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## Biostratigraphic Zonation and Depositional Environments of the BB Well, Niger Delta Basin: A Foraminiferal Perspective

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### Abstract

This study addresses longstanding chronostratigraphic and paleoenvironmental uncertainties within the hydrocarbon-bearing succession of the Niger Delta through an integrated foraminiferal biostratigraphic, sedimentological, and wireline log approach. Forty-one ditch cutting samples from BB Well were subjected to standardized laboratory procedures, including controlled disaggregation, wet sieving over the 63-500  $\mu\text{m}$  fraction, oven drying, and systematic micropaleontological picking. Taxonomic identification and quantitative assessment of planktonic and benthic foraminifera were undertaken to establish biofacies distribution and age control. These data were integrated with detailed lithologic descriptions and gamma-ray log motifs to generate a composite graphic log, enabling high-resolution correlation between biofacies and lithofacies architecture. Two principal depositional intervals were delineated within the Agbada Formation. Lithofacies A (2100-2500 m) comprises interbedded fine- to medium-grained sands and shales exhibiting coarsening-upward motifs, interpreted as barrier bar and shoreface complexes deposited under wave- and storm-influenced inner neritic conditions. Lithofacies B (2500-3100 m) is dominated by thick, fissile marine shales with minor channelized and turbiditic sand intercalations, reflecting deposition in outer neritic to upper bathyal settings under relatively low-energy conditions. Benthic foraminiferal assemblages document a major transgressive-regressive (T-R) cycle. A Middle Miocene deepening trend from inner neritic to bathyal environments culminates in a regionally correlatable maximum flooding surface (MFS), followed by a Late Miocene progradational, shallowing-upward succession into inner-middle neritic settings. Planktic biozonation establishes a Middle-Late Miocene age, defined by the *Globigerinoides immaturus* - *Globorotalia siakensis* and *Globorotalia tumida* - *Globigerinoides margaritae* Assemblage Biozones, correlating with N14-N15 and N16-N17 of Berggren et al. This multi-proxy integration provides a refined chronostratigraphic framework, constrains key sequence stratigraphic surfaces, and links depositional architecture to relative sea-level fluctuations. The resulting depositional model enhances reservoir prediction, stratigraphic correlation, and exploration risk reduction in the Niger Delta and analogous deltaic petroleum systems.

### Keywords

Biozone,  
Ditch Cuttings,  
Miocene,  
Niger Delta,  
Paleoenvironmental

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## INTRODUCTION

The Niger Delta Basin, renowned as a major petroleum-producing region (Doust and Omatsola, 1990), has captivated geoscientists for decades due to its intricate depositional systems and resource wealth. Emerging during the Cenozoic era, through the dynamic interplay of riverine, coastal and marine forces (Allen, 1965), this basin preserves a layered archive of Tertiary sediments that chronicle shifting environmental conditions influenced by sea-level oscillations (Haack *et al.*, 2000), tectonic adjustments (Reijers, 2011) and variable sediment influx. Despite extensive research into its hydrocarbon reservoirs, gaps persist in synthesizing the basin's stratigraphic evolution and paleoenvironmental drivers, particularly where biostratigraphic data intersect with lithologic variability (Selley, 1997).

Foraminifera are microscopic fossils that serve as reliable markers of geologic age, water depth and climate (Jones, 2013) zones providing a temporal lens to decode the basin's environmental transitions. Complementing these biotic clues, lithologic features like sedimentary texture, bedding patterns, mineral composition and facies relationships reveal physical processes of deposition, sediment origins, and post-burial changes (Reading, 1996). While these methods are powerful in tandem, their integrated use in the Niger Delta remains underexplored (Ajaegwu *et al.*, 2020), hindering progress in clarifying stratigraphic uncertainties, reservoir segmentation and ancient landscape dynamics.

