



Foraminifera Biostratigraphy Study of Neritic–Bathyal Sandstones, Deep Offshore, Niger Delta, Nigeria

Ayomide Samson Ifanegan ^a, Bosede Taiwo Ojo ^{a*}
and Faith Obasuyi ^b

^a *Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria.*

^b *Department of Physics, University of Jos, Plateau State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

One of the factors needed to unravel hydrocarbon accumulations, volumetric computation and reservoir performance in a field is to have the proper view and understanding of the environment of depositions and the age of deposited sediments. Some fossils such as the foraminifera species from three wells namely (AO-01, AO-03, and AO-04) in "AO"-Field, deep offshore, Niger Delta were studied to evaluate the paleoenvironment, age of sediments and the penetrated formations in the field. Well logs and biostratigraphy data were analyzed using the SPDC Zonation Scheme and Niger Delta Cenozoic Chronostratigraphic chart. The biostratigraphic analysis was conducted for well AO-01, AO-03, and AO-04 in the depth intervals (6810-3270) ft., (6989 – 9900) ft., and (4970 – 8670) ft respectively. The index fossils were identified and their respective foraminifera zones were conducted based on the SPDC zonation scheme and the Niger Delta Cenozoic Chronostratigraphic Chart. The environment of deposition was determined by plotting the fauna abundance against the depth intervals where the recovered index fossils were encountered. Results of the analysis show that the wells drilled within the field are rich in their preserved Benthonic and Planktonic

*Corresponding author: Email: btojo@futa.edu.ng;

foraminifera species which are relevant in the finding of hydrocarbon deposits. The forams recovered from the wells are the *Ammonia becarii*, *Bolivia scalprata miocenica*, *Bolivia scalprata retiformis*, *Cibicorbis inflata*, *Cyclammina minima*, *Epistominella vitrea*, *Hanzawaia strattoni*, *Haplophragmoides compressa*, *Lenticulina inornata*, *Praeglobobulimina ovata*, *Quinqueloculina microstate*, *Rectuvigerina spp.*, *Saccamina complanata*, *Textularia spp.* and *Valvulina flexilis* and other foraminifera such as *Brizalina beyrichi*, *Heterostegina costata*, *Uvigerina spp.* were exclusively discovered in well AO-03 and AO-04 but absent in AO-01. The sediments identified in the field fall within the inner neritic to middle bathyal. However, the study generally presents the step-by-step technique for an improved interpretation of the environment of deposition and aid in the successes of hydrocarbon exploitation.

Keywords: Foraminifera; species diversity; paleobathymetry; facies; chronostratigraphic chart.

1. INTRODUCTION

Today, petroleum industries are more concerned about reservoir and well management. This birthed the reason for the studies on environment of deposition and determining the age of formations necessary to unravel hydrocarbon accumulation, volumetric estimation, and reservoir performance. The search for hydrocarbon accumulations and its production requires creative efforts in optimizing and integrating reservoirs which will subsequently produce a well-managed field [1]. Depositions in the marine environment of Niger Delta (Fig. 1) commenced within the Southern Nigerian Basin during Early Cretaceous time [2]. The Post-Tertiary times sedimentological history is dominated by marine regressions resulting in deltaic build-up. Thus the Upper Cretaceous-Tertiary sediments are made up of fluvio-marine deposits and coarse continental sands [3]. The sandy shale of the Agbada formation are very fossiliferous than the silty shale of Akata formation. The benthonic foraminifera are more abundant than the planktonics in all the three units (Oloto et al., 2014). It is quite important to understand the depositional environment and the preservation history of a formation being one of the findings necessary for unraveling prolific hydrocarbon and determining reservoir quality [4]. The determination of the depositional environment is achieved through the detailed description of responses, signatures and conditions preserved in a deposit that are peculiar to characterizing the environment of 'AO' field, deep offshore, Niger Delta. However, the understanding of the environment of deposition and Chronostratigraphical relationship is important due to its distinct hydrocarbon potentials [5]. The field under study has two straight wells and a deviated well (Fig. 2), however, the wells were drilled at the 'AO'-Field, eastern part of the Niger Delta basin. The study

identified the different lithological units and reservoirs encountered, and correlated across the drilled wells in a specific direction. The recovered foraminifera species with the well log motifs were used to determine the environment of deposition, age of sediments, biozones, and build the sequence stratigraphic pattern of the field based on the SPDC Cenozoic Chronostratigraphic Chart of Niger Delta (Fig. 3).

1.1 Geology of the Study Area

The Niger Delta basin (Fig. 1) is identified as a product of triple junction having the Gulf of Guinea, South Atlantic Ocean and Benue depression that was created in the late Jurassic during the separation of the South American plate from the African plate [6]

The basin is Situated in the Gulf of Guinea, and extending all over the Niger Delta domain/province, is the Niger Delta [7]. Delta prograde southwestward from Eocene to the present, creating depo-belts that signify the most active percentage of the delta at each phase of its expansion (Doust and Omatsola, [8]. These depo-belts become one of the major regressive deltas globally. One petroleum system had been identified in the Niger Delta province which is the Tertiary Niger Delta [9]. The main source rock remains the upper Akata formation consisting of the marine-shale facies with probably influence of interbedded marine shale in the lowermost Agbada Formation [10]. Agbada formation sandstone accommodate hydrocarbon whereas, the upper Akata formation turbidite sand units serve as potential reservoirs in deep water offshore (Okpoli and Arogunyo. 2020).

2. METHODOLOGY

The study utilized the well logs (GR, Resistivity) for lithology identification and reservoir

delineation from three wells (AO- 01, AO-03, and AO-04) in AO- Field. The recovered foraminifera species were analyzed using the SPDC Zonation Scheme and Niger Delta Cenozoic Chronostratigraphic chart [12]. The biostratigraphic analysis was conducted for the

depth intervals (6810 - 13270) ft, (6989 - 9900) ft and (4970 -8670) ft in AO-01, AO-03 and AO-4 respectively. After a thorough check on the fossils, the recovered forams were inputted into the Microsoft excel and the foraminifera distribution/ abundance were generated.

