subtropical
		2	Rainforest	Tropical to subtropical
	Cyathidites minor	1	Swamp Forest	Shallow marine
	Laevigatosporites sp.		Mangrove	
7010	*Botryococcus braunii*	4	Freshwater	Lacustrine setting
	Laevigatosporites sp.	2	Mangrove	Shallow marine
	Diatom frustules	8	Freshwater	Coastal
	Polypodiaceoisporites sp.	3	Mangrove	Coastal
	Psilatricolporites crassus	1	Rainforest	Tropical to subtropical
	Verrucatosporites sp.	1	Rainforest	Tropical to subtropical
	Longapertites sp.	2	Rainforest	Transitional
	Psilamonocolpites marginatus	2	Mangrove	Tropical to subtropical
7310	*Polypodiaceoisporites sp.*	2	Mangrove	Coastal
	Diatom frustules	2	Freshwater	Coastal
	Botryococcus braunii	3	Freshwater	Lacustrine setting
	Monocolpites sp.	1	Rainforest	Coastal and Deltaic
7560	Diatom frustules	1	Freshwater	Coastal
	Polypodiaceoisporites sp.	2	Mangrove	Coastal
	Echitriporites trianguliformis	1	Rainforest	Coastal and Deltaic
		3	Tropical	Lacustrine and Deltaic
	Fungal spores		Rainforest	

7880	*Verrucatosporites sp.*	3	Rainforest	Tropical to subtropical
	Monocolpites sp.	2	Rainforest	Coastal and Deltaic
	Diatom frustules	3	Freshwater	Coastal
8089	*Retibrevitricolporites*	13	Lowland	Coastal and Deltaic
	triangulates	1	Rainforest	Coastal and Deltaic
	Monocolpites sp.	2	Shallow marine	Shallow marine
	Lingulodinium	3	Rainforest	Coastal
	machaerophorum	2	Freshwater	Coastal
	Polypodiaceoisporites sp.		Savanna	Open grassland
	Diatom frustules			
	Charred graminae cuticle			
8640	*Echitriporites*	2	Rainforest	Coastal and Deltaic
	trianguliformis	1	Mangrove	Tropical/Transitional
	Retidiporites sp.	1	Rainforest	Tropical to subtropical
	Verrucatosporites sp.	2	Shallow marine	Shallow marine
	Palaeocystodinium	1	?	?
	australinum	2	Mangrove	Coastal
	Dinocysts indeterminate			
	Polypodiaceoisporites sp.			
8830	Diatom frustules	6	Freshwater	Coastal
	Botryococcus braunii	4	Freshwater	Lacustrine setting
	Verrucatosporites sp.	4	Rainforest	Tropical to subtropical
	Leoisphaeridia sp.	1	Shallow Marine	Shallow Marine
9310	Charred graminae	1	Savanna	Open grassland
	cuticles	2	Mangrove	Coastal
	Polypodiaceoisporites sp.	3	Freshwater	Lacustrine setting
	Botryococcus braunii			
9420	*Verrucatosporites sp.*	2	Rainforest	Tropical to subtropical
	Proxapertites cursus	1	Lowland	Transitional
	Botryococcus braunii	3	Rainforest	Lacustrine setting
	Diatom frustules	3	Freshwater	Coastal
	Polypodiaceoisporites sp.	2	Freshwater	Coastal

			Mangrove	
9780	Fungal spores	2	Tropical	Lacustrine and Deltaic
	Cyathidites sp.	2	Rainforest	Tropical to subtropical
	Crototricolpites	1	Swamp Forest	Open grassland
	crotonoisculptus	2	Savanna	Coastal
	Polypodiaceoisporites sp.		Mangrove	

Table 4: The percentage values and count of the different types of palynomorph in VF well.