This research addresses this shortfall by synthesizing foraminiferal biostratigraphy with high-resolution sedimentological analysis across the delta's Akata, Agbada and

Benin Formations (Short and Stauble, 1967). The study seeks to reconstruct paleoenvironmental shifts that influenced sediment deposition (Van der Zwaan *et al.*, 1999), improve stratigraphic models to better predict reservoir distributions (Catuneanu, 2006) and evaluate how depositional variability impacts hydrocarbon exploration strategies (Evamy *et al.*, 1978). By correlating microfossil zonation with lithofacies trends, the work provides a dual-perspective framework to unravel the basin's geologic narrative while offering actionable insights for resource management.

This study highlights the synergy between biostratigraphic and lithologic proxies in resolving the multifaceted evolution of sedimentary basins, a strategy adaptable to other deltaic regions facing similar exploration and academic challenges (Reijers, 2011; Ajaegwu *et al.*, 2020).

The Niger Delta Basin, situated in southern Nigeria and extending into the Gulf of Guinea, is a globally significant hydrocarbon province (Tuttle *et al.*, 2015). This Cenozoic clastic-dominated passive margin delta, covering a subaerial area of approximately 75,000 km<sup>2</sup> (with a total area of about 300,000 km<sup>2</sup>), contains a sedimentary succession exceeding 12 km in thickness, deposited from the Eocene to the Recent (Adegoke *et al.*, 2017). Its evolution has been governed by the interplay of tectonic subsidence, eustatic sea-level fluctuations, and high sediment supply from the Niger River system. The basin's stratigraphy is classically defined by a tripartite division: the deep marine Akata Formation (source rock), the paralic Agbada Formation (the primary reservoir interval) and the continental Benin Formation. Understanding the depositional architecture within this

sequence, particularly in the Agbada Formation, is critical for hydrocarbon exploration and reservoir characterization. (Oluwajana *et al.*, 2017). The study well is

located in the Central Swamp Depobelt within latitude 5° 10'N and longitude 5° 45'E.

