

FORAMINIFERA BIOSTRATIGRAPHY STUDY OF NERITIC –BATHYAL SANDSTONES, DEEP OFFSHORE, NIGER DELTA, NIGERIA

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 foraminifera species which are relevant in the finding of hydrocarbon deposits. The forams recovered from the wells are the *Ammonia beccarii*, *Bolivina scalpratiocenic*, *Bolivina scalprataretiformis*, *Cibicides inflata*, *Cyclamina minima*, *Epistominella vitrea*, *Hanzawaia strattoni*, *Haplophragmoides compressa*, *Lenticulina ornata*, *Praeglobobulimina ovata*, *Quinqueloculina microstata*, *Rectuvigerina* spp., *Saccammina complanata*, *Textularia* spp. and *Valvulinaflexilis* 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.

Comment [1]: scientific names must be in italics

Keywords: Foraminifera, Species diversity, paleobathymetry, Abundance

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 which are 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 (Ojo *et al.*, 2019). Depositions in the marine environment of Niger Delta (Figure 1) commenced within the Southern Nigerian Basin during Early Cretaceous time (Pettersen *et al.*, 1979). 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 (Ayonma *et al.*, 2015). 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 (Olotu *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 (Oluwaseye *et al.*, 2020). 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 (Nwachukwu *et al.*, 1986). The field under study has two straight wells and a deviated well (Figure 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 (Figure 3).

Comment [2]: follow same writing pattern for *et al.*, every where

LOCATION AND GEOLOGY OF THE STUDY AREA

The Niger Delta basin (Figure 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 (Short and Stable, 1967).

The basin is Situated in the Gulf of Guinea, and extending all over the Niger Delta domain/province, is the Niger Delta (Adegoke *et al.*, 1971). 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, 1990). 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 (Adeniyi *et al.*, 2021). 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 (Klett *et al.*, 1997). 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).

Comment [3]: Replace with Geology of the study area

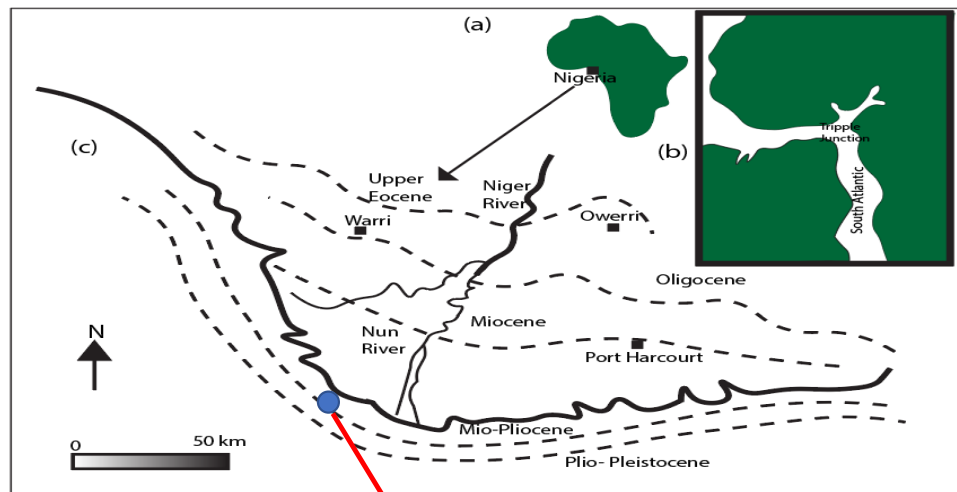


Figure 1: Location of Niger Delta in Nigeria (Modified After Burke *et al.*, 1971).

