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Foraminiferal Biostratigraphic Study of "VC" Well in the Central Niger Delta

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Abstract: *Ditch cutting samples obtained from the interval of 2340 metres to 3350 metres of the "VC" well, located within the coastal swamp depobelt of the Central Niger Delta, were analyzed in order to establish a foraminiferal biostratigraphic framework for the Agbada Formation. The study yielded moderately diverse planktonic and benthic foraminiferal assemblages with good preservation. Key planktonic foraminiferal events identified include the first downhole occurrence of Epistominella vitrea, the last downhole occurrence of Globigerinoides primordius, and the co-occurrence of Praeorbulina glomerosa and Orbulina suturalis. These bioevents constrain the studied interval to the Middle to Late Miocene and correlate with the Blow's Neogene Zones N9–N15The lithofacies and lithological succession, characterized by alternating sand and shale units with silt intercalations, are typical of the Agbada Formation and are associated with three foraminiferal microzones, namely Neogene Zone Sixteen, Neogene Zone Fifteen, and Neogene Zones Fourteen to Nine. These zones were defined on the basis of the Top Regular Occurrence (TRO) of Florilus ex gr. costiferum at 2500 metres, the isolated occurrence of Globorotalia acostaensis at 2530 metres, alongside the First Downhole Occurrence (FDO) of Globorotalia continuosa at 2640 metres and Praeorbulina glomerosa at 3250 metres, respectively. Consequently, the sediments were dated as Middle to Late Miocene.*

Keywords: *Foraminifera, Biostratigraphy, Miocene, Niger Delta, Agbada Formation, Biozones.*

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1.0 Introduction

The Niger Delta is an arcuate shaped basin protruding southerly into the Atlantic, along the West African Gulf of Guinea. This basin which is the largest along the West Coast of Africa is a wave-dominated clastic depositional system on the passive continental margin of the Gulf of Guinea, Southern Nigeria. It occupies the Gulf continental margin in equatorial West Africa between latitudes 3° and 6° N and longitudes 5° and 8° E (Fig. 1). This basin covers75,000km^2 on shore and extends another 300,000km^2 offshore and is characteristic of regressive clastic sequences with a maximum thickness of about 12,000m at the center of the basin and 6000 to 9000m along the flanks (Evamy *et al.,* 1978). The delta began prograding in the Paleocene and is still active, fed by the Niger-Benue River system which drains ~ 2.2 million km^2 of West Africa.

The Niger Delta Basin is the most prolific hydrocarbon province along the West African continental margin and is subdivided into three major Tertiary to Recent lithostratigraphic units: the Akata, Agbada, and Benin Formations.

