Original Research Article

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 becarii, Bolivia scalprata miocenica, Bolivia scalprata retiformis, Cibicorbis inflate, Cyclammina minima, Epistominella vitrea, Hanzawaia strattoni, Haplophragmoides compressa, Lenticulina inornata, Praeglobobulimina ovata, Quinqueloculina microstate, Rectuvigerina spp., Saccammina 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.

K**eywords:** 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 (Petters 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 (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 (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).

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).

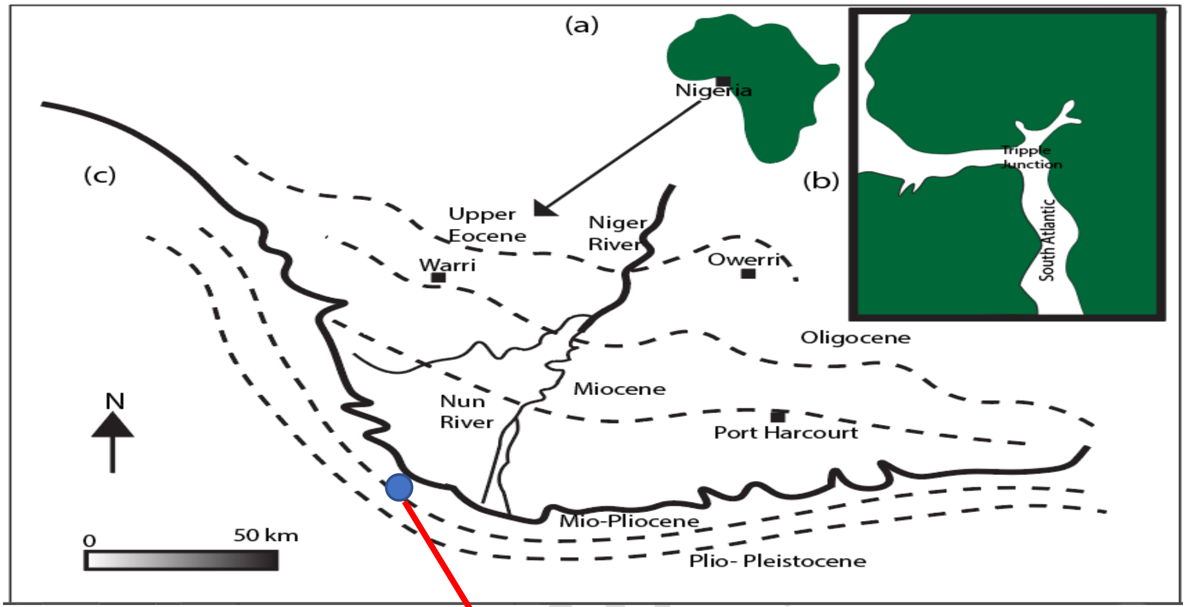


Figure 1: Location of Niger Delta in Nigeria (Modified After Burke *et al.*, 1971).