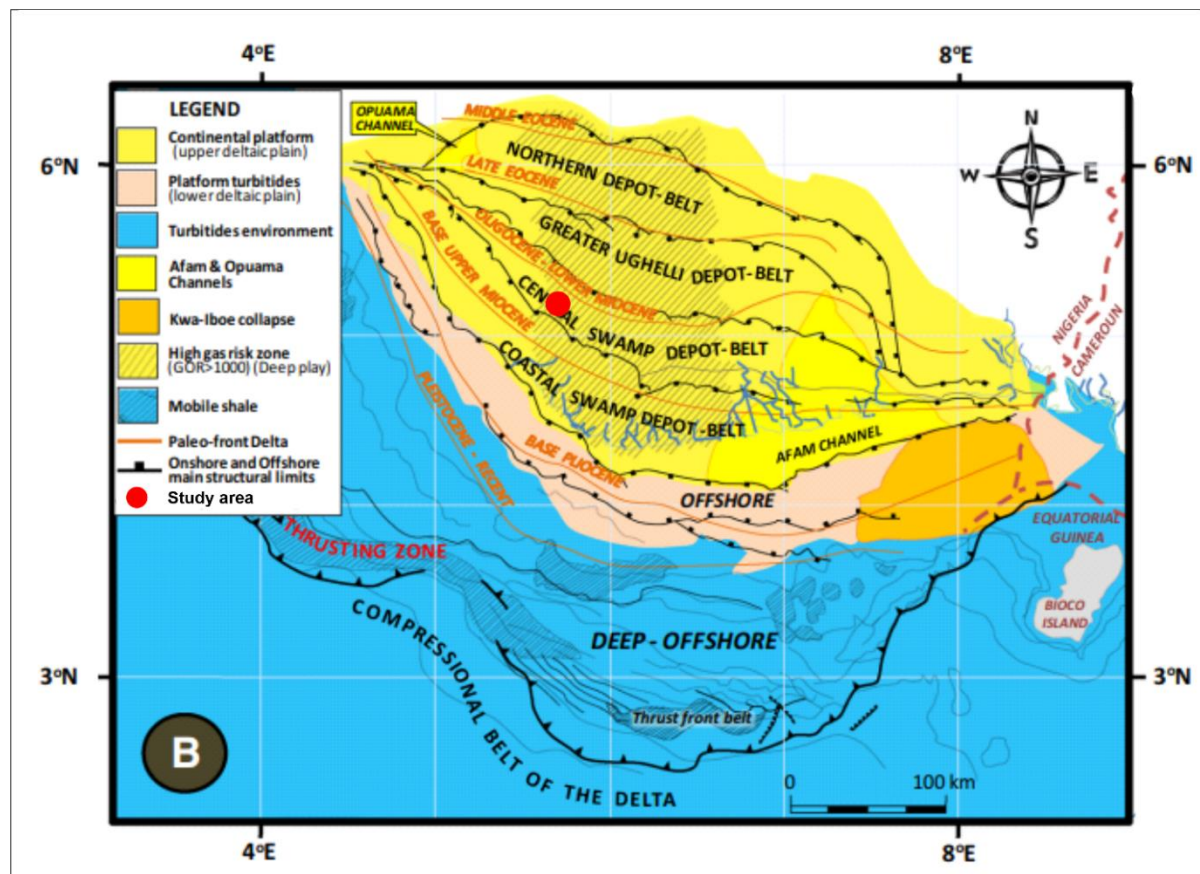


Figure 1: Geologic map of Niger Delta Basin showing the study area (redrawn from Ebong *et al.* 2017)

## MATERIALS AND METHODS

### Foraminiferal Sample Processing

Foraminifera were extracted from ditch cutting samples collected between 2100 to 3100 meters for biostratigraphic analysis. The laboratory processing followed a standardized physical and chemical disaggregation procedure of Ha *et al.*, (2025).

20 grams of dried sediment was treated with a sodium hexametaphosphate solution (5%) in distilled water. The mixture was gently

heated and stirred to break down clay aggregates without damaging fragile calcareous foraminiferal tests. The disaggregated sample slurry was washed over a 63  $\mu\text{m}$  stainless steel sieve. A gentle, steady stream of water was applied until the effluent ran clear, ensuring the removal of fine clay and silt particles while retaining the microfossil fraction. The sieved residue was transferred onto a labeled filter paper and oven-dried at a controlled temperature of 40-55°C. This low-temperature drying prevented the thermal alteration or cracking of delicate foraminiferal tests.

The dried residue was homogenized and a representative subsample was obtained using a microsplitter. All foraminifera were systematically picked from this subsample under a stereomicroscope using a fine brush and mounted on a micropaleontological slide for identification and counting.

### **Integration of Lithological Descriptions and Wireline Log Data**

A standardized procedure of Radwan (2022) was employed to integrate physical sedimentology with digital log data for comprehensive subsurface interpretation. The methodology consisted of two primary phases: data synthesis/visualization and interpretative unit definition.

Direct lithological descriptions from cuttings analysis including grain size and mineralogical composition were systematically correlated with the digital gamma-ray (GR) log (Chen *et al* 2021). A depth-registered database was constructed containing the following fields: lithology code, grain size, GR value (in API units) and descriptive notes. This database was imported into SedLog software to generate a standardized composite graphic log (Zervas *et al.*, 2009).

Lithology was plotted using industry-standard fill patterns. Grain size variations were represented by a variable-width column. The GR curve was plotted directly adjacent to the lithology column to enable immediate visual correlation.

Integrated units were established by correlating characteristic GR log motifs (e.g., funnel, bell, cylindrical shapes) with the physical attributes observed in cuttings. For example, a cylindrical GR motif associated with cuttings of well-sorted, coarse sand was interpreted as a high-energy channel fill deposit (Chahadeh *et al.*, 2026).

The consistent vertical stacking and association of these defined facies units within the composite lithologic section facilitated a systematic interpretation of the temporal evolution of depositional environments throughout the studied interval.