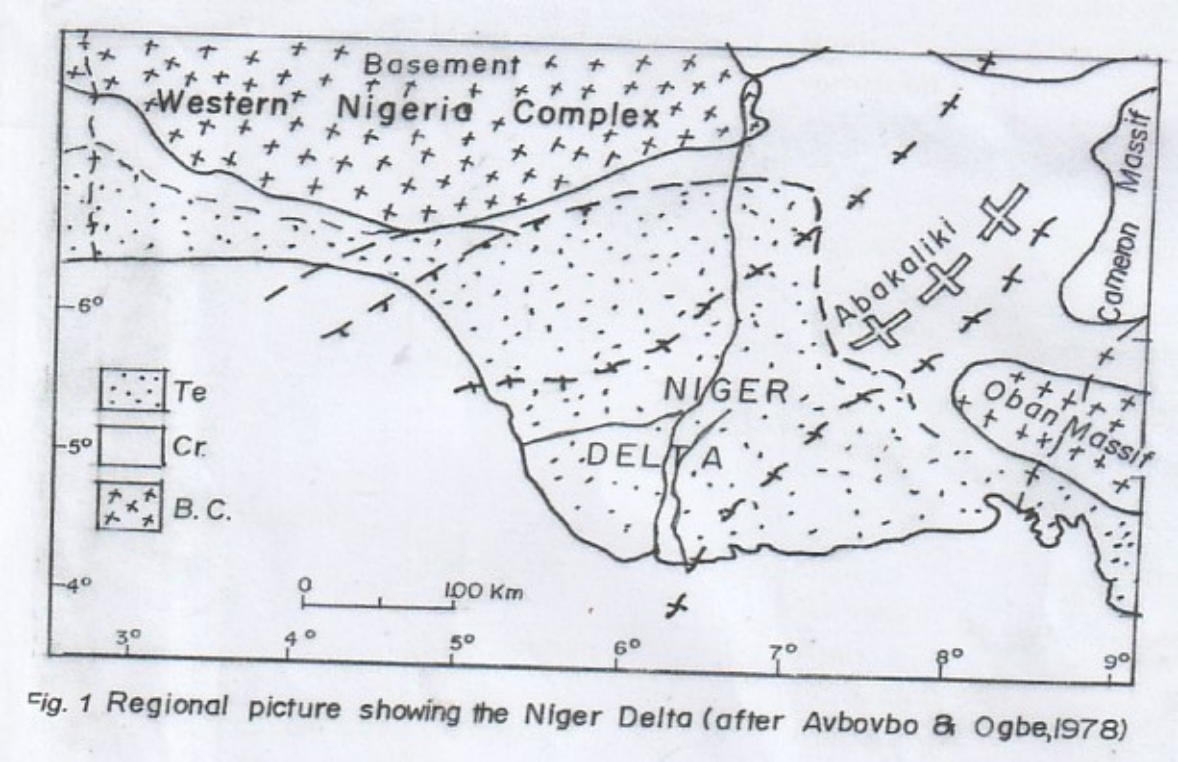

Fig. 1: Location map of the Study area

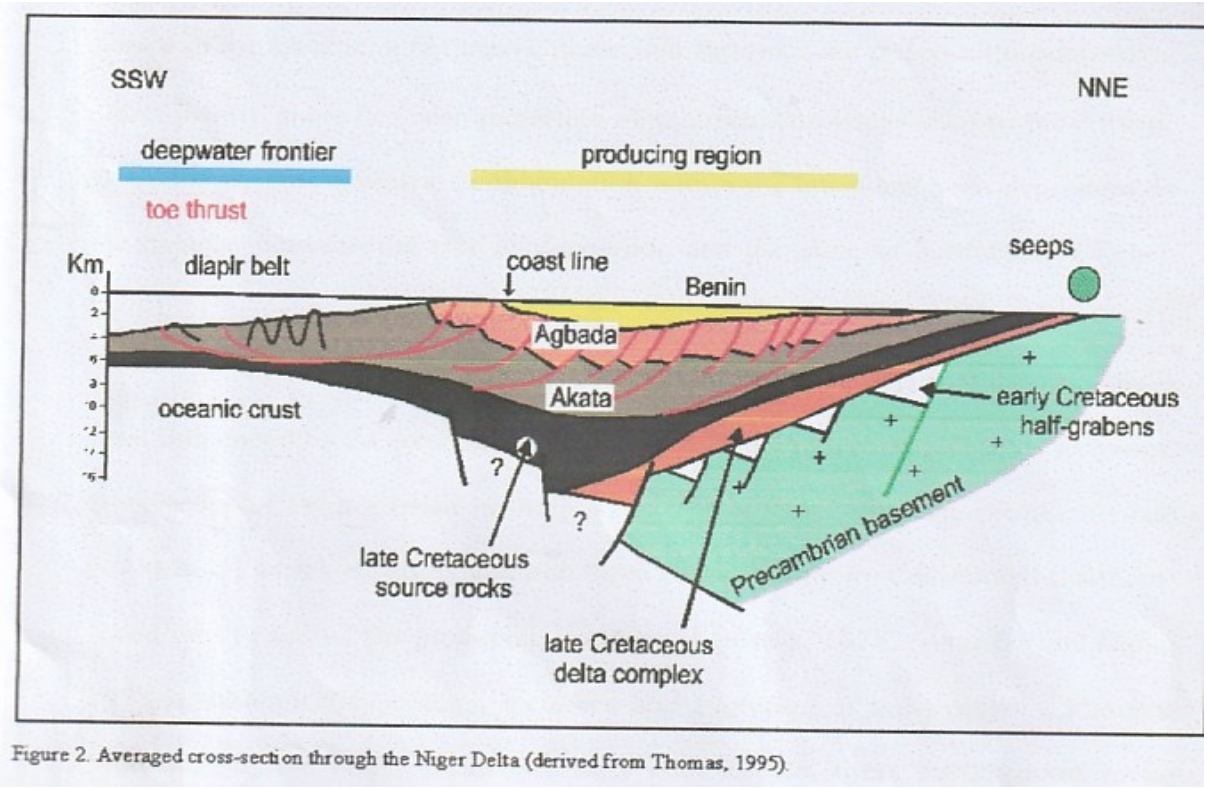

Fig.2: Showing the different formations in the Niger Delta

The basal unit is the Akata Formation, and it consists of marine, pro-delta shales. It is generally over-pressured and acts as the primary source rock for Niger Delta hydrocarbons.

The Agbada Formation is the central paralic (alternating sand and shale) sequence and serves as the primary reservoir for most oil and gas fields in the delta. Benin Formation, which is the youngest and uppermost unit, is composed entirely of continental and coastal plain sands and gravels. Because the Niger Delta is highly faulted and dynamic, standard physical rock correlation is difficult. Foraminifera—microscopic single-celled shelled protozoans—are highly sensitive to changes in depositional environments and are widely used in biostratigraphic correlation and paleoenvironmental reconstruction.

Planktonic forms in the Delta include Globigerinoides, Globorotalia, etc., and they occur within the water column and are highly reliable for age dating and regional correlation. Benthic forms here include Ammonia, Bolivina, and Lenticulina, which all live on the seafloor and strongly controlled by water depth, salinity, and oxygen levels.

1.1 Geological Setting

The Niger Delta sits on top of the Anambra Basin and Oceanic Crust and its geological setting is defined by a distinct tripartite lithostratigraphic framework and regional tectonic features.