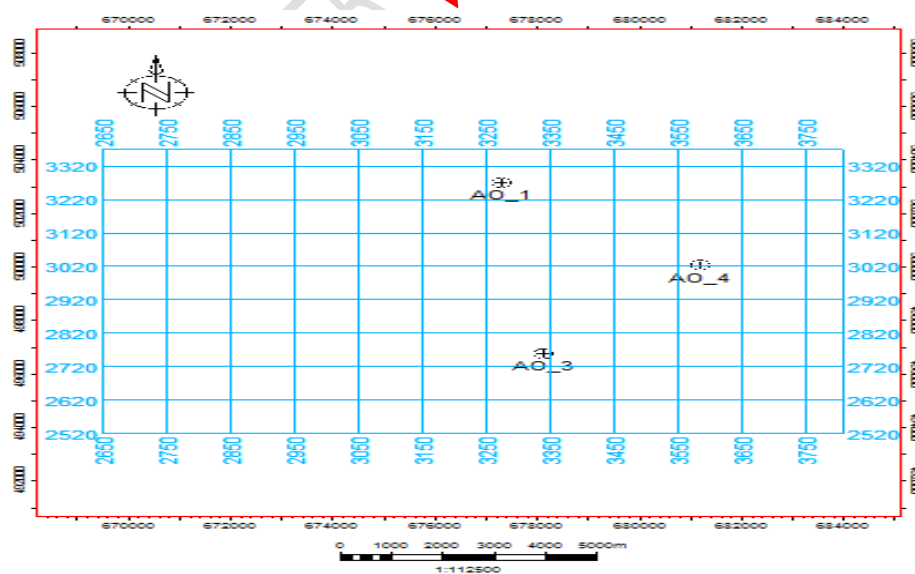


Figure 2: Base Map of the Study Area Showing Well Locations and Seismic Lines

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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 (After Haq et al., 1988). 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.

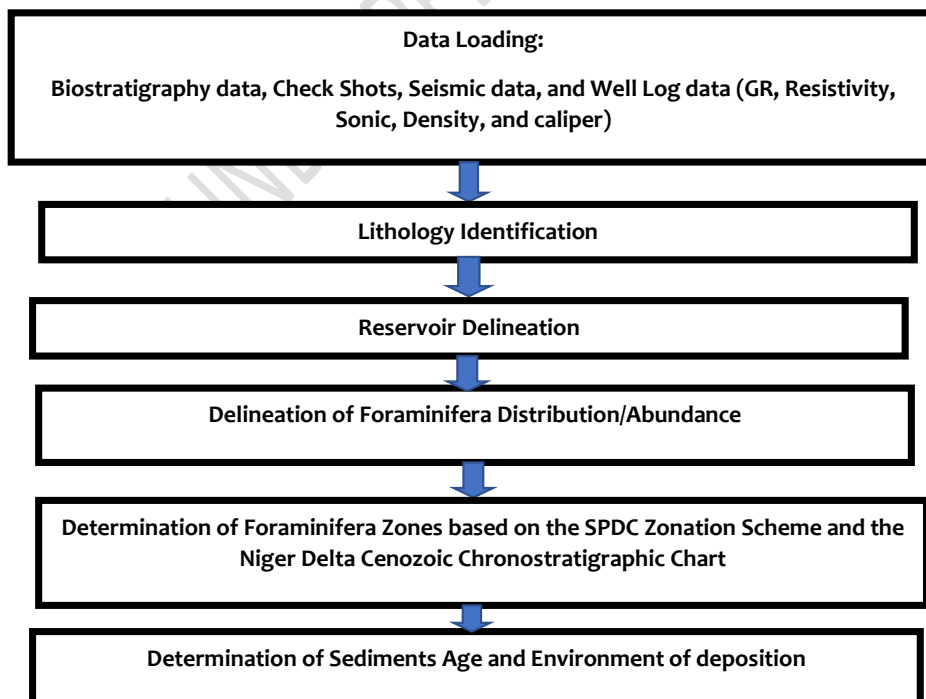


Figure 5: Methodology Workflow

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 AssemblagePaleobathymetry / 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 (Figure 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. (1988). 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.

The benthonic foraminifera encountered in the wells are dominated by the following species: *Uvigerinaspinicostata*, *Brizalinabeyrichi*, *Cibicorbisinflata*, *Lenticulinainornata*, *Hopkinsinabononiensis*, *Hanzawaiastratonii*, *Ammonia beccarii*, *Heterolepafloridana*, *Uvigerina* spp., *Valvulinaflexilis*, and *Haplophragmoidescompressa*. Some of the species have poor occurrences as in the case of *Textularialaminata*, *Ammobaculites* spp. and *Bolivinaspinata* that are sparsely identified.