Type of palynomorph	Pollen	Spore	Dinoflagellate cysts
Palynomorph count	13	8	4
Percentage value	52	32	16

The prevalence of spores signifies a major input from spore-producing vegetation and infers significant input from humid lowland environments. These spores are largely gotten from lower plants such as ferns and bryophytes, and the increased comparative abundance implies a vegetation cover dominated by these groups instead of seed plants (angiosperms and gymnosperms). This association is generally connected to wet, swampy settings where elevated moisture conditions enhance both the production and preservation of spores. This spread is usual of poorly drained, low-energy depositional environments, including swamps, floodplains, and marginal lacustrine settings, where organic matter is mainly sourced from in situ vegetation with little upland input (Zargar et al., 2025).

The comparatively rare occurrence of dinoflagellate cysts implies minimal marine influence during sedimentation. Dinoflagellate cysts are strongly influenced by salinity and marine productivity, therefore, their paucity reflects restricted marine conditions, probably resulting from freshwater dilution or poorly connected to open-marine waters (Hoang et al., 2021; Ojo et al., 2020). This type of association is usually connected with marginal marine settings such as lagoons, estuaries, and delta-front environments.

The presence and abundance of botryococcus braunii point to freshwater to mildly brackish settings. Their presence is commonly regarded as a marker of low-energy, freshwater-dominated settings, such as lakes, floodplains, and sheltered lagoonal settings (El Beialy et al., 2021; Ojo et al., 2020). The event of elevated distribution signifies a major impact of poorly circulated water bodies with constrained water circulation.

Also, the richness of diatom frustules implies high primary productivity in an aquatic setting. Diatoms are photosynthetic microalgae that thrive in nutrient-enriched, shallow-water environments and are generally used as markers of water quality, including salinity levels and trophic conditions (Mishra et al., 2025). Their occurrence assists the inference of a shallow, well-lit environment (photic zone) aquatic system, probably marked by stagnant or slow-flowing waters.

The presence of fungal spores suggests continuing decay of organic matter in a close terrestrial environment, revealing humid or episodic wet conditions that improve microbial activity and organic degradation (Colombaroli et al., 2018). This indicates the presence of vegetated areas with sufficient moisture to assist fungal expansion.

Furthermore, the rare event of charred graminae cuticles implies paleo-wildfire activity. Their occurrences are usually used as representative for fire events and are generally connected to seasonal dry conditions and the expansion of grass-dominated or open vegetation (El Atfy et al., 2019; Colombaroli et al., 2018).

4.5 Quantitative Paleoenvironmental Analysis

The percentage values (table 4) of the palynomorph assemblage recovered from the VF well shows that pollen has higher diversity in the association (52% - 13 species), followed by spores (32% - 8 species), whereas dinoflagellate cysts have low abundance (16% - 4 species). The dominance of pollen and spores - 84% (terrestrial palynomorphs) over dinoflagellate cysts 16% (marine palynomorphs) indicates that deposition occurred under robust continental impact, and significant input of plant-derived material. Such associations show sedimentation in a proximal marginal marine to deltaic setting. The low abundance of dinoflagellate cysts indicates sporadic marine intrusions and confirms an estuarine depositional setting rather than an entirely continental environment. Comparable palynomorph assemblage have been commonly construed to indicates deltaic to nearshore marine settings caused by oscillations in relative sea level and sediment supply (Tyson, 1995; Traverse, 2007; Batten, 1996).

4.6 Integrated Paleoenvironmental Reconstruction

The combined sedimentological and palynological indication implies sedimentation in a low-energy, fine-grained siliciclastic environment predominated by shale, with insignificant clayey shale and shaly clay, coherent with sedimentation in a quite calm water setting. The palynomorph assemblage is characterized by higher pollen diversity, followed by spore and a low abundance of