A) Basin Evolution & Tectonics

The basin's foundation formed during the Late Jurassic to Cretaceous, was driven by a failed rift triple-junction created as the South American and African plates separated to open the South Atlantic Ocean (Gondwana breakup). The Benue trough to the north is the failed arm, while the Niger Delta Proper developed on the divergent margin as the South Atlantic opened.

As the delta prograded (built seaward) over time, it created discrete depositional units known as depobelts, which are bound by large-scale growth faults & characterized by intense syn-sedimentary deformation and shale diapirism (upward movement of deep pressurized shale).

B) Stratigraphy (The Three Formations)

The delta is subdivided into three diachronous, coarsening upwards regressive association of clastics which makes up the entire sedimentary sequence and are Tertiary Formations. They include:

Akata Formation (Base) — Paleocene to Recent

This is the oldest unit and is composed of thick, marine shales deposited in a deep-water, anoxic pro-delta environment, with hemipelagites, and turbidite channel-levee complexes. It has a thickness of about 6–7km in the depocenter, and is highly over pressured due to rapid burial & disequilibrium compaction, serving as the primary source rock for the region's prolific hydrocarbon system. This formation also acts as a ductile detachment surface for gravity tectonics. It is dominated by planktic assemblages and agglutinated benthics in deeper settings. High P/ B ratios, with species like *Globigerina bulloides, Globorotalia menardii, Cyclammina, Haplophragmoides*, etc.

Agbada Formation (Middle) — Eocene to Recent

This is the main deltaic sequence with a thickness between 3 and 4km. Facies here consists of alternating paralic to shallow marine alternations of sandstones, siltstones and shales, representing cyclical marine, coastal, and fluvial deposits. It forms the primary reservoir rock for oil and gas, which are trapped in rollover anticlines, growth faults, closures, and stratigraphic traps. Foraminiferal assemblages here are mixed with distal Agbada, having planktonic-rich intervals marking maximum flooding surfaces, while proximal Agbada is benthic-dominated with forms like *Bolivina, Uvigerina, Ammonia, Elphidium, Cibicides* and agglutinated *textularia, Trochammina*, etc., which are used to pick parasequences and system tracts.

Benin Formation (Top) — Oligocene to Recent

This is the youngest unit and is made up of t hick, continental, fluviatile and delta plain sands, gravels and minor clays. Thickness is

up to 0–2km and is still being deposited today. The formation serves as a major shallow freshwater aquifer with little hydrocarbon potential except shallow biogenic gas. The foraminifera availability here is barren to very low diversity, with freshwater/brackish-taxa only near the base.

Several authors have applied foraminiferal biostratigraphy in the Niger Delta Basin for age determination, paleoenvironmental reconstruction, and regional stratigraphic correlation (Blow, 1969; Petters, 1982; Avbovbo, 1978). These studies established important planktonic and benthic zonation schemes for the Tertiary sediments of the basin. However, detailed foraminiferal investigations within the coastal swamp depobelt remain relatively limited.

Despite numerous regional studies, limited high-resolution biostratigraphic data are available for the studied interval of the "VC" well. Consequently, further investigation is required to improve stratigraphic resolution and regional correlation within the Central Niger Delta.

Therefore, this study aims to establish the foraminiferal biostratigraphic framework of the "VC" well using planktonic and benthic foraminiferal assemblages in order to determine the age and biozones of the Agbada Formation sediments encountered within the studied interval. The study will contribute to improved regional stratigraphic correlation, depositional interpretation, and hydrocarbon exploration within the Niger Delta Basin.