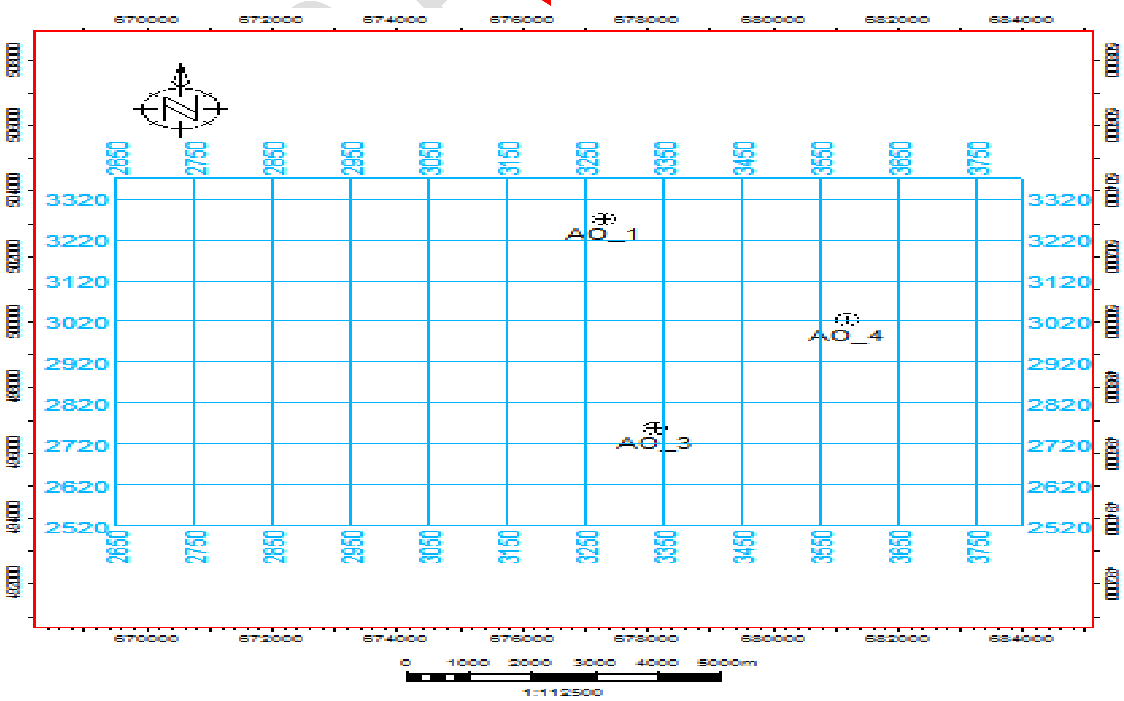


Figure 2: Base Map of the Study Area Showing Well Locations and Seismic Lines

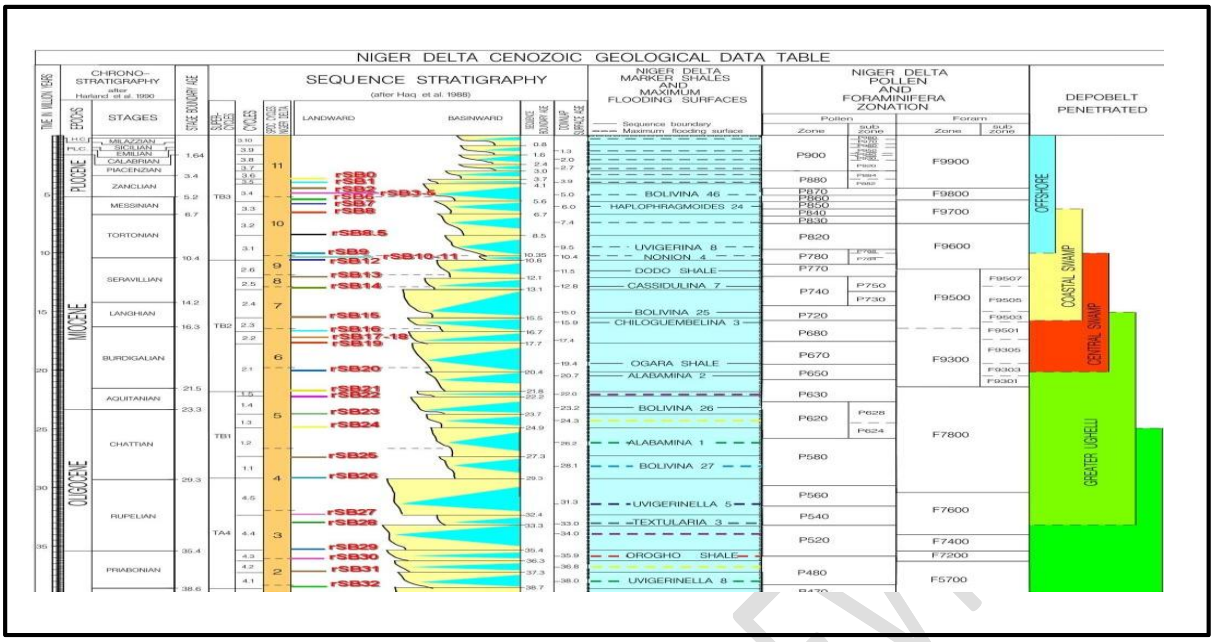


Figure 3: SPDC Cenozoic Chronostratigraphic Chart of Niger Delta (After Haq *et al.*, 1988)

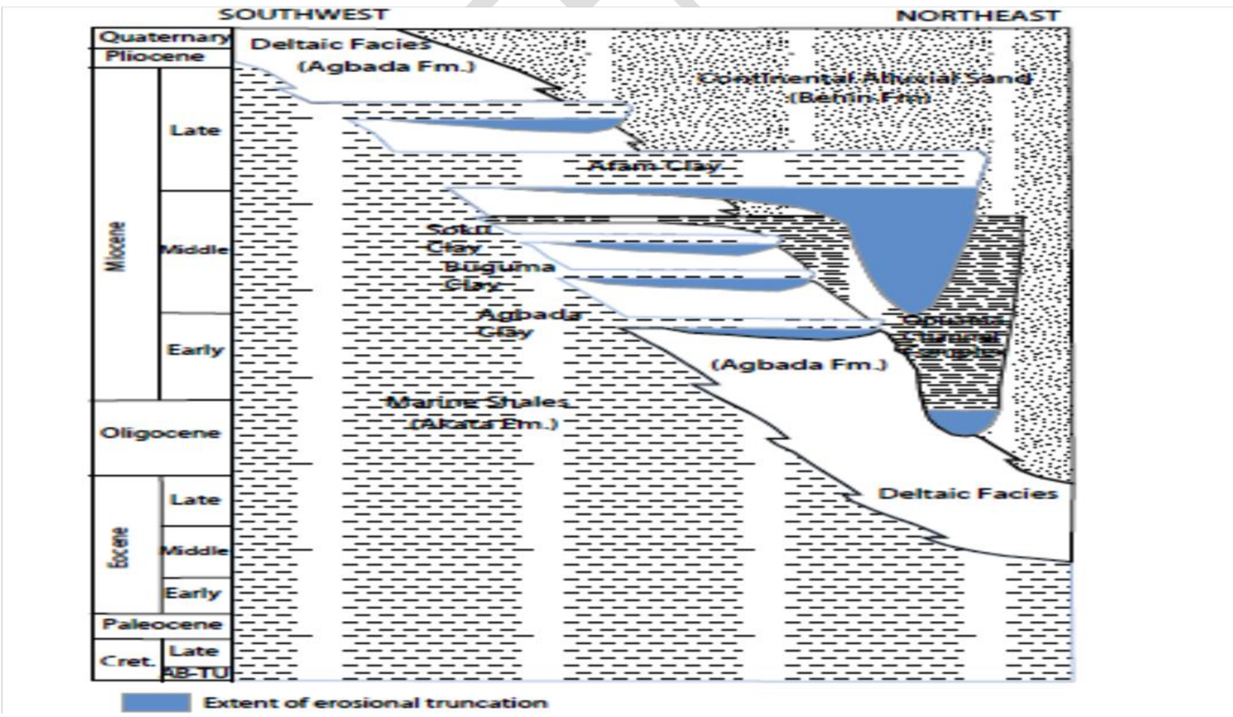


Figure 4: The Stratigraphic units of the Niger Delta. Modified from Shannon and Naylor (1989) and Doust and Omatsola (1990) as cited in Tuttle *et al.*, (1999).

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.