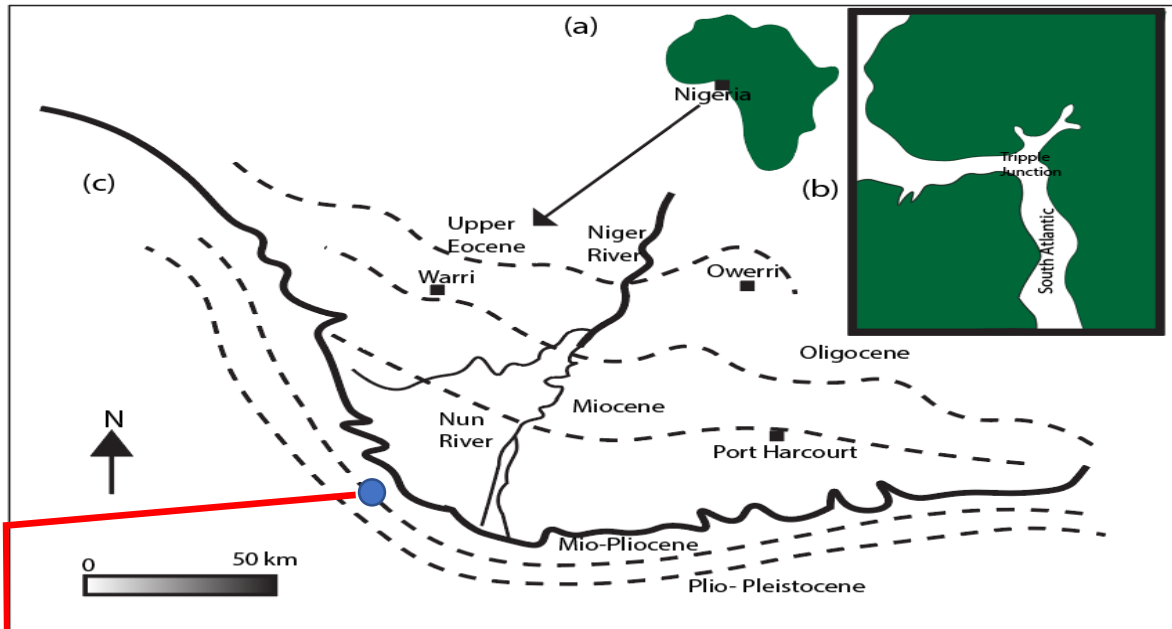


Fig. 1. Location of Niger Delta in Nigeria (Modified After Burke et al. [13])