In the field, some benthonic calcareous foraminifera are identified as *Quinqueloculinaamarckiana*, *Ammonia beccarii*, *Uvigerinaspinicostata*, *Brizalinabeyrichi*, *Quinqueloculina* spp., *Uvigerina* spp., *Hopkinsinabononiensis*, *Lenticulinainornata*, *Hanzawaiastratonii*, *Myogypsinoides* spp., *Quinqueloculinamicrocostata*, *Uvigerinasparsicostata*, *Bolivina* spp., *Bulimina* spp., *Hanzawaiacentrica*, *Heterolepapseoudoungeriana*, *Bolivinascalprataretiformis*, *Bolivinascalpratamiocenica*, *Epistominellavitrea*, *Uvigerinatopilensis*, *Cibicorbis inflata*, *QuinqueloculinaBrizalinabeyrichi*, and *Epistominellavitrea*.

The benthonic areneous foraminifera are the *Ammobaculites* spp. *Spiroplectammina* spp., *Spiroplectammina*wrightii *Haplophragmoides* spp. *Textularialaminata* *Textularia*panamensis.

The planktonics identified are *Globorotalia*continua, *Globigerina* spp. *Orbulinasaturalis*, *Praeorbulinaglomerosa*, and *Planktic* indet spp. Other important planktonic foraminifera species recovered include *Catapsydrax*dissimilis, and *Praeorbulinasicana*. *Globigerina* spp. *Globigerina* venezuelana *Orbulina*universa Planktic indet spp. *Globorotalia*continua *Praeorbulinaglomerosa* *Praeorbulinasicana* *Orbulinasaturalis* *Globigerinoides* mmaturus *Globigerinoides*sacculifer *Globigerinoides*trilobus *Globigerinoides*quadrilobatus *Catapsydrax*dissimilis *Globigerinoides* spp.

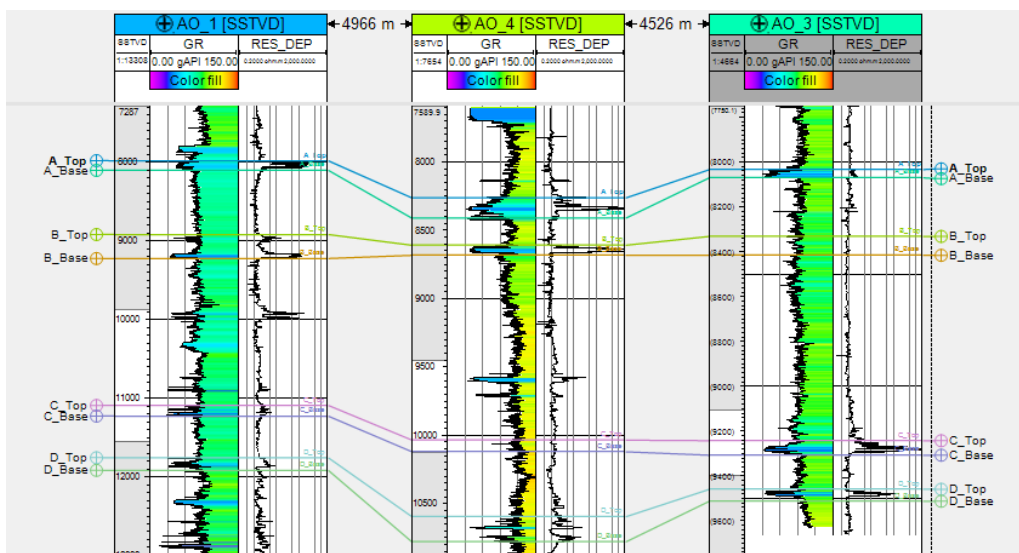
In well AO-01 (Figure 7), the most abundant foraminifera are *Haplophragmoides*compressa while the least abundant is the *Textularia* spp. The Index Fossils and Foraminifera Zonations in brackets are *Bolivinasca*prata miocenica (F9601), *Bolivinasca*prata retiformis (F9650), *Epistominella*vitrea (F9620),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

The age of the sediments was identified based on the delineated foraminifera zones and index fossils (Figure 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).

