FORAMINIFERAL BIOSTRATIGRAPHY AND PALAEOENVIRONMENTAL INTERPRETATION OF WELL – 004 (OML – 34) CENTRAL SWAMP SECTION OF THE NIGER DELTA, NIGERIA

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Abstract

A total of seventy – two ditch cutting samples from well – 004 in OML – 34 onshore Niger Delta were described and analyzed for their foraminiferal content. Lithologic description of the samples shows that the entire sediments belong to the paralic sequence of Agbada Formation. A total of sixty three foraminiferal species were recovered out of which forty – five were benthonics and eighteen are planktonics. The planktonic foraminifera index species recovered from the well revealed that the sediments penetrated in the well range in age from Late Oligocene to Early Middle Miocene. Five planktonic foraminiferal zones namely Globigerina ciperoensis - Globorotalia opima nana Interval zone, Globigerina ciperoensis - Globigerinoides altiaperturus Interval zone, Globigerinoides altiaperturus – Catapsydrax dissimilis Interval zone, Catapsydrax dissimilis - Catapsydrax stainforthi Interval zone and Catapsydrax stainforthi - Praeorbulina sicana Interval zone have been identified based on First Downhole Occurrences and Last Downhole Occurrences of the planktonic foraminiferal index forms. Based on the triangular plot of the wall composition of the foraminiferal suborders the sediments in the study well are considered to be of normal salinity depositional environment deposited in dysoxic to oxic condition. Paleobathymetric ranges of some selected benthic foraminifera species shows that the palaeobathymetry of the studied well section ranges from non-marine to outer neritic.

Keywords: Foraminifera, Biostratigraphy, Palaeobathymetry, Oxygen, Salinity, Niger Delta

Introduction

The Niger Delta Basin is situated in the Gulf of Guinea on the margin of West Africa (Fig. 1), and is one of the largest deltaic system in the world (Doust and Omatsola, 1990). The importance of the basin lies in its hydrocarbon resources and it ranks among the world's most prolific petroleum – producing Tertiary deltas (Reijers et al., 1997). Foraminiferal biostratigraphic study of several wells in the Niger Delta Basin have been published by many workers (e.g. Fayose, 1970; Adegoke, 1978; Petters, 1979, 1982, 1983; Ozumba 1995; Bassey and Alalade 2005; Obiosio 2011, Okosun et al. 2012, Obiosio 2013, Obiosio et al. 2017). The researches on foraminiferal biostratigraphy in the basin gained importance owing to increase in exploration for hydrocarbons. This paper report on the foraminiferal biostratigraphy and palaeoenvironmental study of the Late Oligocene to Early Middle Miocene sequences penetrated by well – 004. Well – 004 is a Shell Petroleum Development Company of Nigeria (SPDC) well drilled in 1962, to a total depth of 4,359 m, it is located in central swamp section of the onshore Niger Delta Basin on OML 34 (Fig. 1). The well penetrated the paralic sequence of Agbada Formation having a total thickness of 1,326 m and consist of alternation of sand, shale and traces of silt (Fig. 2). Previous authors (e.g. Avbovbo, 1978) interpreted the alternation of sandstones and shales of the Agbada Formation as delta-front, distributary – channel, and deltaic-plain origin. The objectives of the paper are to:

1. Construct lithostratigraphic section of the well and identified distinct lithostratigraphic units from the section;
2. Carry out taxonomic identification of foraminifera species;
3. Construct a range chart of foraminifera species for the well; Attempt zonation of the well using foraminifera species;
4. Deduce palaeoenvironment of deposition of the sediments

5. well using foraminiferal assemblages;