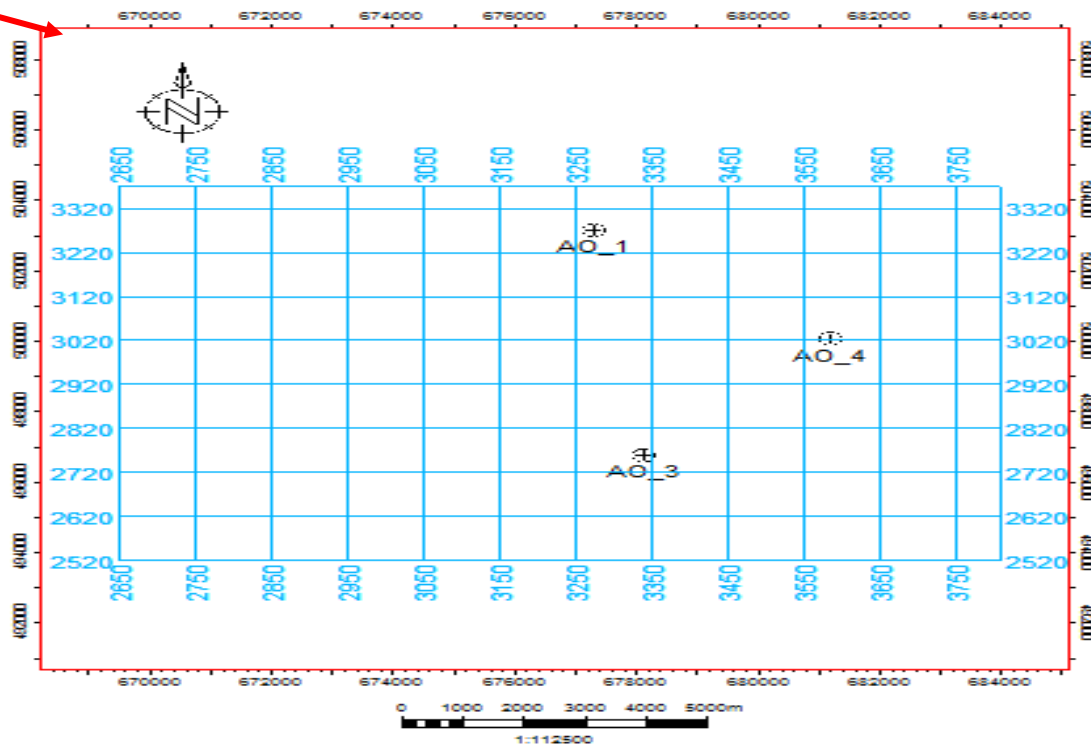


Fig. 2. Base map of the study area showing well locations and seismic lines

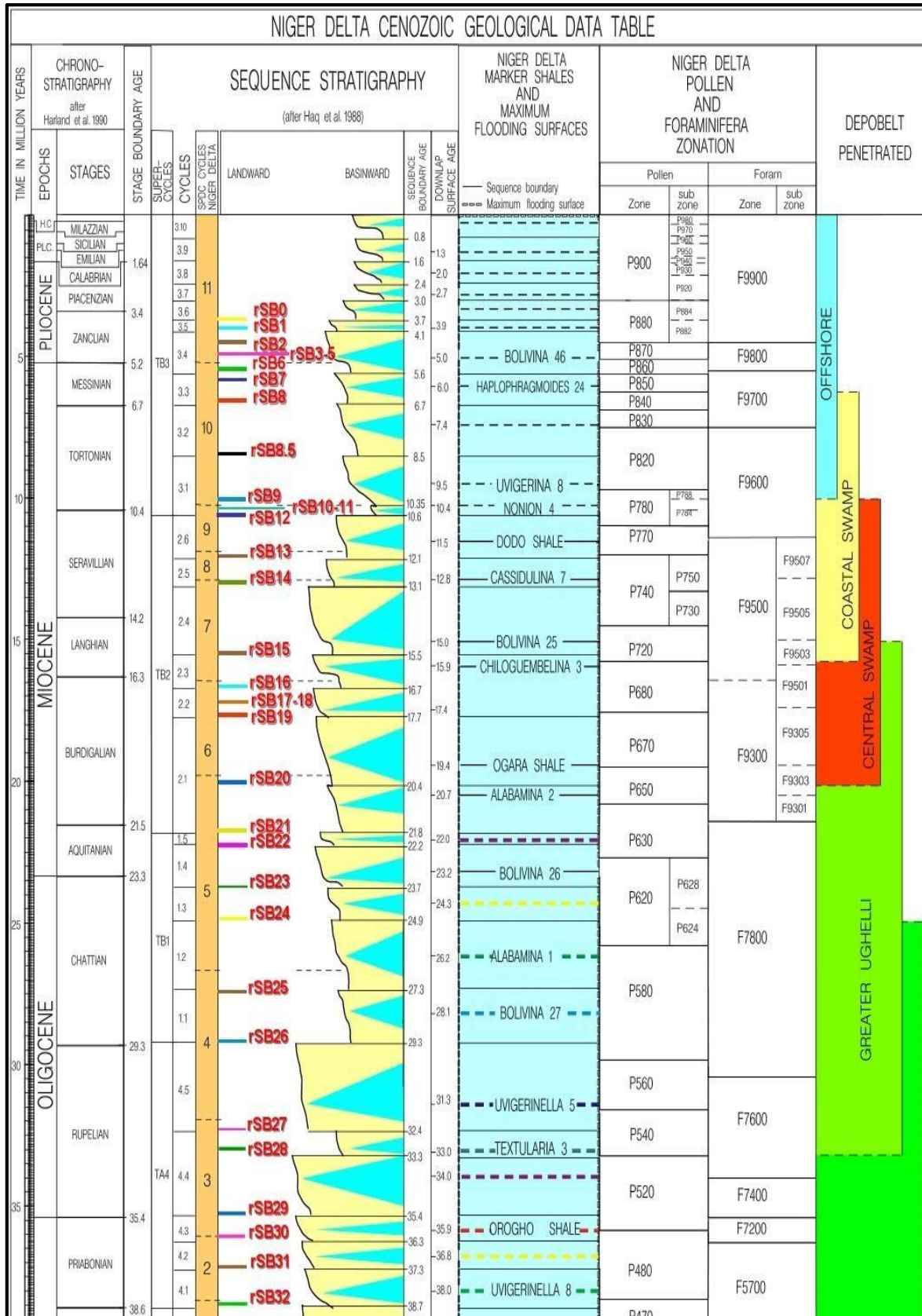


Fig. 3. SPDC cenozoic chronostratigraphic chart of Niger Delta (After Haq et al. 1988)

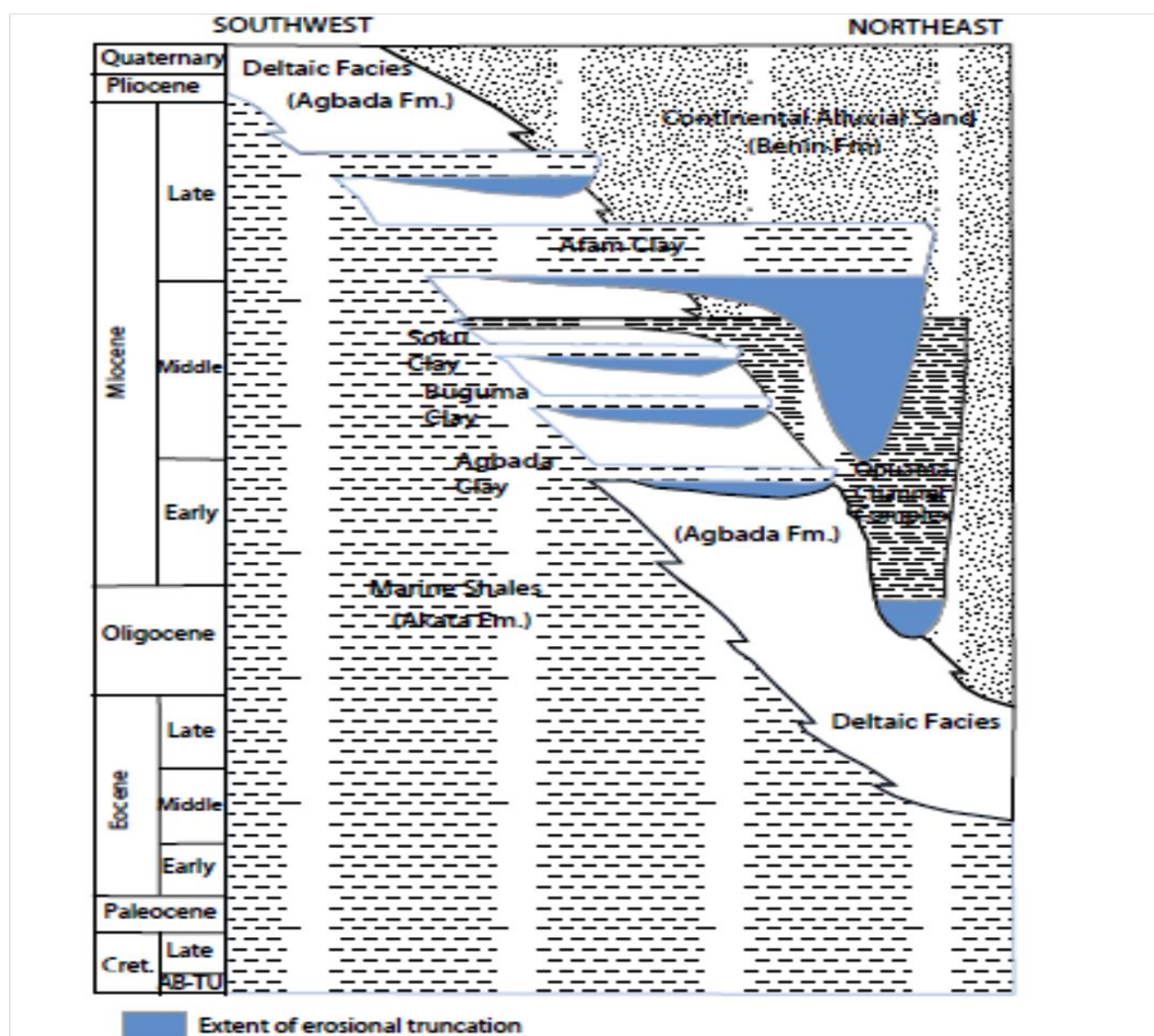


Fig. 4. The Stratigraphic units of the Niger Delta. Modified after Shannon and Naylor (1989) and Doust and Omatsola [8] as cited in Tuttle et al. [11]

3. RESULTS AND DISCUSSION

The results obtained are presented in the form of logs, tables and graphs. The recovered fossils from each of the wells were discussed accordingly.