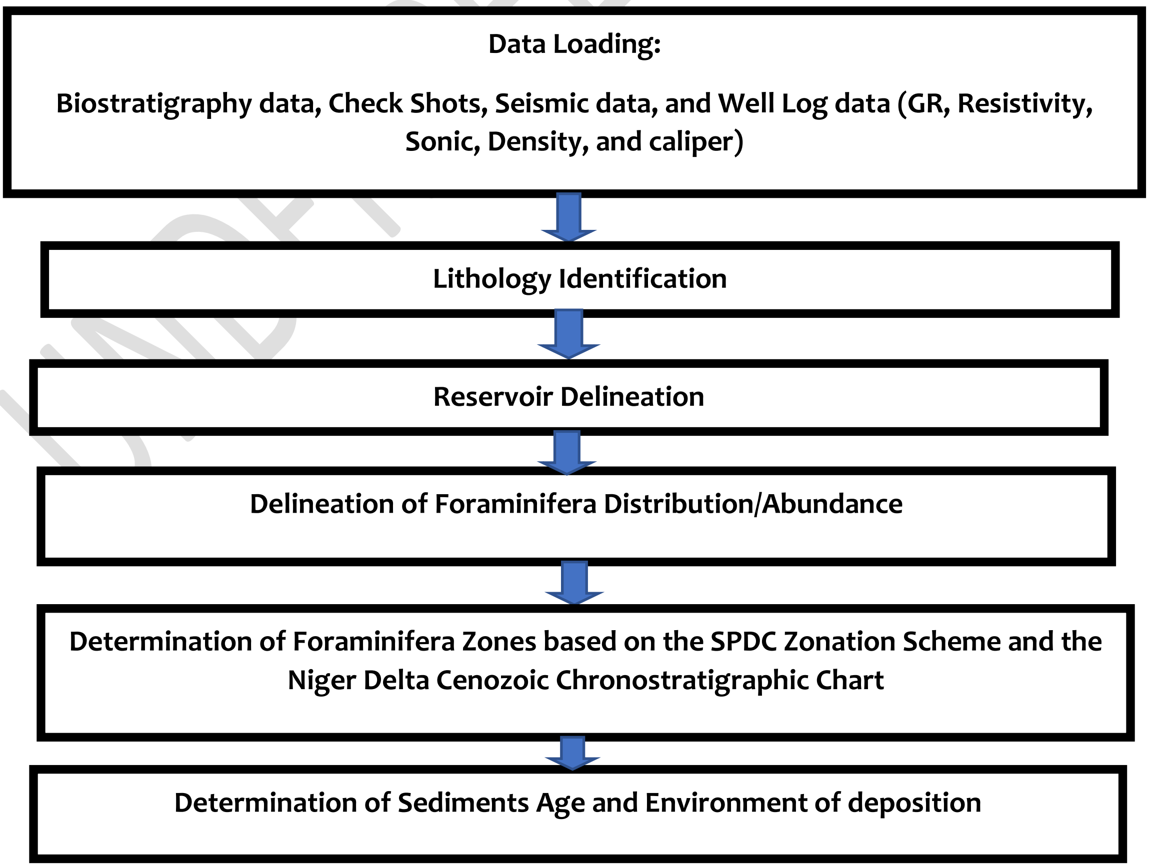


Figure 5: Methodology Workflow

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 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 (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 areneous species, with some planktonic in the wells.

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.*

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

The benthonic areneous 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 saturalis Globigerinoides immaturus Globigerinoides sacculifer Globigerinoides trilobus Globigerinoides quadrilobatus Catapsydrax dissimilis Globigerinoides spp.*

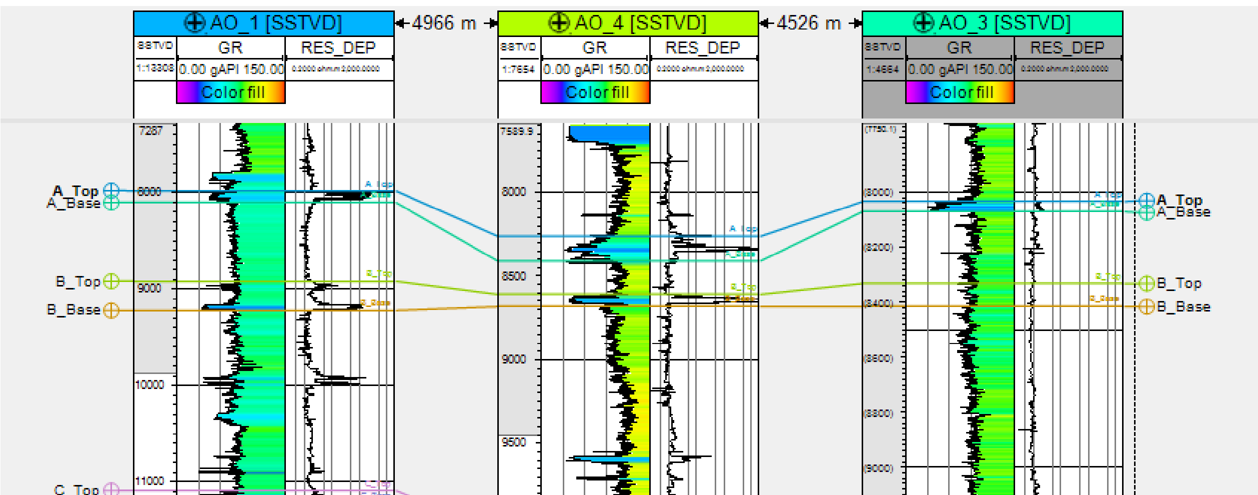
In well AO-01 (Figure 7), the most abundant foraminifera are *Haplophragmoides compressa* while the least abundant is the *Textularia spp*. The Index Fossils and Foraminifera Zonations in brackets are *Bolivina scalprata miocenica* (F9601), *Bolivina scalprata retiformis* (F9650), *Epistominella vitrea* (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 spinicostata* (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 *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).