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*spincostata (F9500) *Uvigerina*subperegrina (F9603) were also discovered.

On the basis of the delineated foraminifera zones and identified index fossil as shown in Figure 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 (Figure 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 *Hanzawia*strattoni (F9305), *Hopkinsina*bononiensis (F7400) and *Oridorsalis*umbonata (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).



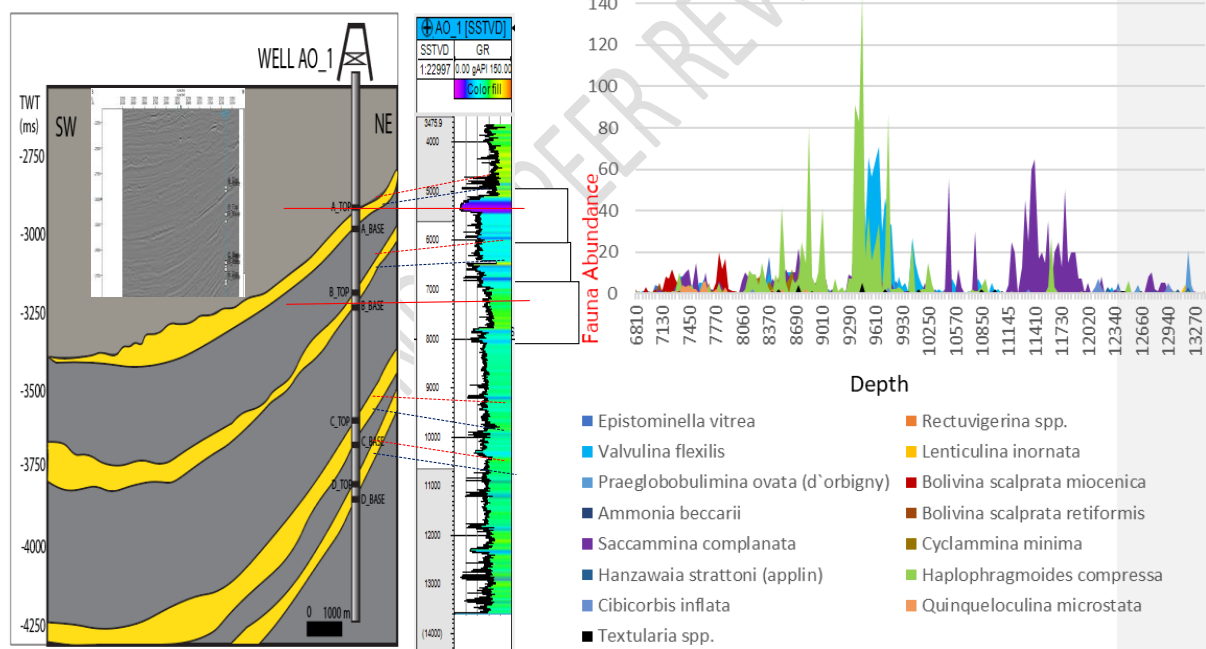


Figure 7: Well AO-01, Environment of Deposition Interpretation

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Table 1: Abundance of Recovered Fossils from Well AO-1 in Colour Code

SPECIES	ENVIRONMENT OF DEPOSITION/ PALEOBATHYMETRIC				
	INNER NERITIC ENVIRONM ENT	MIDDLE NERITIC ENVIRO NMENT	OUTER NERITIC ENVIRO NMENT	UPPER BATHYAL ENVIRONM ENT	MIDDLE BATHYAL ENVIRONMENT
<i>Ammonia beccarii</i>					
<i>Bolivina scalprata micassica</i>					
<i>Bolivina scalprata retiformis</i>					
<i>Cibicides inflata</i>					
<i>Cyclammina minima</i>					
<i>Epistominella vitrea</i>					
<i>Hanzawaiastrorioni (appia)</i>					
<i>Haplophragmoides compressa</i>					
<i>Lenticulina inornata</i>					
<i>Pragelobulimina ovata</i>					
<i>(Forsberg)</i>					
<i>Quinqueloculina microstata</i>					
<i>Rectuvigerina spp.</i>					
<i>Succammina complanata</i>					
<i>Tartarula spp.</i>					
<i>Valvulina flexilis</i>					