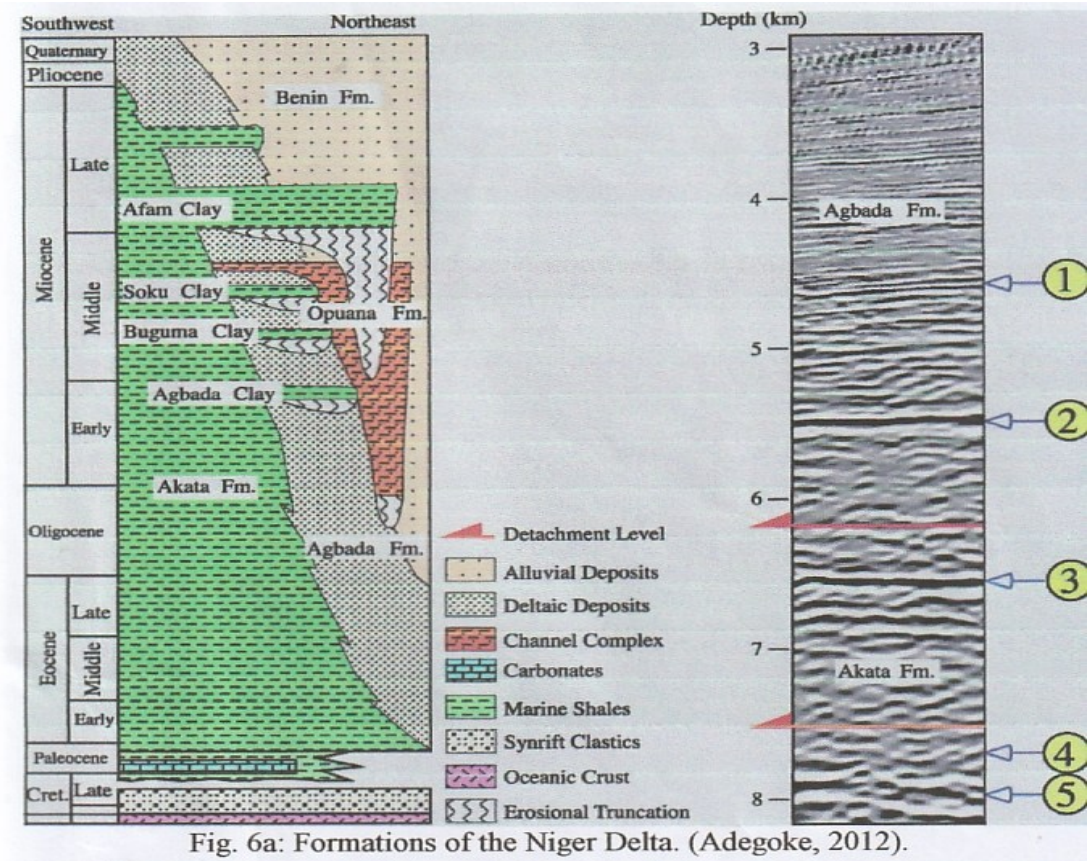

Fig. 3: Showing Formations and lithologies of the Niger-Delta

C) Structural Style

The Niger Delta is structurally characterized by gravity-driven, thin-skinned tectonics, where rapid sedimentary loading causes the underlying ductile marine shales to deform. The structural style can be broadly divided into three main deformation zones from North to South (Adegoke*et al*., 2002; 2012).

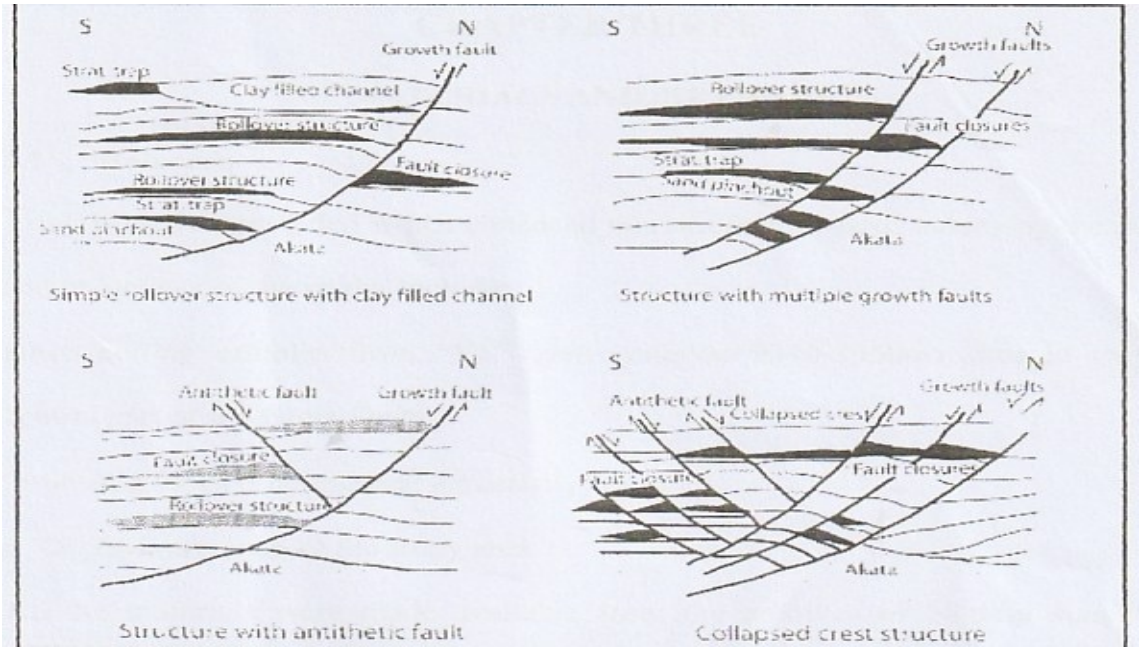

Fig. 4: deformation and structural types of trap and seals within the Niger-Delta (From Doust and Omatsola,1990 and Stacher,1995)

Extensional Province (Onshore and shallow offshore):

Dominated by large-scale listric normal growth faults and counter-regional faults that form major depobelts. These faults create structures like rollover anticlines, synthetic/antithetic faults and collapsed crestal structures that act as traps for oil and gas. All grow contemporaneously with sedimentation Fig. 4).

Transitional/Diapir Province (Mid-Slope):

This is characterized by the upward movement of over pressured shales. This creates mud diapirs, mud volcanoes, and shale ridges that pierce through the overlying sediments. The diapirs and ridges are due to differential loading & overpressure in Akata.