Foraminiferal Diversity, Age of Sediments, Abundance and Assemblage Paleobathymetry/ Environment of Deposition Determination.

The biostratigraphic analysis of the wells presented was based on the identification and integration of fossils in well AO-01, AO-03 and AO-04 (Fig. 6). Meanwhile, the biozonation was based largely on Sequence Stratigraphic principles with precise age dating of the zonal boundaries. The Chronostratigraphic scheme adopted follows the usage of Haq, et al. [12]. The

environment of deposition was determined by plotting the Fauna Abundance against the depth intervals where the recovered index fossils were encountered. Some of the fossils encountered are benthonic calcareous and arenaceous species, with some planktonic in the wells [14].

The benthonic foraminifera encountered in the wells are dominated by the following species: *Uvigerina spinicostata*, *Brizalina beyrichi*, *Cibicorbis inflata*, *Lenticulina inornata*, *Hopkinsina bononiensis*, *Hanzawaia stratonii*, *Ammonia beccarii*, *Heterolepa floridana*, *Uvigerina* spp. *Valvulina flexilis*, and *Haplophragmoides compressa*. Some of the species have poor occurrences as in the case of *Textularia laminata*, *Ammobaculites* spp. and *Bolivina spinata* that are sparsely identified [15].

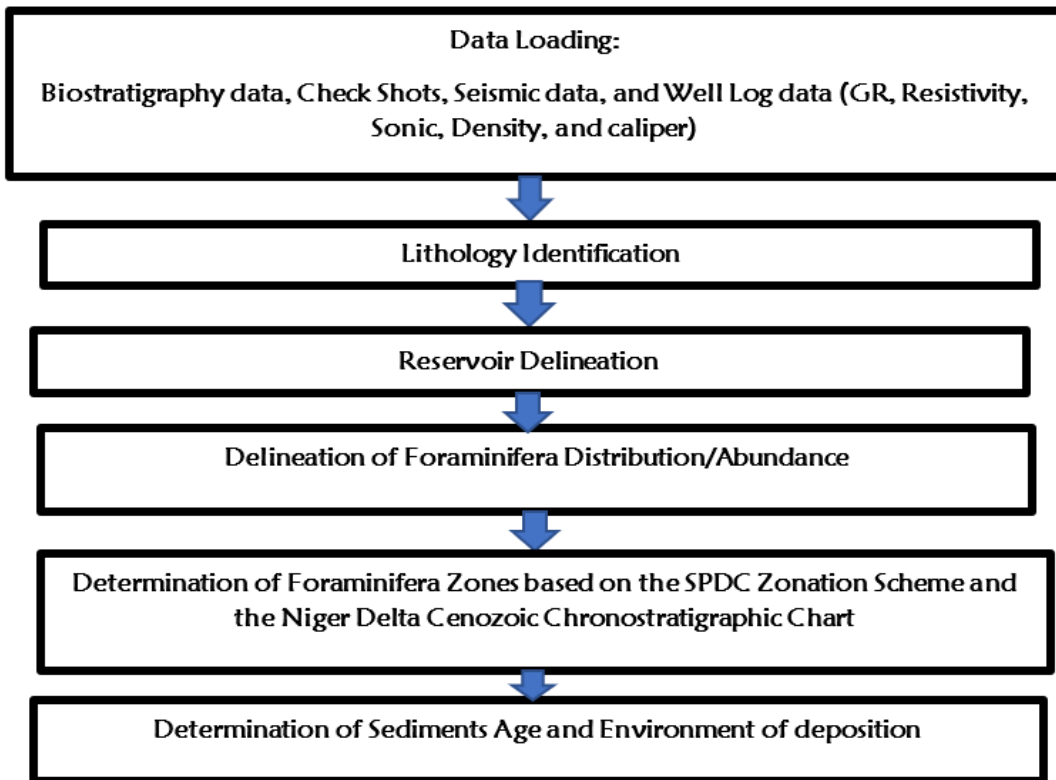


Fig. 5. Methodology workflow

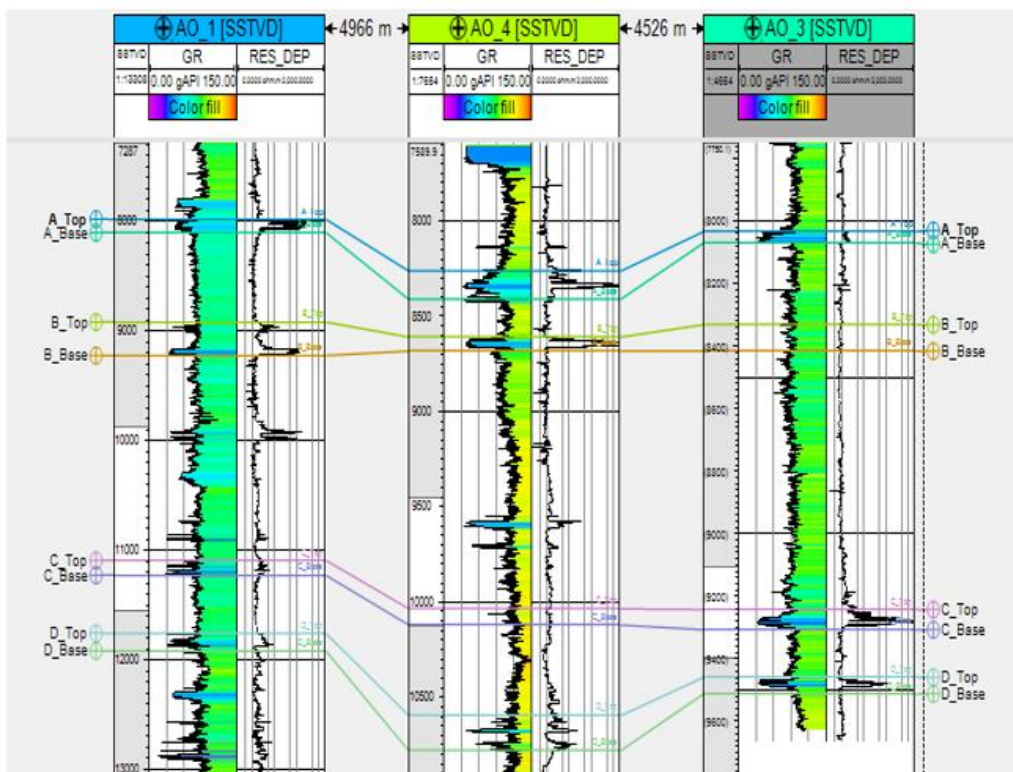


Fig. 6. Well Log Correlation Section of AO-01, AO-04 and AO-03

In the field, some benthonic calcareous foraminifera are identified as *Quinqueloculina lamarckiana*, *Ammonia beccarii*, *Uvigerina spinicostata*, *Brizalina beyrichi*, *Quinqueloculina* spp., *Uvigerina* spp., *Hopkinsina bononiensis*, *Lenticulina inornata*, *Hanzawaia stratonii*, *Myogypsinoidea* spp., *Quinqueloculina microcostata*, *Uvigerina sparsicostata*, *Bolivina* spp., *Bulimina* spp., *Hanzawaia concentrica*, *Heterolepa pseudoungeriana*, *Bolivina scalprata retiformis*, *Bolivina scalprata miocenica*, *Epistominella vitrea*, *Uvigerina topilensis*, *Cibicorbis inflata*, *Quinqueloculina* *Brizalina beyrichi*, and *Epistominella vitrea*.

The benthonic arenaceous foraminifera are the *Ammobaculites* spp., *Spiroplectammina* spp., *Spiroplectammina wrightii* *Haplophragmoides* spp. *Textularia laminata* *Textularia panamensis*.

The planktonics identified are *Globorotalia continuosa*, *Globigerina* spp. *Orbulina suturalis*, *Praeorbulina glomerosa*, and *Planktic indet* spp. Other important planktonic foraminifera species recovered include *Catapsydrax dissimilis*, and *Praeorbulina sicana*. *Globigerina* spp. *Globigerina venezuelana* *Orbulina universa* *Planktic indet* spp. *Globorotalia continuosa* *Praeorbulina glomerosa* *Praeorbulina sicana* *Orbulina suturalis* *Globigerinoides immaturus*

Globigerinoides sacculifer *Globigerinoides trilobus* *Globigerinoides quadrilobatus* *Catapsydrax dissimilis* *Globigerinoides* spp.

In well AO-01 (Fig. 7), the most abundant foraminifera are *Haplophragmoides compressa* while the least abundant is the *Textularia* spp. The Index Fossils and Foraminifera Zonations in brackets are *Bolivina scalprata miocenica* (F9601), *Bolivina scalprata retiformis* (F9650), *Epistominella vitrea* (F9620), *Lenticulina inornata* (F9600), *Quinqueloculina microstate* (F9640), *Saccamina complanata* (F9700), and *Valvulina flexilis* (F9700).

The age of the sediments was identified based on the delineated foraminifera zones and index fossils (Fig. 5), the sediments in the well are identified in their age to be within the middle – late Miocene. The paleobathymetric fluctuates between the inner neritic to middle bathyal (as shown in Table 1). It is observed that there is a high proportion of shale over the well section, an indicative of dominance of low-energy depositional conditions. To better illustrate the amount of fossils in the environment, the recoverable index fossils in the identified environment are denoted in different colours (Table 2).