Comment [6]: all the scientific names in Table 2 must be in italics

Table 2: Recovered Fossils from Well AO-1 and their respective Environment of Depositions

LEGEND

INE- INNER NERITIC ENVIRONMENT

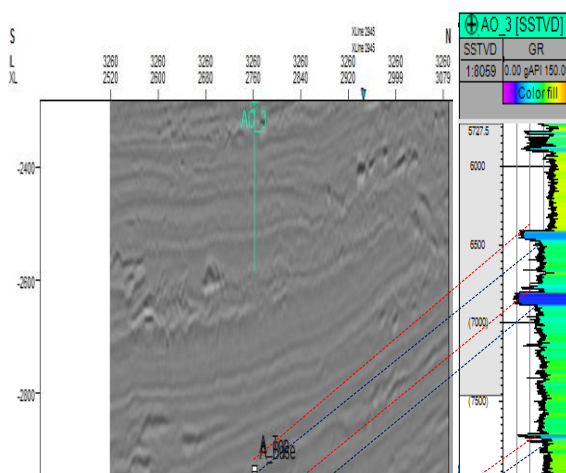
MNE- MIDDLE NERITIC ENVIRONMENT

<i>Ammonia beccarii</i>	IN
<i>Bolivinascalpratamiocenic</i>	IN, MN, ON,UB
<i>Bolivinascalprataretiformis</i>	IN,MN
<i>Cibicorbis inflat</i>	IN, MN, ON
<i>Cyclamina minima</i>	OU, UB,MB
<i>Epistominellavitrea</i>	IN, MN
	Hanzawaiastrattoni (applin)
<i>Haplophragmoidescompressa</i>	MN, ON, UB,MB
<i>Lenticulinainornata</i>	IN, MN, ON, UB
<i>Praeglobobulimina ovata</i> (d'orbigny)	ON, UB, MB
<i>Quinqueloculina microstate</i>	IN, MN, ON, UB, MB
<i>Rectuvigerina spp.</i>	IN,MN,ON,UB
<i>Saccaminacomplanata</i>	MN, ON,UB,MB
<i>Textularia spp.</i>	IN, MN, ON, UB
<i>Valulinaflexilis</i>	ON, UB, MB