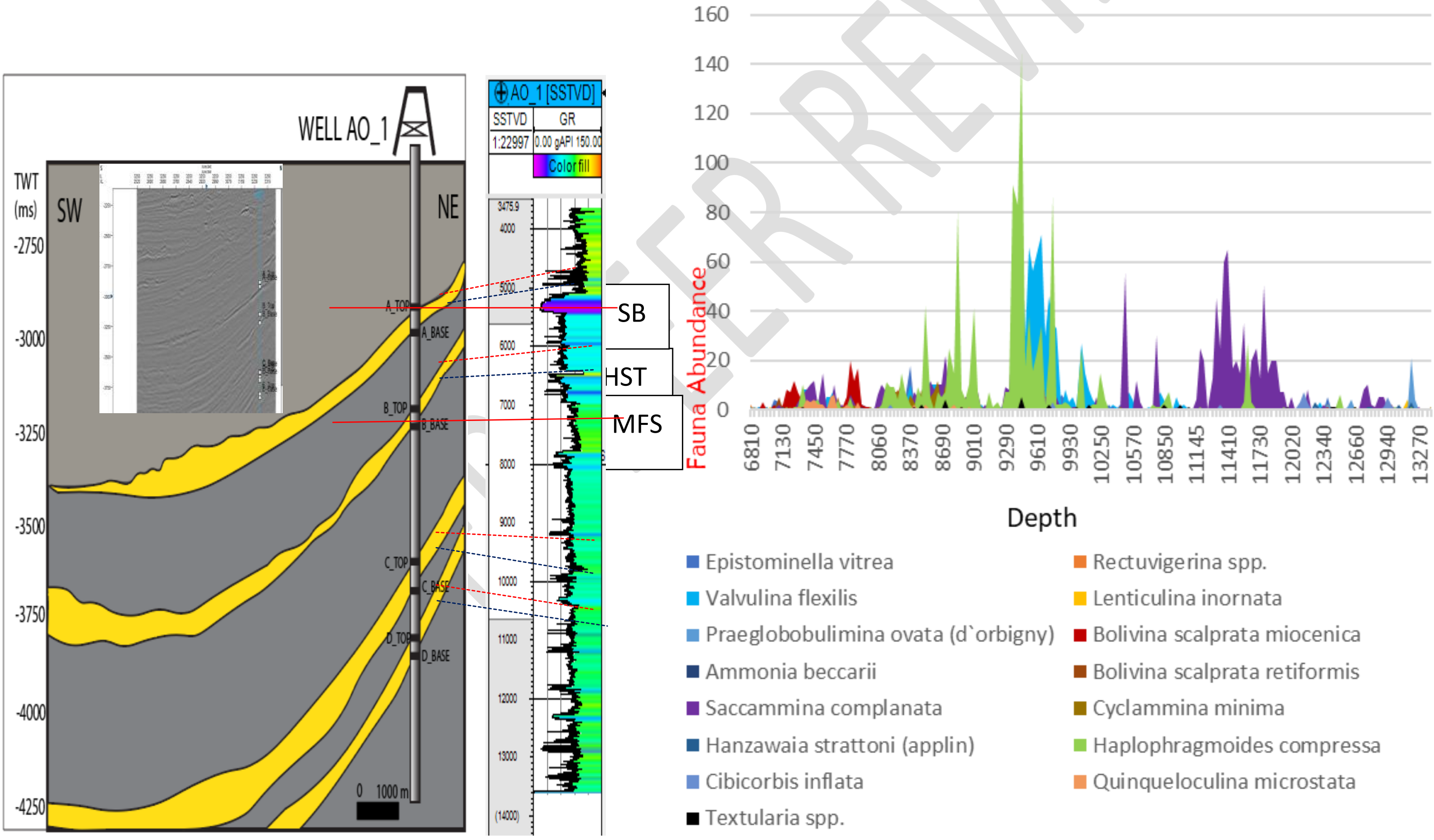


Figure 7: Well AO-01, Environment of Deposition Interpretation

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

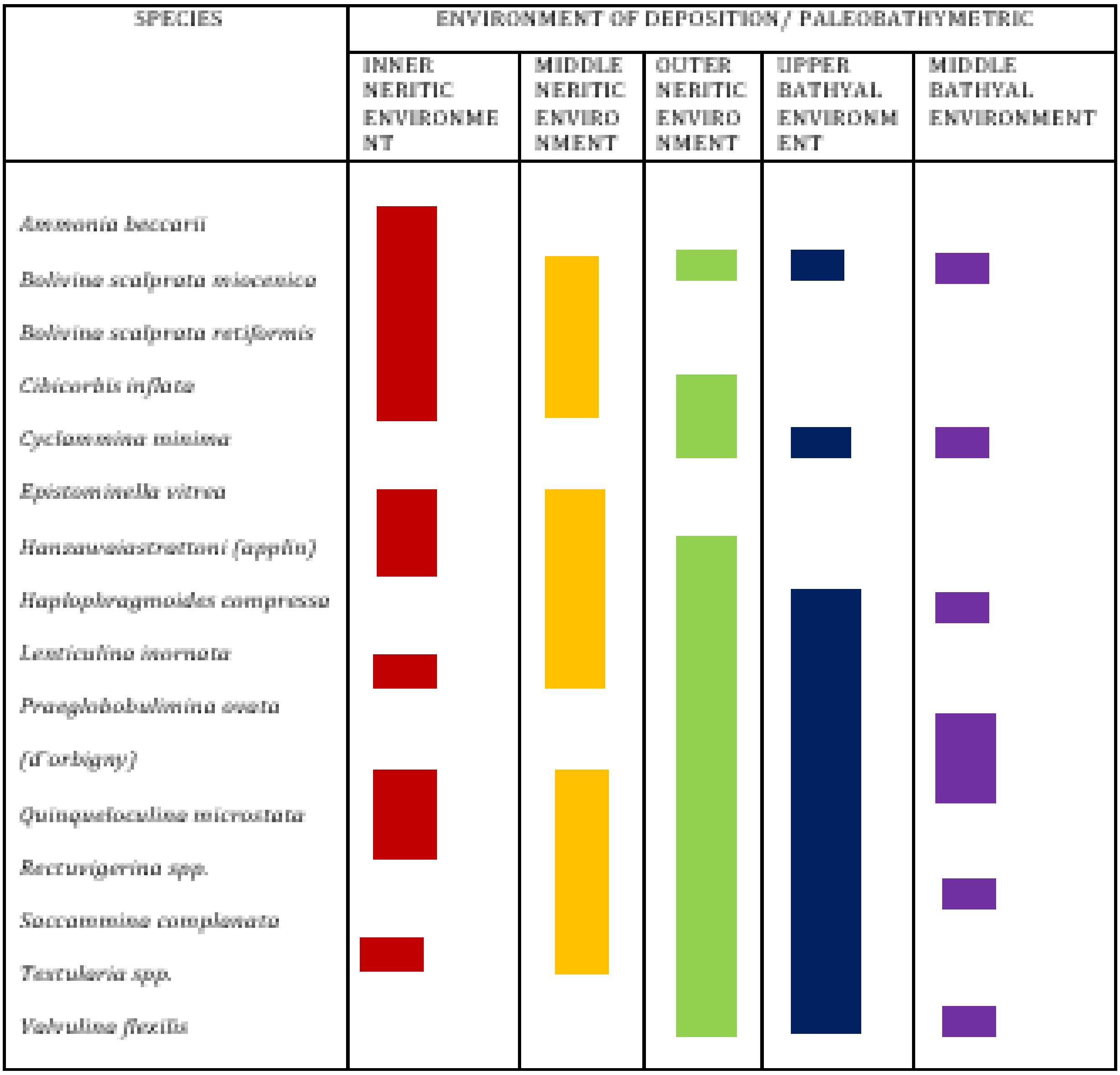


Table 2: Recovered Fossils from Well AO-1 and their respective Environment of Depositions