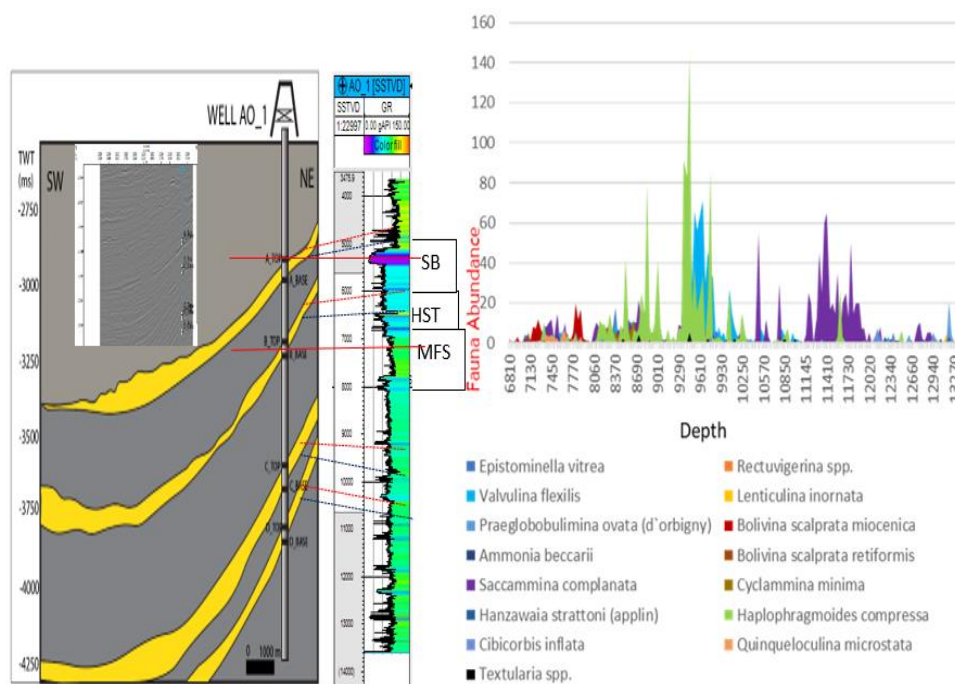


Fig. 7. Well AO-01, Environment of deposition interpretation

Table 1. Abundance of recovered fossils from well AO-1 in colour code

Species	Environment of deposition/ paleobathymetric				
	Inner Neritic	Middle Neritic	Outer Neritic	Upper Bathyal	Middle Bathyal
Ammonia beccarii	Red		Light Green	Dark Blue	
Bolivina scalprata miocenica	Red	Yellow			Purple
Bolivina scalprata retiformis	Red		Light Green	Dark Blue	
Cibicorbis inflata	Red	Yellow			
Cyclamina minima			Light Green		Purple
Epistominella vitrea	Red	Yellow			
Hanzawaia strattoni (applin)	Red				
Haplophragmoides compressa				Dark Blue	Purple
Lenticulina inornata	Red	Yellow			
Praeglobobulimina ovata (d'orbigny)					Purple
Quinqueloculina microstata	Red	Yellow			Purple
Rectuvigerina spp.	Red				
Saccamina complanata			Light Green		Purple
Textularia spp.	Red	Yellow		Dark Blue	
Valvulina flexilis				Dark Blue	Purple

AO-03 well is identified to have the some of the index fossils present in well AO-1 with the exemption of *Bolivina spp.*, In addition to the available fossils in the well, *Brizalina beyrichi* (F7870), *Uvigerina spinicostata* (F9500) *Uvigerina subperegrina* (F9603) were also discovered.

On the basis of the delineated foraminifera zones and identified index fossil as shown in Fig. 8, the sediment is dated middle–Late Miocene. Thus, the environment of deposition fluctuates between the inner neritic to middle bathyal (as shown in Table 3). The recoverable index fossils in the identified environment are also displayed in

varying colours which denote the amount of fossils present in the environment (Table 4).

The third well (Fig. 9), AO-04 was delineated to have the recoverable index fossils as itemized in well AO-01 and AO-03 but in addition to the fossils are *Hanzawaia strattoni* (F9305), *Hopkinsina bononiensis* (F7400) and *Oridorsa lisumbonata* (F9650). The delineated fossils and zones were dated middle – Late Miocene. The environment of deposition fluctuates between the inner neritic to middle bathyal (as shown in Table 5). The fossils present in the well are displayed in various colours in order to deduce its range of predominance (Table 6).

Table 2. Recovered fossils from well AO-1 and their respective environment of depositions

<i>Ammonia beccarii</i>	IN
<i>Bolivina scalprata miocenica</i>	IN, MN, ON,UB
<i>Bolivinascalprata retiformis</i>	IN,MN
<i>Cibicorbis inflata</i>	IN, MN, ON
<i>Cyclammina minima</i>	OU, UB,MB
<i>Epistominella vitrea</i>	IN, MN
<i>Hanzawaiastrattoni (applin)</i>	IN, MN, ON
<i>Haplophragmoides compressa</i>	MN, ON, UB,MB
<i>Lenticulina inornata</i>	IN, MN, ON, UB
<i>Praeglobobulimina ovata (d'orbigny)</i>	ON, UB, MB
<i>Quinqueloculina microstate</i>	IN, MN, ON, UB, MB
<i>Rectuvigerina spp.</i>	IN,MN,ON,UB
<i>Saccamina complanata</i>	MN, ON,UB,MB
<i>Textularia spp.</i>	IN, MN, ON, UB
<i>Valvulina flexilis</i>	ON, UB, MB

Legend

INE- Inner Neritic Environment, MNE- Middle Neritic Environment
 UBE- Upper Bathyal Environment , MBE- Middle Bathyal Environment
 ONE- Outer Neritic Environment