UBE- UPPER BATHYAL ENVIRONMENT

MBE- MIDDLE BATHYAL ENVIRONMENT

ONE- OUTER NERITIC ENVIRONMENT



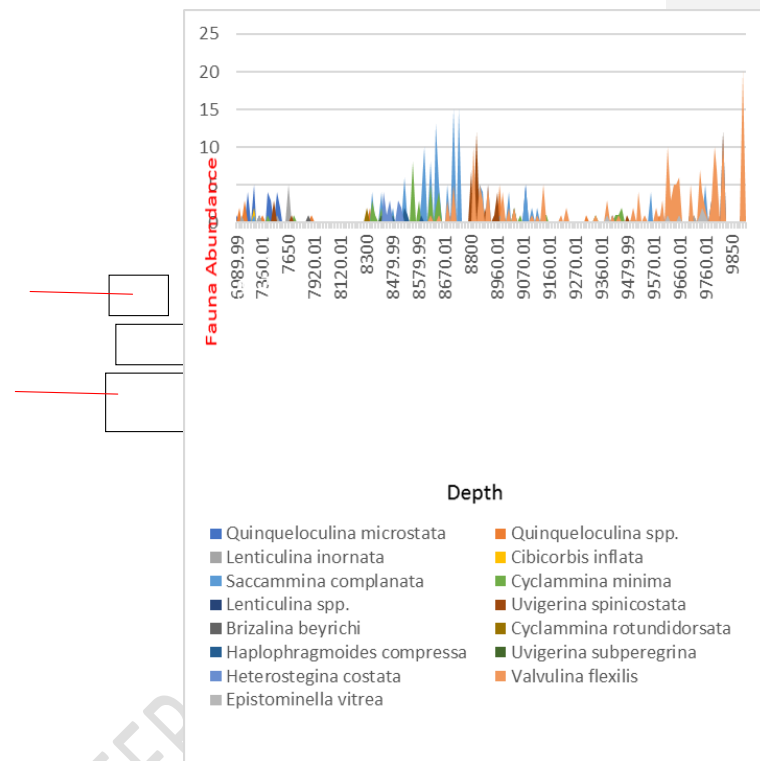


Figure 8: Well AO-03, Environment of Deposition Interpretation

Table 3: Recovered Fossils from Well AO-3 and their respective Environment of Depositions

LEGEND

<i>Brizalinabeyrichi</i> (F7870)	INE,MNE
<i>Cibicorbis inflata</i>	INE,MNE,ONE
<i>Cyclammina minima</i>	ONE,UBE,MBE
<i>Cyclamminarotundidorsata</i>	ONE,UBE,MBE
<i>Epistominellavitrea</i> (F7850)	INE,MNE
<i>Haplophragmoidescompressa</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 microstate</i> (F9640)	INE,MNE,ONE,UBE,MBE
<i>Quinqueloculina</i> spp.	INE,MNE,ONE,UBE,MBE
<i>Saccammina complanata</i> (F9700)	MNE,ONE,UBE,MBE
<i>Uvigerina spinicostata</i> (F9500)	MNE,ONE,UBE,MBE
<i>Uvigerina subperegina</i> (F9603)	MNE,ONE,UBE
<i>Valvulina flexilis</i> (F9700)	ONE,UBE,MBE

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

SPECIES	ENVIRONMENT OF DEPOSITION/ PALEOBATHYMETRIC				
	INNER NERITIC	MIDDLE NERITIC	OUTER NERITIC	UPPER BATHYAL	MIDDLE BATHYAL
<i>Brizalina beyrichi</i>					
<i>Cibicides inflata</i>					
<i>Cyclammina minima</i>					
<i>Cyclamminarotundi dorsata</i>					
<i>Epistominella vitrea</i>					
<i>Haplaphragmoides compressa</i>					
<i>Heterostegina costata</i>					
<i>Lenticulina inornata</i>					
<i>Lenticulina</i> spp.					
<i>Quinqueloculina microstata</i>					
<i>Quinqueloculina</i> spp.					
<i>Succummina complanata</i>					
<i>Uvigerina spinicostata</i>					
<i>Uvigerina subpergrina</i>					
<i>Valvulina flexilis</i>					