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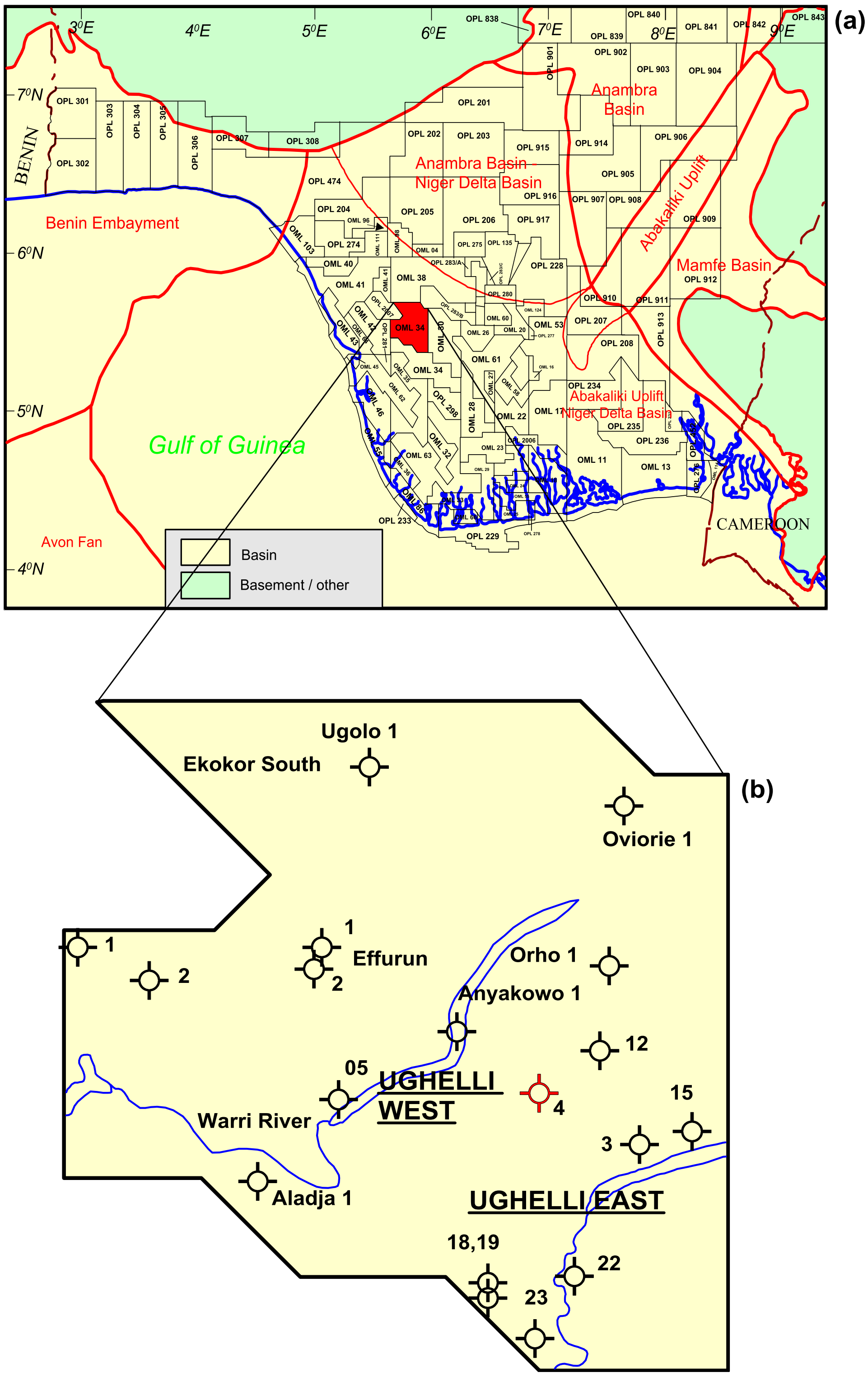


Fig. 1. (a) Index Map of Onshore Niger Delta Basin Showing Location of OML – 34 (b) Location of the studied well (well – 004) in the OML 34 (Modified after ISH, 2007)