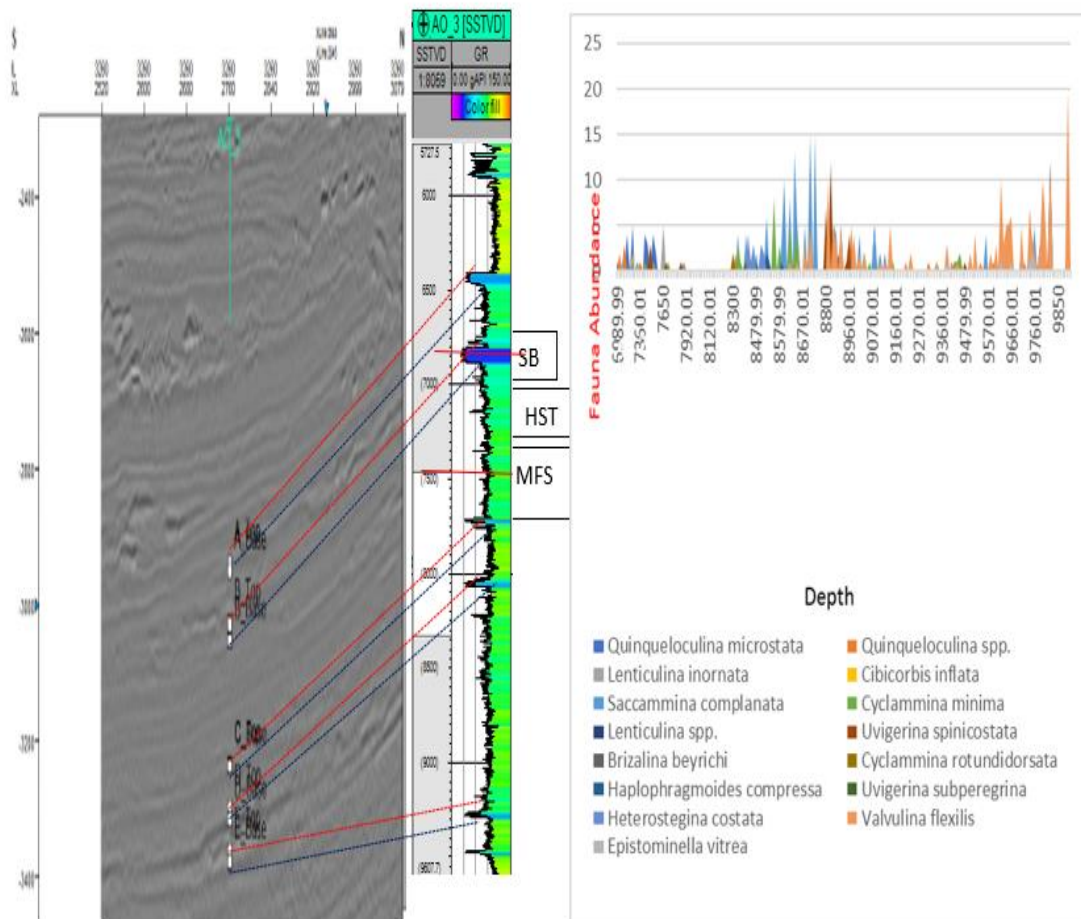


Fig. 8. Well AO-03, environment of deposition interpretation

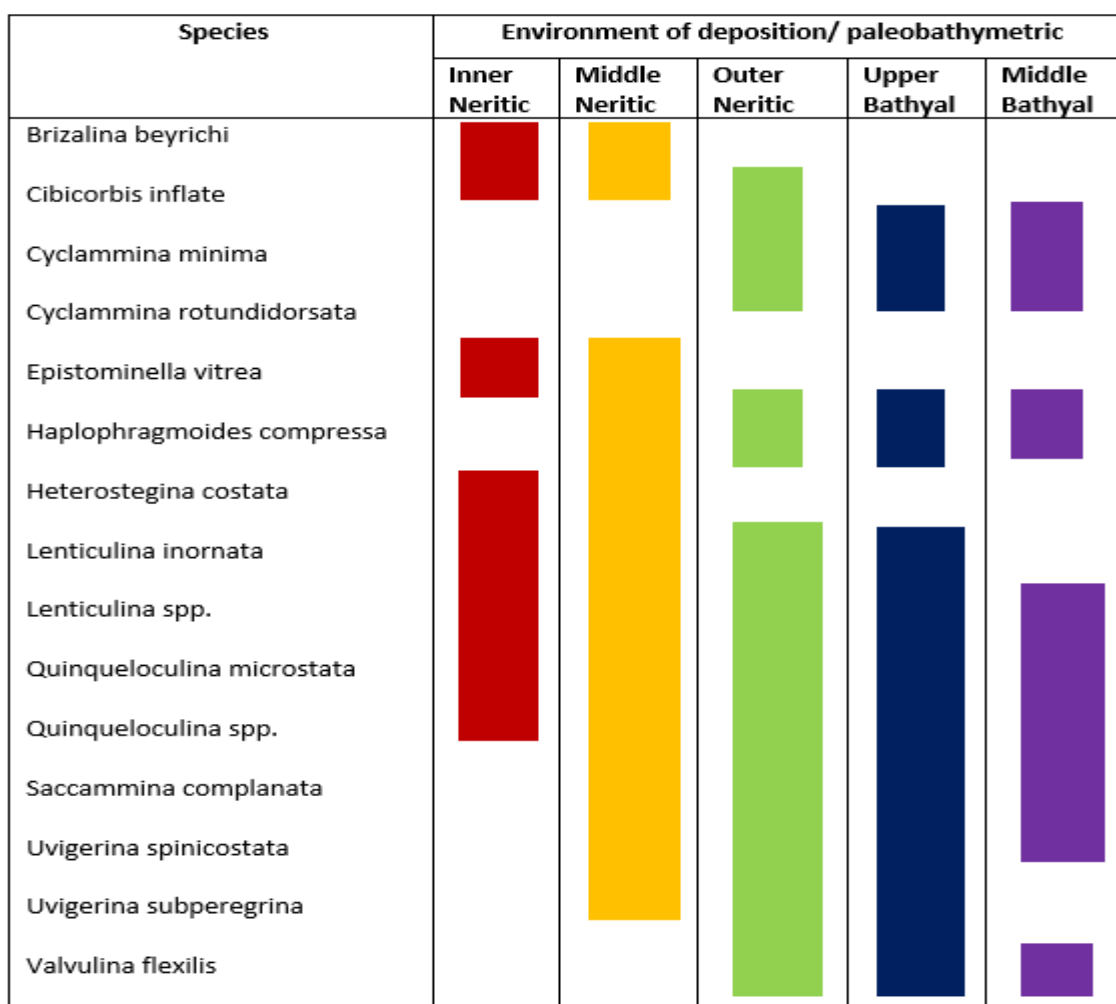
Table 3. Recovered fossils from well AO-3 and their respective environment of depositions

<i>Brizalina beyrichi</i> (F7870)	INE, MNE
<i>Cibicorbis inflata</i>	INE, MNE, ONE
<i>Cyclammina minima</i>	ONE, UBE, MBE
<i>Cyclammina rotundidorsata</i>	ONE, UBE, MBE
<i>Epistominella vitrea</i> (F7850)	INE, MNE
<i>Haplophragmoides compressa</i>	MNE, ONE, UBE, MBE
<i>Heterostegina costata</i>	INE, MNE
<i>Lenticulina inornata</i> (F9600)	INE, MNE, ONE, UBE
<i>Lenticulina</i> spp.	INE, MNE, ONE, UBE, MBE
<i>Quinqueloculina microstata</i> (F9640)	INE, MNE, ONE, UBE, MBE
<i>Quinqueloculina</i> spp.	INE, MNE, ONE, UBE, MBE
<i>Saccamina complanata</i> (F9700)	MNE, ONE, UBE, MBE
<i>Uvigerina spinicostata</i> (F9500)	MNE, ONE, UBE, MBE
<i>Uvigerina subperegrina</i> (F9603)	MNE, ONE, UBE
<i>Valvulina flexilis</i> (F9700)	ONE, UBE, MBE

Legend

INE- Inner Neritic Environment, MNE- Middle Neritic Environment
 UBE- Upper Bathyal Environment, MBE- Middle Bathyal Environment
 ONE- Outer Neritic Environment