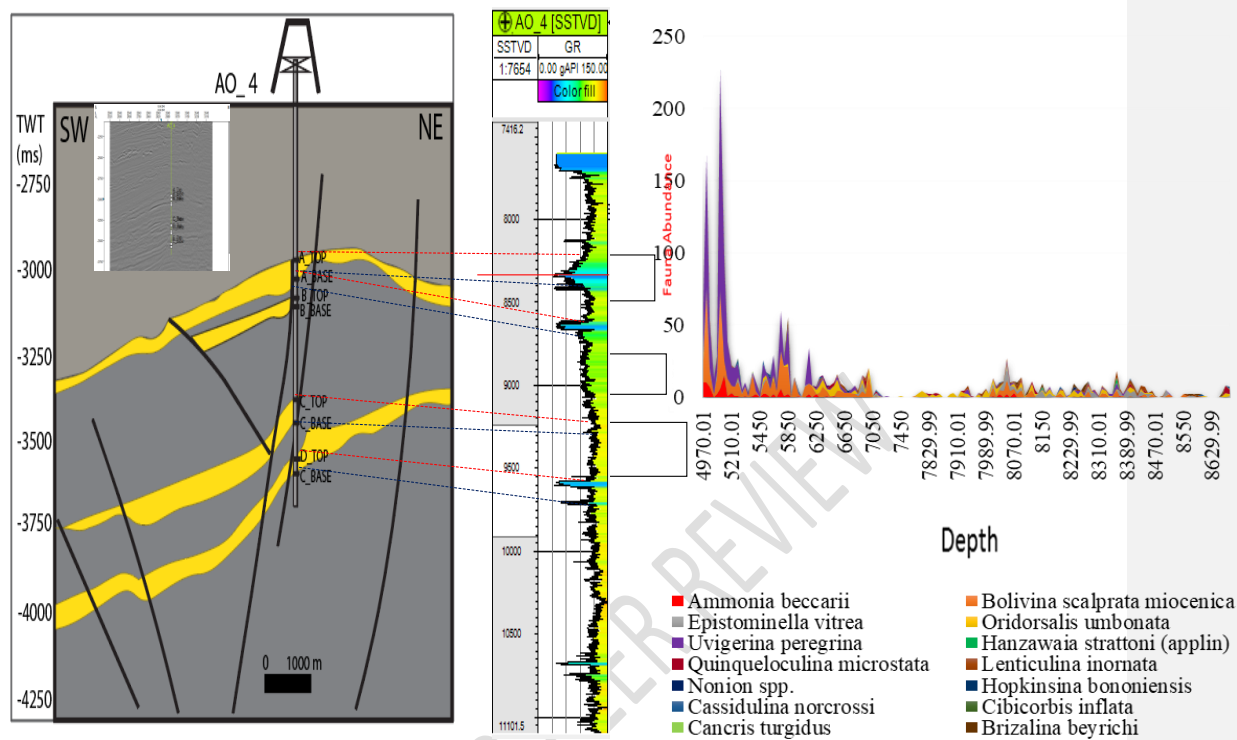


Figure 9: Well AO-4, Environment of Deposition Interpretation

Table 5: Recovered Fossils from Well AO-4 and their respective Environment of Depositions

<i>Ammonia beccarii</i>	INE
<i>Bolivinascalpratamiocenica</i> (F9601)	INE,MNE,ONE,UBE
<i>Brizalinabeyrichi</i> (F7870)	INE,MNE
<i>Cancristurgidus</i>	INE,MNE,ONE
<i>Cassidulinanorcrossi</i>	INE,MNE,ONE
<i>Cibicorbis inflata</i>	INE,MNE,ONE
<i>Epistominellavitrea</i> (F7850)	INE,MNE,
<i>Hanzawaiastrattoni</i> (F9305)	INE,MNE,ONE
<i>Hopkinsinabononiensis</i> (F7400)	INE,MNE,ONE,UBE
<i>Lenticulinainornata</i> (F9640)	INE,MNE,ONE
<i>Oridorsalisumbonata</i> (F9650)	MNE,ONE,UBE,MBE
<i>Quinqueloculina microstate</i>	INE,MNE,ONE,UBE,MBE
<i>Textulariapanamensis</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 ENVIRON MENT	MIDDLE NERITIC ENVIRON MENT	OUTER NERITIC ENVIRON MENT	UPPER BATHYAL ENVIRON MENT	MIDDLE BATHYAL ENVIRON MENT
<i>Ammonia beccarii</i>					
<i>Bolivinaaalgata miocenica</i>					
<i>Buccella biguttata</i>					
<i>Cassidulinoides</i>					
<i>Cassidulinoides noronensis</i>					
<i>Cibicides lobatulus</i>					
<i>Epistominella vitrea</i>					
<i>Hanzawaia strattoni</i>					
<i>Hopkinsina bononiensis</i>					
<i>Lenticulina inornata</i>					
<i>Oridanella umbonata</i>					
<i>Quinqueloculina miocenica</i>					
<i>Tartaricella parvula</i>					
<i>Uvigerina parvula</i>					

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 (Figure 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 *Hanzawaiastrattoni*, *Hopkinsinabononiensis*, *Lenticulinainornata*, *Valvulinaflexilis*, *Uvigerinaspinicostata*, *Epistominellavitrea* 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

Comment [7]: all scientific names must be in italics

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.

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