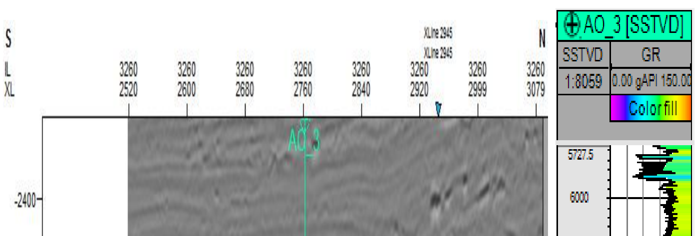
LEGEND

INE- INNER NERITIC ENVIRONMENT MNE- MIDDLE NERITIC ENVIRONMENT

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

UBE- UPPER BATHYAL ENVIRONMENT MBE- MIDDLE BATHYAL ENVIRONMENT

ONE- OUTER NERITIC ENVIRONMENT



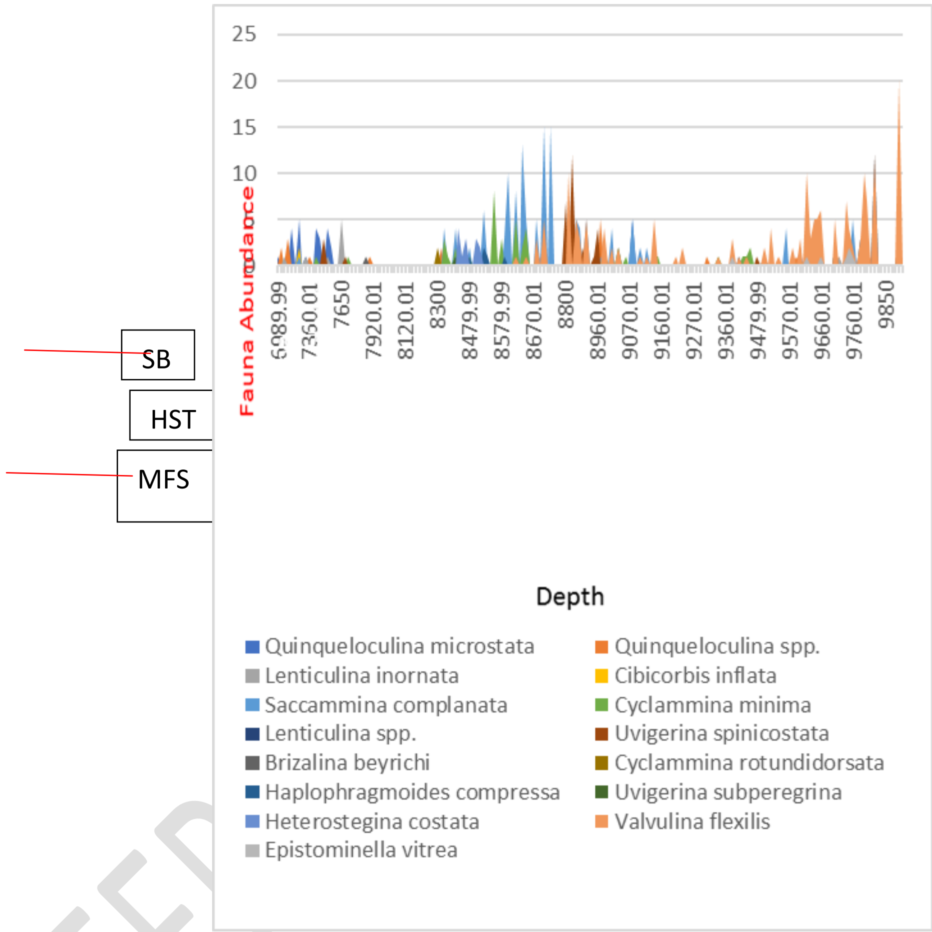


Figure 8: Well AO-03, Environment of Deposition Interpretation

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

LEGEND

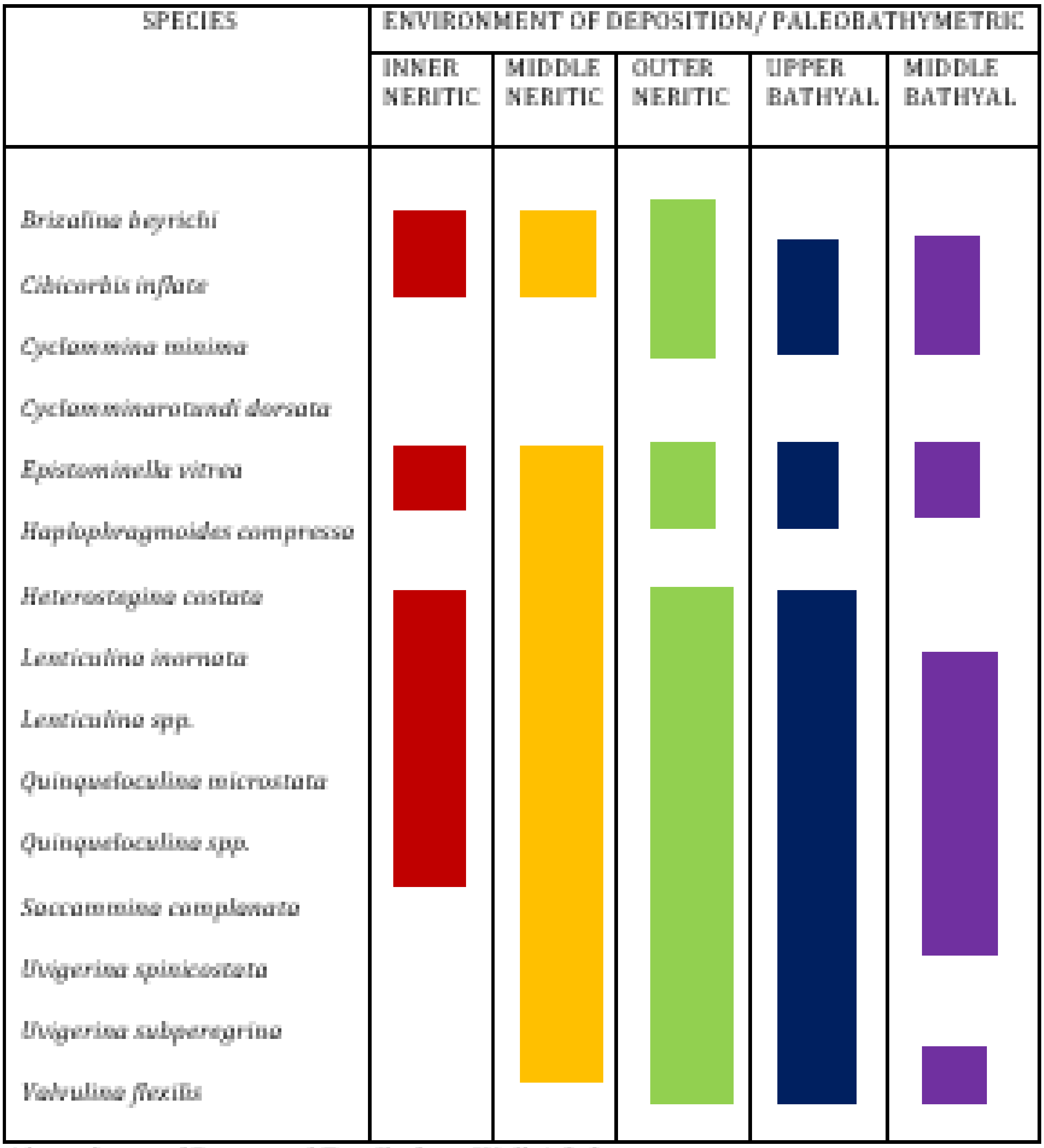
Brizalina beyrichi (F7870)	INE,MNE
Cibicorbis inflate	INE,MNE,ONE
Cyclammina minima	ONE,UBE,MBE
Cyclammina rotundidorsata	ONE,UBE,MBE
Epistominella vitrea (F7850)	INE,MNE
Haplophragmoides compressa	MNE,ONE,UBE,MBE
Heterostegina costata	INE,MNE
Lenticulina inornata (F9600)	INE,MNE,ONE,UBE
Lenticulina spp.	INE,MNE,ONE,UBE,MBE
Quinqueloculina microstate (F9640)	INE,MNE,ONE,UBE,MBE
Quinqueloculina spp.	INE,MNE,ONE,UBE,MBE
Saccammina complanata (F9700)	MNE,ONE,UBE,MBE
Uvigerina spinicostata (F9500)	MNE,ONE,UBE,MBE
Uvigerina subperegrina (F9603)	MNE,ONE,UBE
Valvulina flexilis (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: Aboundance of Recovered Fossils from Well AO-3