## **RESULTS AND DISCUSSION**

### **Lithofacie A Upper Agbada Formation 2100m -2500m**

The lithofacies sequence is predominantly composed of alternation alternating sandstones, shaly sands, shales and sandy shale beds. The thickness of the shale increases with depth within the intervals. The signature wireline logs show deposition of barrier bars, barrier fronts and transgressive sands and clays. Index accessories contain carbonaceous detritus, mica flakes, ferruginous matter and shell fragments of molluscs and brachiopods. The lithologic attributes of the well interval have allowed the studied section to be assigned Upper Agbada Formation.

### **Lithofacie B Lower Agbada Formation 2500m - 3100m**

This interval is composed of thick shale units intercalated with minor channel fills and turbidite sandstones. The shale grades into silt at lower depth. The sands are quartose, fine to medium-grained, occasionally coarse to very coarse-grained and granular (Figure 2). Sands are poorly to well sorted. Terrigenous materials, abundant mica flakes, clay, low amount of carbonaceous detritus plus shell fragments of molluscs occur at upper depth of this interval. The high occurrence of mica could indicate that the sediments within the intervals were not far from their origin. Therefore, mica flakes were not subjected to adequate weathering

which could have led to their alteration to clay minerals. The lithologic attributes of

this interval have allowed its assignment to Lower Agbada Formation.