Compressional Province (Deep Water Toe):

This zone represents the distal part of the delta, where gravitational sliding stops, resulting in an inner fold and thrust belt. This zone is defined by detachment folds, toe thrusts, and imbricate fault systems.

These structural styles are entirely detached and glide upon the deep, under-compacted, and over pressured Akata formation shales, which act as a massive detachment layer.

The Niger Delta is characterized by a prolific Tertiary petroleum system commonly referred to as the Akata–Agbada petroleum system, which constitutes one of the world's major hydrocarbon provinces. The petroleum system is composed of three principal lithostratigraphic units: the Akata Formation, Agbada Formation, and Benin Formation, which function respectively as the source rock, reservoir rock, and overburden succession.

The Akata Formation, which forms the basal unit of the delta, consists predominantly of massive, under-compacted and overpressured marine shales deposited in prodelta to open marine environments. The organic matter within these shales comprises both marine Type II and terrestrial Type III kerogens, thereby enabling the generation of both oil and gas. Due to deep burial, the Akata shales attained thermal maturity within the oil window during the Eocene to Oligocene, while some portions progressed further into the gas-condensate window.

Overlying the Akata Formation is the Agbada Formation, which is composed of interbedded sandstones and shales representing paralic depositional sequences. These sediments were deposited within tide- and river-dominated delta-front, distributary-channel, and delta-plain environments. The sand bodies generally possess good porosity and permeability, making them the principal hydrocarbon reservoirs within the basin.

Hydrocarbon accumulation is commonly associated with structural and stratigraphic trapping mechanisms, particularly rollover anticlines formed within the hanging walls of synsedimentary growth faults, as well as fault closures and turbidite-related stratigraphic traps. Interbedded marine shales within the Agbada Formation, together with clay smears along faults, serve as effective seals for hydrocarbon entrapment.

The Benin Formation constitutes the uppermost unit of the Niger Delta succession and is composed mainly of continental sands and gravels. This formation acts primarily as an overburden sequence, providing the pressure conditions necessary for hydrocarbon maturation within the underlying Akata source rocks. Hydrocarbon migration within the basin occurs mainly through regional growth faults that connect the mature Akata shales with the shallower Agbada reservoirs. The timing of hydrocarbon generation and expulsion coincided with the development of structural traps, thereby enhancing hydrocarbon accumulation within the basin.

Structurally and depositionaly, the Niger Delta is subdivided into six major shore-parallel depobelts representing successive stages of delta progradation. These include the Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp, Offshore, and Deepwater depobelts (Fig. 4). Among these, the Central Swamp and Coastal Swamp depobelts contain the majority of the proven hydrocarbon reserves, although deepwater exploration activities have become increasingly significant in recent years.

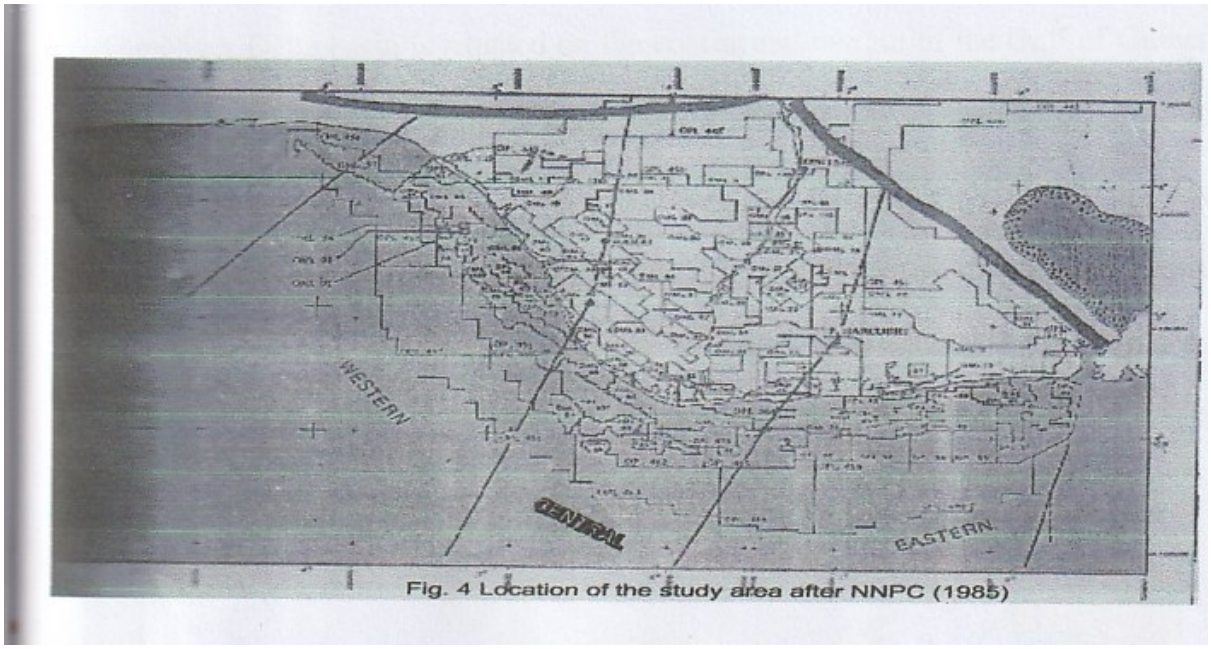

Fig. 5: Showing different depo-belts within the Niger-Delta

2.0 Materials and Methods

2.0 Materials and Methods

The materials used for this study included ditch cutting samples obtained from the "VC" Well within the depth interval of 2340–3350 m in the Central Niger Delta, gamma ray and resistivity well logs, and a location map of the study area. These materials were obtained from the archives of the Nigerian Agip Oil Company through permission granted by the Department of Petroleum Resources.