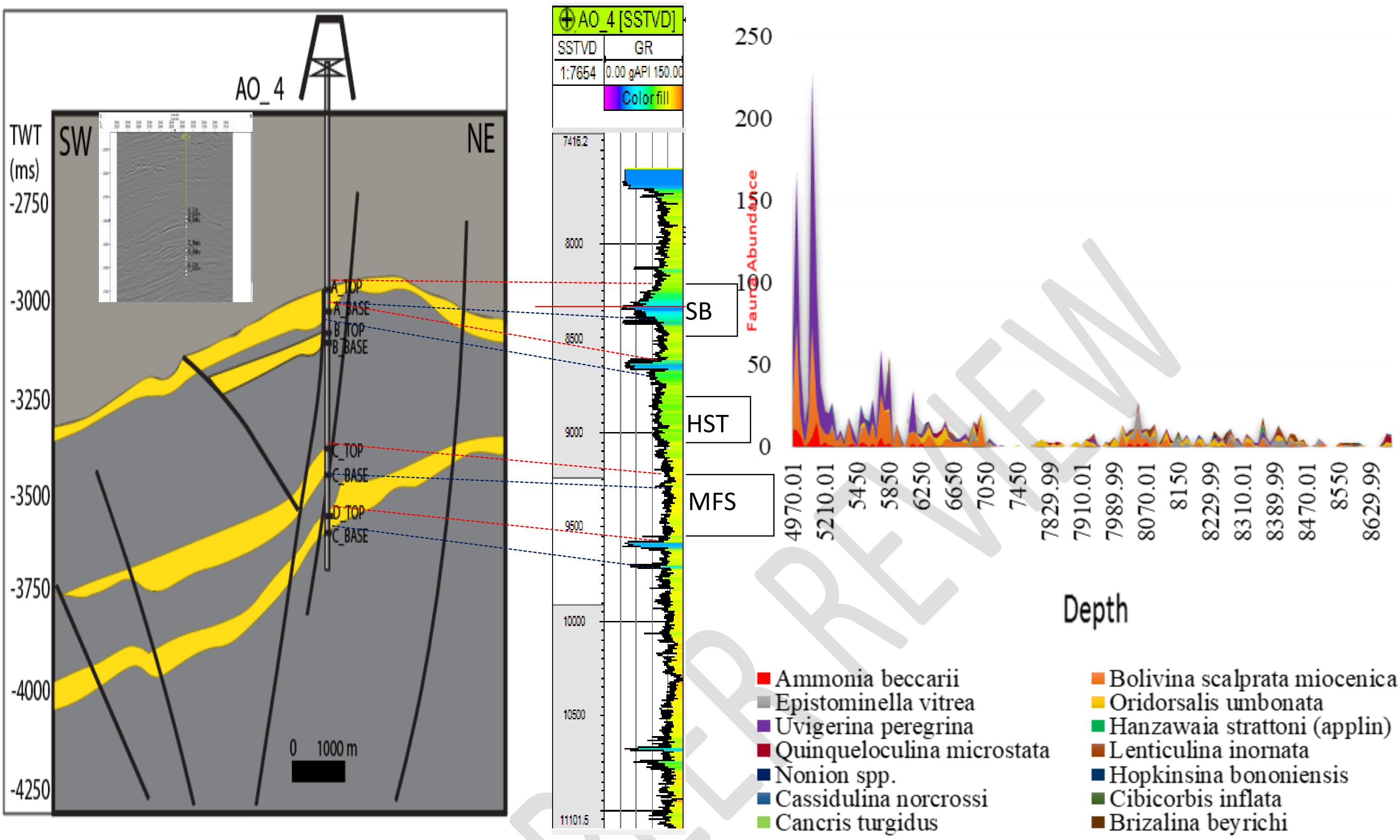


Figure 9: Well AO-4, Environment of Deposition Interpretation

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

Ammonia beccarii	INE
Bolivinascalprata miocenica (F9601)	INE,MNE,ONE,UBE
Brizalina beyrichi (F7870)	INE,MNE
Cancristurgidus	INE,MNE,0NE
Cassidulina norcrossi	INE,MNE,ONE
Cibicorbis inflate	INE,MNE,ONE
Epistominella vitrea (F7850)	INE,MNE,
Hanzawaia strattoni (F9305)	INE,MNE,ONE
Hopkinsinabono niensis (F7400)	INE,MNE,ONE,UBE
Lenticulina inornata (F9640)	INE,MNE,ONE
Oridorsalis umbonata (F9650)	MNE,ONE,UBE,MBE
Quinqueloculina microstate	INE,MNE,ONE,UBE,MBE
Textularia panamensis	INE,MNE,ONE,UBE
Uvigerina peregrine	MNE,ONE,UBE