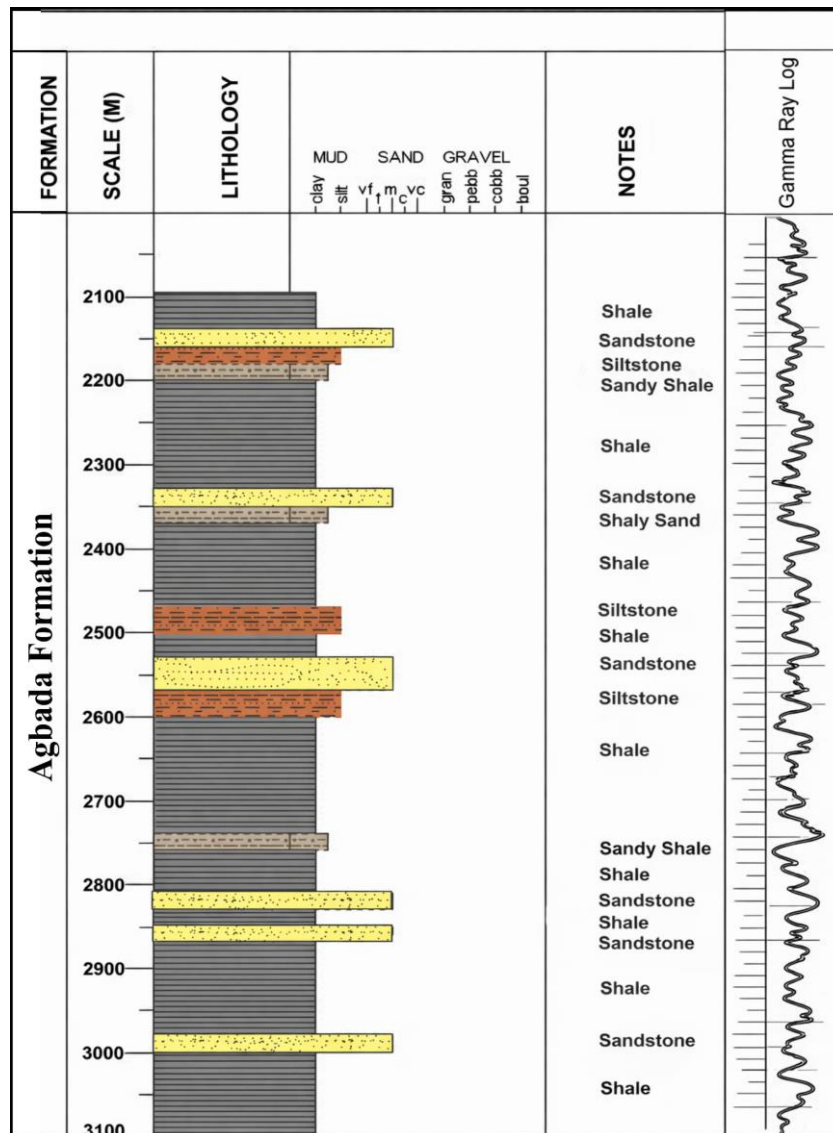


Figure 2: Lithostratigraphic section of BB Well

### Biochronology and Biostratigraphic Zonation of BB Well

The foraminiferal assemblage indicates a depositional age ranging from the Middle to Late Miocene. The zonation follows the standard P-N (Planktic) biozones established for the Niger Delta (Berggren *et al.*, 1998). The total number of species identified in BB Well is 136 foraminiferal species with 105 benthic species and 31 planktic species.

The benthic community is highly diverse with species distributed across several key genera. The most significant genera to the diversity are *Lenticulina*, *Bolivina*, *Eponides*, *Bulimina* and *Cibicides*

The planktic community are primarily used to determine the geological age of the well's sections. The diversity is concentrated in the following genera: *Globigerina*, *Globigerinoides*, *Globorotalia*. Other taxa includes species such as *Orbulina universa*, *Sphaeroidinella subdehiscens*, and

*Catapsydrax dissimilis*. The biostratigraphic synthesis chart of BB well and photomicrographs of some recovered foraminifera species are shown in Figures 3 and 4 respectively

#### **Late Miocene (2125 - 2625 m) (*Globorotalia tumida* to *Globigerinoides margaritae* Zones)**

Consistent presence of *Globorotalia tumida* and *Sphaeroidinella subdehiscens*. Occurrence of *Globigerinoides margaritae* at 2175 m. Last Occurrence (LO) of *Globorotalia plesiotumida* (near base). The co-occurrence of *Globorotalia tumida* and *Sphaeroidinella subdehiscens* is a definitive Late Miocene signal in the Niger Delta (Pessagno, 1967; Bolli and Saunders, 1985). *Globigerinoides margaritae* is a well-documented marker for the basal Late Miocene (Short and Stauble, 1967).

#### **Late/Middle Miocene Boundary (2600 - 2625 m)**

High diversity peak in planktic foraminifera. Transitional interval with final appearances of Middle Miocene taxa. Boundary Interval (Top of N16 / Base of N17). This peak likely reflects the Middle Miocene Climatic Optimum (MMCO) decline or a major flooding surface, creating optimal open-marine conditions [Van der Zwaan *et al.*, 1999].

#### **Middle Miocene (2650 - 3100 m) (*Globigerinoides immaturus* to *Globorotalia siakensis*)**

Consistent presence of *Globorotalia siakensis*. Presence of *Globorotalia opima opima*. Occurrence of *Globigerinoides diminutus*. First Occurrence (FO) of *Globigerinoides trilobus* and *Globigerinoides immaturus* at base (3100m). N14 - N15 (*Globigerinoides immaturus* - *Globorotalia siakensis*). *Globorotalia siakensis* has its Last

Occurrence (LO) near the Middle/Late Miocene boundary [Pessagno, 1967; Wade *et al.*, 2011]. *Globorotalia opima opima* and *Globigerinoides diminutus* are characteristic Middle Miocene taxa. The assemblage at 3100 m suggests an early Middle Miocene age.

#### **Paleoenvironmental Interpretation**

Paleoenvironmental and paleobathymetric interpretations for the BB Well are based on the composition, diversity, and paleoecological preferences of benthic foraminiferal assemblages. The model applied follows established paleobathymetric frameworks for the Niger Delta. The results depict a dynamic depositional setting, recording a general transition from shallow-marine shelf environments to deeper bathyal (slope) conditions with increasing depth, followed by a major regressive shallowing-upward trend.