Table 4. Abundance of Recovered Fossils from Well AO-3



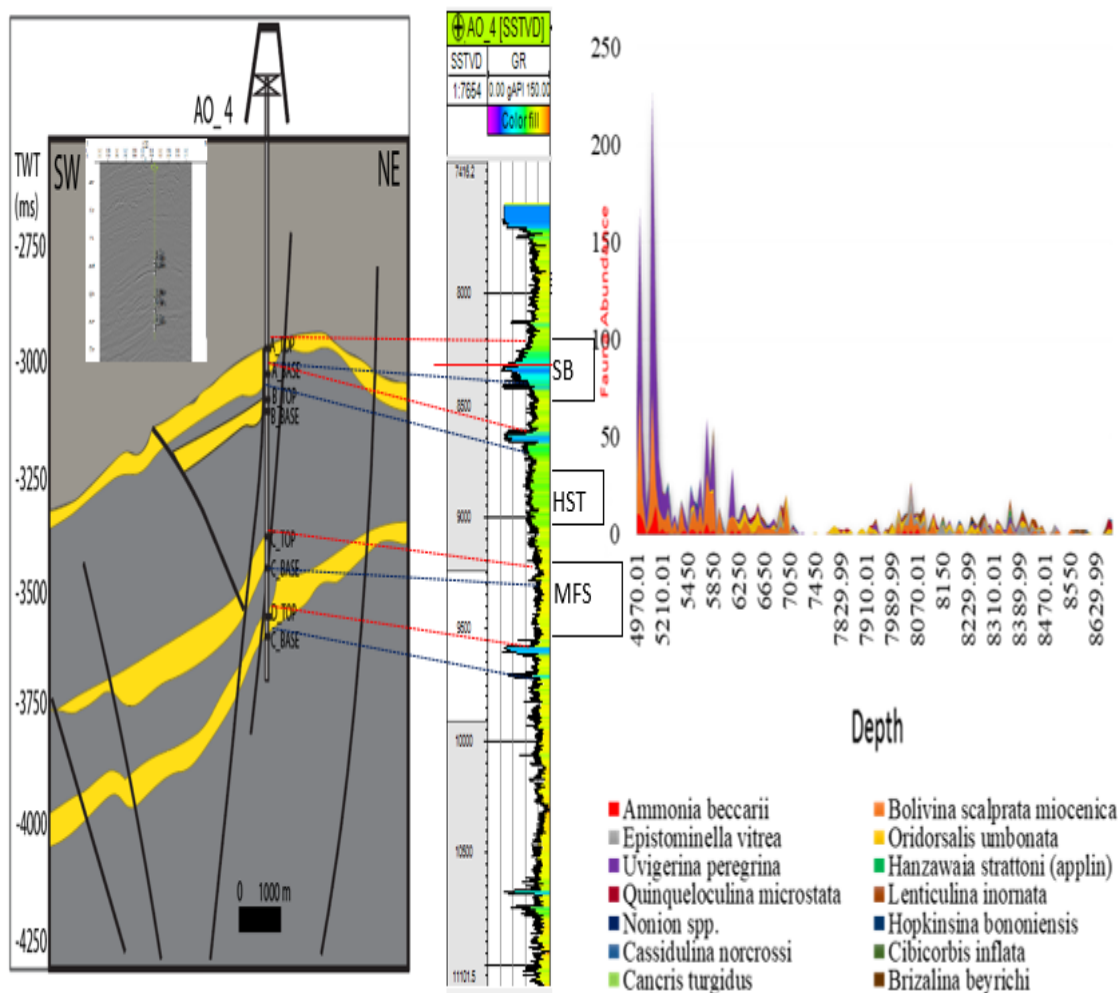


Fig. 9. Well AO-4, environment of deposition interpretation

Table 5. Recovered fossils from well AO-4 and their respective environment of depositions

<i>Ammonia beccarii</i>	INE
<i>Bolivinascalprata miocenica</i> (F9601)	INE,MNE,ONE,UBE
<i>Brizalina beyrichi</i> (F7870)	INE,MNE
<i>Cancristurgidus</i>	INE,MNE,ONE
<i>Cassidulina norcrossi</i>	INE,MNE,ONE
<i>Cibicorbis inflata</i>	INE,MNE,ONE
<i>Epistominella vitrea</i> (F7850)	INE,MNE,
<i>Hanzawaia strattoni</i> (F9305)	INE,MNE,ONE
<i>Hopkinsinabono niensis</i> (F7400)	INE,MNE,ONE,UBE
<i>Lenticulina inornata</i> (F9640)	INE,MNE,ONE
<i>Oridorsalis umbonata</i> (F9650)	MNE,ONE,UBE,MBE
<i>Quinqueloculina microstate</i>	INE,MNE,ONE,UBE,MBE
<i>Textularia panamensis</i>	INE,MNE,ONE,UBE
<i>Uvigerina peregrine</i>	MNE,ONE,UBE

Legend

INE- Inner Neritic Environment, MNE- Middle Neritic Environment
 UBE- Upper Bathyal Environment, MBE- Middle Bathyal Environment
 ONE- Outer Neritic Environment

Table 6. Abundance of recovered fossils from well AO-4

Species	Environment of deposition/ paleobathymetric				
	INNER NERITIC	Middle Neritic	Outer Neritic	Upper Bathyal	Middle Bathyal
Ammonia beccarii					
Bolivina scalprata miocenica					
Brizalina beyrichi					
Cancristurgidus					
Cassidulina norcrossi					
Cibicorbis inflata					
Epistominella vitrea					
Hanzawaia strattoni					
Hopkinsina bononiensis					
Lenticulina inornata					
Oridorsa lisumbonata					
Quinqueloculina microstata					
Textularia panamensis					
Uvigerina peregrina					

4. CONCLUSION

A total of 250 foraminifera were recovered in the three wells and they are made up of both the planktonic and benthonic foraminifera. AO-01, AO-03 and AO-4 wells (Fig. 4) were drilled in the deep offshore of Niger delta, for the depth intervals (6810 -13270) ft., (6989 - 9900) ft. and (4970 - 8670) ft. respectively, and they were subjected to biostratigraphic studies and lithological analyses to reveal the age and the paleoenvironment of the foraminifera species.

Six (6) foraminifera zones were established (F9300, F9400, F9500, F9600, F9700, and F9800) with the aide of SPDC Zonation scheme. As such, the recovered index fossils are the

Hanzawaia strattoni, *Hopkinsinabono niensis*, *Lenticulina inornata*, *Valvulina flexilis*, *Uvigerina spinicostata*, *Epistominella vitrea* zone.

The ages of the sediments were identified based on the delineated foraminifera zones and index fossils, which fall between the middle – late Miocene. It was observed that there is a high proportion of shale over the well sections which is an indicative of dominance of low-energy depositional conditions. However, the paleobathymetric fluctuates between the inner neritic to middle bathyal.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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