LEGEND

INE- INNER NERITIC ENVIRONMENT

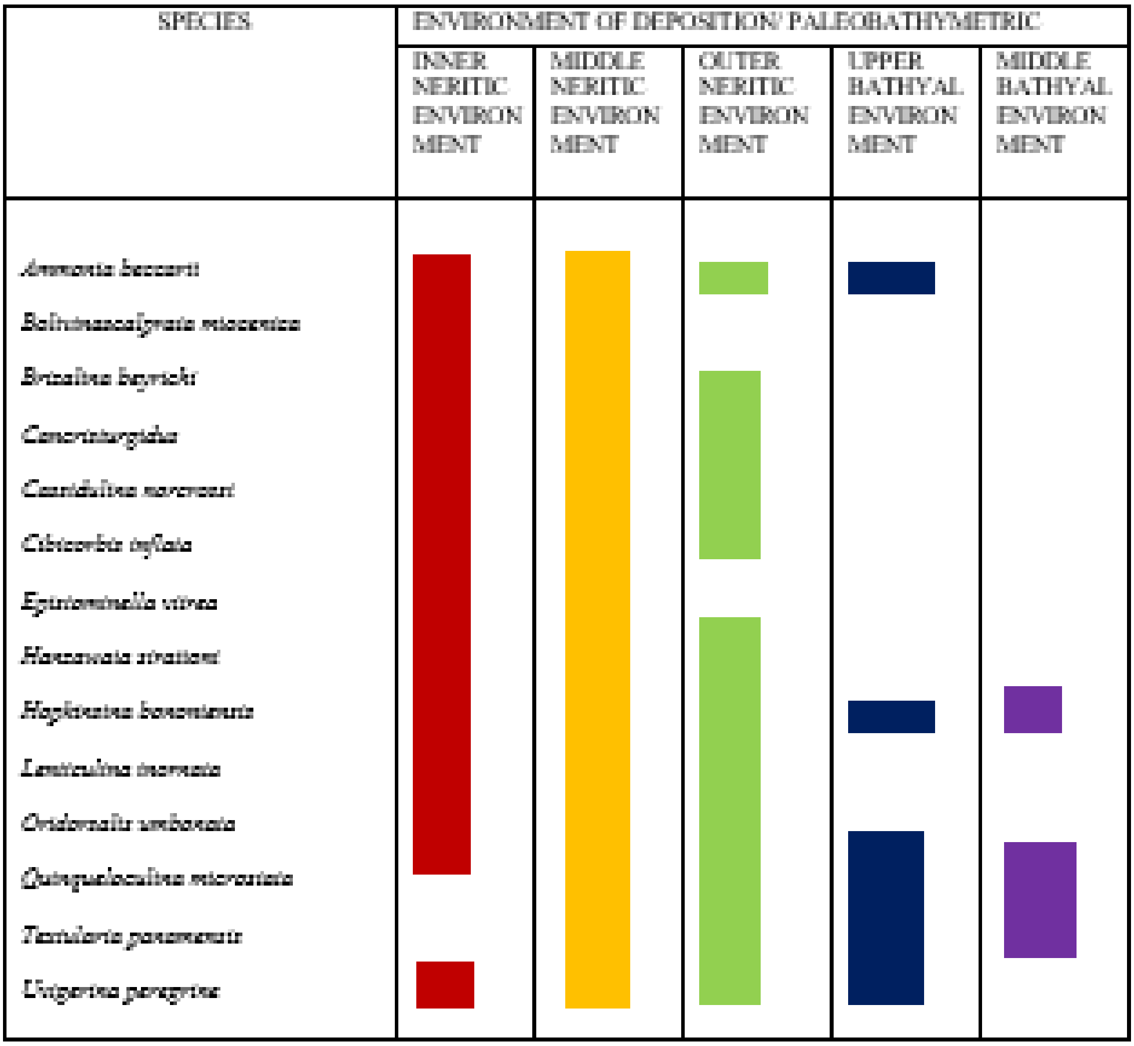
MNE- MIDDLE NERITIC ENVIRONMENT

UBE- UPPER BATHYAL ENVIRONMENT

MBE- MIDDLE BATHYAL ENVIRONMENT

ONE- OUTER NERITIC ENVIRONMENT

Table 6: Aboundance of Recovered Fossils from Well AO-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 (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 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.

REFERENCES

1. ***Adegoke, O. S., Dessauvagie, T. P. J., and Kogbe, C. A. (1971):*** Planktonic Foraminifera in Gulf of Guinea Sediments. Micropaleontology, U.S.A; Vol 17, no 12, pp 197-213.

2. ***Adeniyi, A., Oluwaseye P. O., Suyi L. F., Oluwabamiwa F. (2021):*** Sequence Stratigraphic Analysis and Hydrocarbon Prospectivity of AMO Field, Deep Offshore Niger Delta, Nigeria, Energy Geoscience.

3. ***Ayonma, W., (2015):*** Sequence Stratigraphy and Depositional Environments of Middle-Late Miocene Sediments in the Eastern part of the Coastal Swamp Depobelt, Niger Delta Basin, Nigeria.

4. ***Burke, K., (1972):*** *Longshore Drift, Submarine Canyons and Submarine Fans in Development of Niger Delta, American Association of Petroleum Geologists Bulletin,* v.56, pp. 1975-1983.

5. ***Doust H, Omatsola E (1990):*** Niger Delta. In: Edwards JD, et al. (Eds.), Divergent / Passive margins. Bulletin Memoir 48:239-248.

6. ***Haq B. U., (1988):*** *Mesozoic Cenozoic Chronostratigraphy and Cycles of Sea Level Change.* SEPM Special Publication 42, pp.7-108.

7. ***Klett, T. R., Ahlbrandt, T. A., Schmoker, J. W. and Dalton, G.L (1997):*** Ranking of the Wold's oil and Gas Provinces by Known Petroleum Volumes. U. S. Geological Survey Open File Report 96-463, One CD-ROM. https://doi.org/10.3133/ofr97463

8. ***Nwachukwu, J. I., and Chukwurah, P.I. (1986):*** *Organic Matter of Agbada Formation, Niger Delta, Nigeria. American Association of Petroleum Geologists Bulletin,* 70, 48-55.

9. ***Oluwaseye P. O., Suyi L. F., and Olatunbosun A. A., (2020).*** *Application of Sequence Stratigraphy for an Enhanced Hydrocarbon Reservoir Correlation in "OSP" Field Niger Delta, Nigeria, Journal of Petroleum Exploration and Production Technology.*

10. ***Ojo B.T, Olowokere, M.T, Oladapo M.I. (2021):*** Sensitivity analysis of changing Reservoir Saturation involving Petrophysics and Rock Physics in 'Royal G' field, Niger Delta, *Results in Geophysical Sciences*, Vol 7.https://doi.org/10.1016/j.ringps.2021.1018.

11. ***Ojo, B.T., Olowokere, M.T., and Oladapo, M.I, (2018):*** Quantitative Modeling of the Architecture and Connectivity Properties of Reservoirs in 'Royal' Field, Niger-Delta. Journal of Applied Geology and Geophysics, IOSR Journal Volume 6, Issue 2, Ver 11, PP 1-*10.* DOI:10.9790/0990-0602020110

12. ***Petters, S. W. (1979):*** *Some Late Tertiary Foraminifera from Parabe-1 well, Western Niger Delta. Revista Espanola de Micropaleontologia, Spain; 11:119-133.*

13. ***Short, K. C. and Stauble, A. J. (1967):*** *Outline of geology of Niger Delta. American Association of Petroleum Geologist Bulletin,* v.51, pp. 761-799.

14. ***Tuttle M. L. W., Charpentier R. R., and Brown field M. E., (1999):*** *The Niger Delta Petroleum System*: Niger Delta Province, Nigeria Cameroon, and Equatorial Guinea. Open-File Report 99-50-H, P. 65.

15. ***Whiteman A (1982):*** *Petroleum geology, resources and potential: London, pp:394.*