#### **Upper to Middle Bathyal and Marginal Marine/Inner Neritic (3100 m - 2850 m)**

This interval reveals a complex transition. The base (3075m-3100m) is characterized by an assemblage including *Uvigerina mexicana* and *Valvulineria aff. miocenica*, which confirms deposition in a deep marine slope (bathyal) environment. Slightly shallower (2975m-3050m), the presence of robust agglutinated taxa such as *Cyclammina cancellata* and *Alveolophragmium subglobosum* further indicates deep-water, bathyal conditions.



However, the abundance of *Ammobaculites* sp., *Haplophragmoides* sp., and miliolids suggests intercalation or influence from much shallower waters (0-50 m), and interpreted as lower shoreface to restricted lagoon settings. This juxtaposition is typical of the progradational Agbada Formation, where deep-water slope sediments may be interbedded with or overlain by shallow-marine delta-front deposits.

Key benthic foraminifera species are *Uvigerina mexicana*, *Valvulineria* aff. *miocenica*, *Cyclammina cancellata*, *Alveolophragmium subglobosum*, *Dorothia bradyi*, *Ammobaculites* sp., miliolids.

#### **Middle to Outer Neritic (2850 m - 2625 m)**

This section marks a significant shift towards more open-marine conditions. An increase in calcareous benthic taxa such as *Uvigerina*, *Bolivina* and most notably, a pronounced peak in both the abundance and diversity of planktic foraminifera signal a deepening to middle neritic conditions (50-100 m water depth). The high-diversity planktic peak, centered around 2600-2625 m, is interpreted as a Maximum Flooding Surface (MFS). This represents the deepest and most marine conditions within the studied interval, associated with sediment starvation and the deposition of a condensed section. The benthic fauna, including *Bolivina spathulata* and *Bulimina* sp., suggests outer shelf to upper bathyal depths with possible lower oxygen levels at the seafloor.

Key Indicators: High planktic foraminiferal abundance/diversity (MFS), *Bolivina spathulata*, *Uvigerina* sp., *Bulimina* sp., *Lenticulina limbosus*.

#### **Inner to Middle Neritic (2625 m - 2125 m)**

Above the MFS, a clear regressive (shallowing-upward) trend is observed. A gradual decrease in planktic foraminiferal percentages and a return to diverse, dominantly calcareous benthic assemblages indicate a progressive decrease in water depth from middle to inner neritic settings. The dominance of *Ammonia beccarii* and *Florilus elongatus* points to shallow, likely nutrient-rich waters influenced by deltaic progradation. The presence of *Cibicides lobatulus*, an epifaunal species attached to hard substrates, indicates a high-energy, inner-shelf environment. This regressive phase is consistent with the continued progradation of the Niger Delta system during the Late Miocene.

Key Indicators: *Ammonia beccarii*, *Florilus elongatus*, *Cibicides lobatulus*, decreasing planktic percentage.