dinoflagellate cysts, alongside abundant botryococcus braunii and diatom frustules, minor fungal spores and charred gramineae cuticles. The dominance of pollen and spores - 84% (terrestrial palynomorphs) over dinoflagellate cysts 16% (marine palynomorphs) indicates sedimentation in a proximal marginal marine to deltaic setting. The low abundance of dinoflagellate cysts indicates sporadic marine intrusions and confirms an estuarine depositional setting rather than an entirely continental environment. The abundance of botryococcus braunii and diatoms supports freshwater to slightly brackish, nutrient-rich, shallow-water conditions with high productivity. Fungal spores reflect active organic decay under humid conditions, whereas charred cuticles indicate episodic wildfire and seasonal variability. Overall, deposition occurred in a low-energy, freshwater-dominated lacustrine to swamp setting with minor, intermittent brackish influence and strong terrestrial input. Figure 4. In general, the integrated palynological indication depicts sedimentation in a low-energy, shallow aquatic environment with significant terrestrial contribution marked by freshwater impact. The association aligns most closely with a deltaic to lagoonal or estuarine setting, characterized by oscillating salinity, high biological productivity, and adjacent to a vegetated coastal plain setting (Ojo et al., 2020; Mishra et al., 2025).

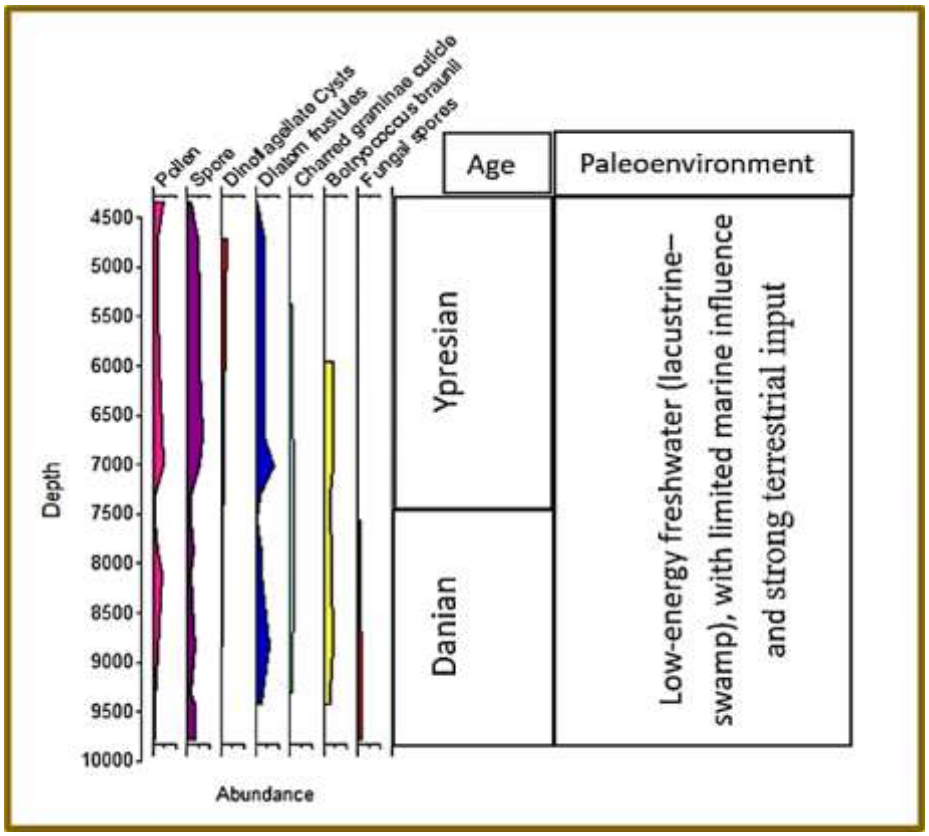


Figure 4: Shows the different palynomorph groups, accessory microfossils, their abundance counts with depth, age, and paleoenvironment reconstructed in the VF well.

5.0 Conclusion

The succession was dominated by shale and yielded diverse palynomorph assemblages, with miospores prevailing over dinoflagellate cysts. Integrated sedimentological and palynological analyses of the studied well suggest an Early Paleocene (Danian)–Early Eocene (Ypresian) age, based on palynostratigraphic evidence. The correlation of sedimentological and palynological data suggest that the sediments were deposited in a low-energy, freshwater-dominated lacustrine to swamp environment with minor, intermittent brackish influence and strong terrestrial input associated with possible PETM event during the Paleocene-Eocene Epoch. The findings emphasize the value of multidisciplinary analysis of data for enhancing the resolution of reinterpreting paleoenvironmental conditions within the Niger Delta Basin.

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