Laboratory preparation of the ditch cutting samples followed standard micropaleontological procedures. Approximately 32 g of each sample was soaked in water to facilitate disaggregation and breakdown of the sediment matrix. The disaggregated samples were subsequently washed through a set of sieves in order to separate the coarse fractions containing potential microfossils. The preparation procedures adopted in this study are consistent with standard micro-

paleontological methods described by Murray (1991, 2006), Armstrong and Brasier (2005), Zarkogiannis *et al*. (2020), Tetard *et al*. (2021), Alkali (2023), Adebambo and Fadiya (2013), and Adeola *et al*. (2021).

The recovered residues were dried and examined under a binocular microscope. Foraminiferal specimens were manually picked using a fine brush and mounted on micropaleontological slides for identification and analysis. Taxonomic identification was carried out using standard foraminiferal reference literature and online databases, including Loeblich and Tappan (1964), Petters (1979, 1982), Foraminifera.eu, and the World Register of Marine Species (WoRMS), as well as more recent studies on West African foraminifera (Emeka *et al*., 2023; Emeka *et al*., 2024). All recovered specimens were counted, and their relative abundance percentages were calculated for each identified genus.

3.0 Results and Discussion

Lithologic/ Lithofacies Analysis of the "VC" well The analyzed interval (2340-3350m) of "VC Well penetrated lithofacies of the Agbada formation. The sediments are dominantly shales with siltstones and fine to coarse-grained, well-sorted sands and sandstones. Detailed descriptions of all the samples are presented in Appendix 1. The entire deposition took place within a prograding deltaic setting with short-lived transgressions.

A lithostratigraphic summary comprising of lithology as well as lithostratigraphy with corresponding depth interval is presented in the table below.

Table 1: Lithologic/Lithofacies summary of the "VC well"

Depth interval (M)	Lithology	Lithofacies	Lithostratigraphic unit
2340 – 25000	Shale with Sand Intercalations	A	AGBADA FORMATION
2505 – 2650	Shale with sand	B	
2665 – 2800	Shale with sand	C	
2810 – 2930	Shale with sand	D	
2940 – 3080	Shale	E	
3090 – 3150	Shale with sand	F	
3160 – 3350	Shale	G	

The lithologic succession encountered in the "VC" Well between 2340 m and 3350 m is characterized predominantly by alternating shale and sand units with minor silt intercalations, typical of the paralic sequences of the Agbada Formation in the Niger Delta Basin. The vertical lithologic variations indicate alternating coarsening-upward and fining-upward depositional cycles, reflecting fluctuations in sediment supply and depositional energy within deltaic to shallow marine environments.

The basal interval between 3350 m and 3160 m is composed predominantly of grey-brown shale with minor occurrences of very fine-grained sand towards the upper section. The progressive increase in sand content upward indicates a coarsening-upward sequence suggestive of increasing depositional energy. Between 3150 and 3090 m, the lithology consists of interbedded shale and sand units occurring in nearly equal proportions at the base, while shale becomes progressively dominant upward. The sand fraction is off-white, fine- to coarse-grained, and moderately sorted, whereas the shale retains the characteristics observed in the underlying interval.

The interval from 3080 m to 2940 m is dominated by shale, constituting approximately 90% of the lithology, with minor sand interbeds. Sand content decreases upward from approximately 70% at the base to complete absence at the top, producing a

fining-upward sequence. The overlying interval between 2930 m and 2810 m consists predominantly of light grey to brown shale that is sub-fissile to fissile, moderately hard, and micromicaceous, with occasional black shale occurrences. In this interval, shale decreases upward while sand content progressively increases, forming a coarsening-upward sequence. The sands are fine-grained and white in colour.

Between 2800 m and 2665 m, the lithofacies consist of alternating sand and shale units with lithologic characteristics similar to those of the preceding interval. Sand content decreases upward from approximately 85% at the base to 45% at the top, while shale content increases correspondingly. The interval from 2650 m to 2505 m is composed mainly of shale with subordinate sand units. The shale is predominantly grey, whereas the sand fraction is white, fine- to medium-grained, and occasionally coarse-grained.

The uppermost interval between 2500 m and 2340 m comprises alternating shale and sand facies. The sand units are colourless to orange, medium- to coarse-grained, sub-rounded to rounded, and well sorted. The shale units are light grey to brown, sub-fissile to fissile, moderately hard, micromicaceous, and occasionally carbonaceous with lignite fragments. Sand content increases upward from approximately 10% at the base to about 100% within the middle section before decreasing slightly towards the top, while shale content shows an inverse relationship. These lithologic characteristics collectively suggest fluctuating depositional environments associated with deltaic progradation within the Agbada Formation.