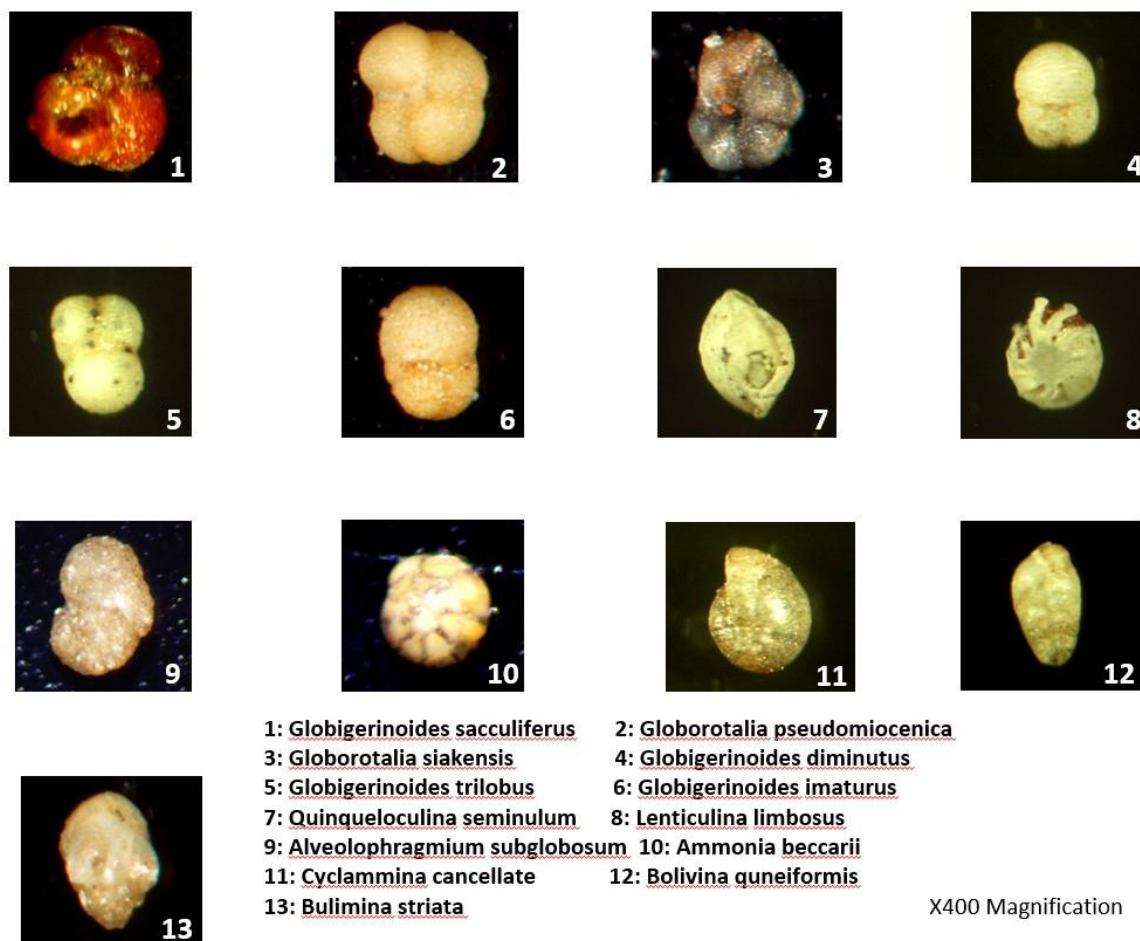


Figure 4: Photomicrographs of recovered foraminifera species from BB Well

## CONCLUSION

This study establishes a refined stratigraphic and paleoenvironmental framework for the Niger Delta's Agbada Formation by integrating foraminiferal biostratigraphy with high-resolution lithofacies analysis. The synthesis reveals a Middle to Late Miocene depositional history defined by a complete transgressive-regressive cycle. A significant maximum flooding surface, identified within the Middle Miocene, marks the peak of open marine conditions. This was followed by a progradational, shallowing-upward sequence

through the Late Miocene, as the delta system advanced. Crucially, the direct correlation between specific benthic foraminiferal biofacies (*Uvigerina*, *Cyclammina*) and distinct lithofacies (turbiditic shales, barrier bar sands) provides a direct link between paleobathymetric changes and the physical rock record.

The combined use of foraminiferal and lithologic data successfully resolves key stratigraphic uncertainties, yielding a robust model for subsurface correlation. By explicitly connecting the progradational clastics of the

Agbada Formation to cyclical sea-level changes, this work provides a validated, high-resolution template. This integrated framework not only advances the understanding of basin evolution but also enhances the predictive mapping of reservoir distribution and subdivision, delivering direct value to hydrocarbon exploration strategies in the Niger Delta Basin

## RECOMMENDATION

This integrated methodology should be applied to additional wells across the Niger Delta's various depobelts to test the regional consistency of the identified biozones and depositional sequences, enabling the construction of a comprehensive basin-wide stratigraphic model.

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