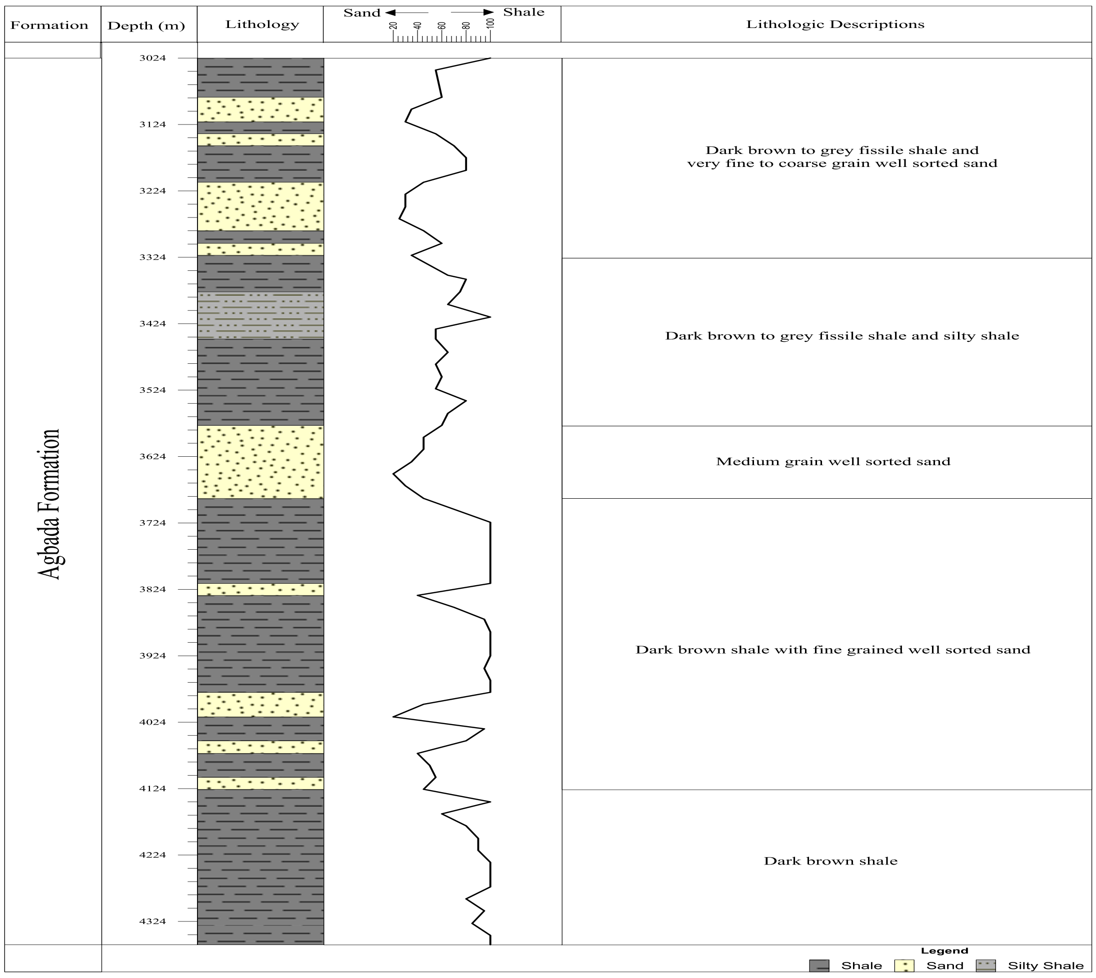


Figure 2. Lithostratigraphic section of the study well.

2. Stratigraphy of the Niger Delta

The Tertiary section of the subsurface Niger Delta is divided into three formations (Fig. 3), representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios (Tuttle et al., 1999). The type sections of these formations are described in Short and Stauble (1967) and summarized in a variety of papers (e.g. Avbobvo, 1978; Doust and Omatsola, 1990; Tuttle et al., 1999).

The Akata Formation (Figure 3) at the base of the delta is of marine origin and is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt (Tuttle et al., 1999). Beginning in the Paleocene and through the Recent, the Akata Formation formed during lowstands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency (Stacher, 1995). Little of the formation has been drilled; therefore, only a structural map of the top of the formation is available (Tuttle et al., 1999). It is estimated that the formation is up to 7,000 m thick (Doust and Omatsola, 1990). The formation underlies the entire delta, and is typically overpressured. Turbidity currents likely deposited deep sea fan sands within the upper Akata Formation during development of the delta (Burke, 1972).

Deposition of the overlying Agbada Formation (Fig. 3), the major petroleum – bearing unit, began in the Eocene and continues into the Recent (Tuttle et al., 1999). The formation consists of paralic siliciclastics over 3,700 m thick and represents the actual deltaic portion of the sequence. The clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environments. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds (Tuttle et al., 1999). The Agbada Formation is overlain by the third formation, the Benin Formation (Figure 3), a continental latest Eocene to Recent deposit of alluvial and upper coastal plain sands that are up to 2000 m thick (Avbovbo, 1978).