Foraminiferal analysis was conducted on one hundred ditch cutting samples obtained from the studied interval of the "VC" Well between 2340 m and 3350 m. Preservation of foraminiferal specimens ranged from fair to good, while abundance and diversity varied from low to moderately high throughout the analyzed section. The recovered foraminifera were identified to species level, where possible, through comparison with established taxonomic references including Petters (1982), Stainforth *et al*. (1975), and Bolli and Saunders (1985).

The distribution of foraminiferal taxa, associated bioevents, and their stratigraphic interpretations, including age determination, foraminiferal zonation, paleoenvironmental interpretation, and sequence stratigraphic significance, were integrated and presented using STRATABUGS software (Enclosure 1). The biostratigraphic analysis indicates that the "VC" Well penetrated three foraminiferal microzones, namely N_{16}, N_{15}, and the composite N_{14}–N_9 zones, which correspond to sediments of Middle to Late Miocene age within the Niger Delta Basin. A summary of the foraminiferal biostratigraphy of the well is presented in Table 2

Table 2: Foraminiferal Biostratigraphic Summary of the "VC" well

Depth i Inerval (m)	F – Zone (Blow, 1969 in Bolli and Saunders, 1985)	Age	Associated Micro-Event
2340 – 2530	N_{16}	Late Miocene	- Top Regular occurrence of Florilus ex. gr. Costiferum at 2500m - Single occurrence of Globorotalia acostaensis at 2530
2530 – 2640	N_{15}		-

2640 – 3350	N_{14} – N_9	Middle Miocene	- Single occurrence of Globorotalia continuosa at 2640m - Single occurrence of Praeorbulina glomerosa at 3350m

The studied interval of the "VC" Well has been subdivided into three foraminiferal biozones (F-zones), namely N_{16}, N_{15}, and the composite N_{14}–N_9 zone, based on diagnostic planktonic and benthic foraminiferal events, species distribution patterns, and established Niger Delta biostratigraphic frameworks.

The uppermost interval (2340–2530 m), assigned to F-Zone N_{16} (Late Miocene), is defined by key bioevents including the top regular occurrence of *Florilus ex gr. costiferum* at 2500 m and the single occurrence of *Globorotalia acostaensis* at 2530 m. This zone, approximately 160 m thick, is characterized by generally low abundances of benthic foraminifera such as *Uvigerina subperegrina*, *Epistominella vitrea*, *Eponides eshira*, *Hopkinsina bononiensis*, and *Hanzawaia strattonii* in the upper part of the interval. The lower portion contains sporadic occurrences of *Amphicoryna scalaris*, *Florilus ex gr. costiferum* (Nonion-4), and *Lenticulina inornata*. These calcareous benthic taxa occur alongside rare arenaceous forms including *Cyclammina cancellata* and *Saccammina complanata*.

The coexistence of both Middle and Late Miocene indicator species suggests a transitional assemblage, reflecting deposition within the basal portion of the Late Miocene (N_{16}) microzone. This interpretation is consistent with previous studies (Petters, 1982; Ozumba and Amajor, 1999; STRATCOM, 2000), which recognized overlapping faunal distributions in transitional stratigraphic intervals. The top regular occurrence of *Florilus ex gr. costiferum* at 2500 m is a significant marker for the basal Late Miocene in the Niger Delta (Ozumba and Amajor, 2000). Furthermore, the single occurrence of *Globorotalia acostaensis* at 2530 m, where considered in situ, indicates penetration into the N_{16} zone of Bolli and Saunders (1985), marking the N_{16}/N_{15} boundary. Accordingly, this interval is interpreted as Late Miocene in age.

The middle interval (2530–2640 m) corresponds to F-Zone N_{15} (Middle Miocene) and is approximately 140 m thick. It is characterized by the single occurrence of *Globorotalia continuosa* at 2640 m, which is used to define the base of the zone. The assemblage within this interval shows low to moderately high and relatively consistent occurrences of *Epistominella vitrea*, *Florilus ex gr. costiferum*, *Hanzawaia strattonii*, *Amphicoryna scalaris*, *Lenticulina inornata*, *Bolivina dilatata*, *Cibicorbis inflata*, *Eponidella aff. venezuelana*, and *Eponides berthelotianus*.

The benthic assemblage is accompanied by arenaceous taxa such as *Textularia laminata* and *Textularia panamensis*, while planktonic forms including *Globigerinoides obliquus*, *Globigerinoides trilobus*, and *Globorotalia continuosa* are also present. The occurrence of *Globorotalia continuosa* at the base of the interval, if in situ, is significant as it represents a diagnostic marker for the N_{15} microzone and is commonly used to define the N_{15}/N_{14} boundary in the Niger Delta biostratigraphic framework of Bolli and Saunders (1985). Consequently, this interval is interpreted as Middle Miocene in age.

The lowermost interval (2640–3350 m) represents a composite F-Zone N_{14}–N_9, interpreted as Middle Miocene in age, with a total thickness of approximately 710 m. This zone is defined by the single occurrence of *Praeorbulina glomerosa* at 3250 m, which serves as a key biostratigraphic marker within the Middle Miocene succession.

The interval is characterized by generally low to moderately high occurrences of *Epistominella vitrea* and associated benthic

foraminiferal assemblages, indicating relatively stable but fluctuating depositional conditions within a deltaic to shallow marine environment. The overall faunal composition suggests continued Middle Miocene sedimentation within the Agbada Formation, consistent with established regional biostratigraphic zonation schemes.

Eponides eshira, Hanzawaia Strattonii, Florilus ex. gr costiferum, Lenticulina inornata, Ammonia beccarii, Cibicorbis inflata, Eponidella aff. venezuelana, Bolivina dilatata, Eponides berthelotianus, Florilus atlanticus, Quinqueloculina seminulum, Gavelinella aff beninensis, Heterolepa floridana and *Uvigerina sparsicostata,* etc. These calcareous benthics are associated with the occurrences of arenaceous taxa such as *Textularia laminata, T. panamensis, T. mexicana* and *Haplophragmoides sp.* The planktic suite in this microzone comprises of an assemblage similar to that of the preceding interval. However, the occurrences of *Globigerina bulloides, G. venezuelana, Orbulina universa, O. suturalis, Globorotalia mayeri, G. obesa* and *Praeorbulina glomerosa* are distinctive of this microzone interval.

The top of this composite microzone (N_{14}) coincides with the base of the preceding one as defined at 2640m. The single occurrence of *Praeorbulina glomerosa* at 3250m (if in-situ), may be an indication of the penetration of the N_9 microzone. The FDO of this planktic species occurs within the No microzone of Bolli and Saunders, (1985). However, the delineation of the N_{14}/N_{13}, N_{13}/N_{12}, N_{12}/N_{11} N_{11}/N_{10}, N_{10}/N_9 (Middle Miocene) boundaries was not possible in this study due to the absence of diagnostic taxa such as *Globigerinoides subquadratus, Globorotalia praemenardii, Globorotalia fohsi fohsi* and *G. peripheroronda* in this interval. The FDOs of these species usually mark these respective boundaries (Bolli and Saunders, 1985).

This composite F-Zone interval is accordingly dated Middle Miocene.

4.0 Conclusion

The foraminiferal biostratigraphic analysis of ditch cutting samples from the "VC" Well, covering the interval 2340–3350 m within the coastal swamp depobelt of the Central Niger Delta, has successfully established a robust chronostratigraphic and biozonation framework for the Agbada Formation succession penetrated by the well. The integration of lithofacies characteristics with detailed micropaleontological data provides a consistent basis for age determination, zonation, and depositional interpretation of the studied interval.

The sedimentary succession is confidently dated as Middle to Late Miocene based on diagnostic planktonic and benthic foraminiferal assemblages and associated bioevents.

Biostratigraphic subdivision of the interval identifies three principal foraminiferal zones correlated with Blow's Neogene zonation scheme. The upper interval (2340–2530 m), assigned to Zone N_{16} (Late Miocene), is defined by the top regular occurrence of *Florilus ex gr. costiferum* at 2500 m and the single occurrence of *Globorotalia acostaensis* at 2530 m. The intermediate interval (2530–2640 m), corresponding to Zone N_{15} (Middle Miocene), is characterized by a relatively consistent assemblage of calcareous and arenaceous benthic foraminifera and is delimited at its base by the occurrence of *Globorotalia continuosa* at 2640 m. The lower interval (2640–3350 m) represents a composite N_{14}–N_9 zone of Middle Miocene age and is defined by the occurrence of *Praeorbulina glomerosa* at 3250 m, with further subdivision constrained by the absence of additional diagnostic index taxa.

Lithofacies analysis reveals a succession dominated by alternating sandstone and shale units with minor silt intercalations, typical of the paralic Agbada Formation. The vertical stacking pattern of coarsening-upward and fining-upward cycles reflects dynamic depositional processes controlled by deltaic progradation and episodic marine transgressions within a shallow marine to deltaic setting.

In conclusion, this study significantly enhances the biostratigraphic database of the coastal swamp depobelt of the Central Niger Delta. The refined zonation framework improves regional stratigraphic correlation, supports more accurate subsurface geological modelling, and provides valuable constraints for hydrocarbon exploration and reservoir characterization within the Akata–Agbada petroleum system.

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Consent for publication

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Availability of data

Data shall be made available on demand.

Competing interests

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Authors' contributions

Godwin Ndarake Enin conceived and supervised the study, interpreted data, and drafted the manuscript. Anthony Ayodeji Adegoke, Kate Onyeje Igoche, and Kooffreh Kooffreh conducted microbiological and antibacterial analyses. Abraham Uduak Ekpe, Ndifreke Ime Asuquo, and Ubong Okon Jeremiah performed extraction, phytochemical, antioxidant, proximate, mineral, and GC–MS analyses. All authors reviewed and approved the final manuscript.