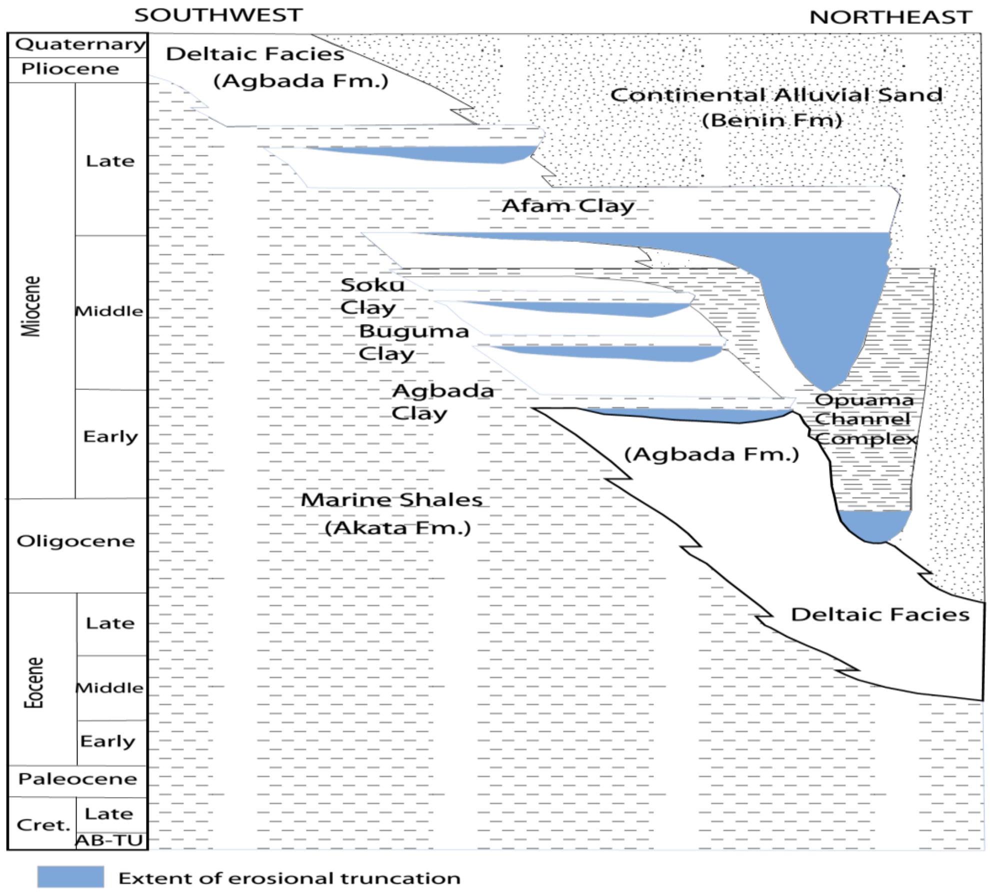


Figure 3. Stratigraphic column showing the three formations of the Niger Delta (Tuttle et al., 1999).

Material and Methods

Data

The material used are seventy two ditch cuttings samples from well - 004 drilled to a total depth of 4,359 m. Available interval is from 3,024 m to 4,359 m depth. The foraminiferal results are based mainly on the analysis of samples from the well. Lithologic interpretations are based on the well cuttings samples.

Sample preparation

The samples were processed for their foraminiferal content, using standard micropalaeontological techniques as outlined in Brasier, (1980). About 30 g of each of the samples was poured into beakers and treated for 10 minutes with hydrogen peroxide to disaggregate and dissolve the rock materials to free the fossils. Water was then added to cover the samples. The samples were then washed under tap water through a 63-µm mesh sieve until clean foraminiferal residues were recovered. The washed samples were dried in an oven at a minimum temperature of 45° C.

Samples were examined on a micropaleontological picking tray with a Fisher Scientific binocular microscopic. Digital photomicrographs were taken with a Nikon SMZ 1500 binocular stereomicroscope. The foraminifera were mounted on microfossils slides and sorted into recognizable species. Loeblich and Tappan (1964) generic classification was followed for generic assignment. Identification at the species level are based on Petters (1982) and (1983).

Results

Faunal Pattern

Sixty – three foraminiferal species comprising 33 genera from 21 families and 3 suborders were recovered and identified. The species recovered are further classified into planktonic (Fig. 4) and Benthonic (Fig. 5). Of the recovered, components benthonic foraminiferal species constitute approximately 71%. Planktonic foraminiferal constitute the remaining 29%.

Eighteen planktonic foraminiferal species belonging to 7 genera and 3 families were identified. Species abundance is poor (Fig. 6). The only exceptionally abundant species are *Praeorbulina glomerosa curva*, and *Praeorbulina glomerosa*. Other important species are *Globigerina ciperoensis*, *Catapsydrax dissimilis*, *Globigerinoides altiaperturus* and *Catapsydrax stainforthi* (Fig. 4). The benthonic foraminiferal species in the studied well are made up of diverse and abundant foraminiferal species (Fig. 6). Faunal preservation is fairly good all through the section. Fourty five benthonic foraminiferal species belonging to 26 genera were identified. Out of this, the calcareous benthonics contributed 40 species belonging to 24 genera while the arenaceous benthonics contributed 5 species belonging to 2 genera (Fig. 5). The calcareous benthonics are dominated by species of *Uvigerina isidroensis*, *Brizalina mandoroveensis*, *Eponides eshira* and *Lenticulina grandis*. The abundance of the remaining species was poor in many instances recording single occurrences (Fig. 5). The arenaceous benthonic foraminifera are dominated by species of *Textularia panamensis*, and *Haplophragmoides* sp. Species of *Textularia panamensis*, *Textularia* sp. have single occurrences (Fig. 5).

Range charts for planktonic foraminiferal species (Fig. 7) were generated and these show great differences in the ranges of the fauna found in the samples of the study well. The range charts form the basis for the biostratigraphic zonation. The planktonic foraminiferal range chart shows that most of the species have short stratigraphic ranges and are also restricted to a particular interval, a criterion that make them good index species. The only exceptional species among the planktonic foraminifera are *Globorotalia sacculifer* and *Globigerinoides immaturus* which have long stratigraphic range.

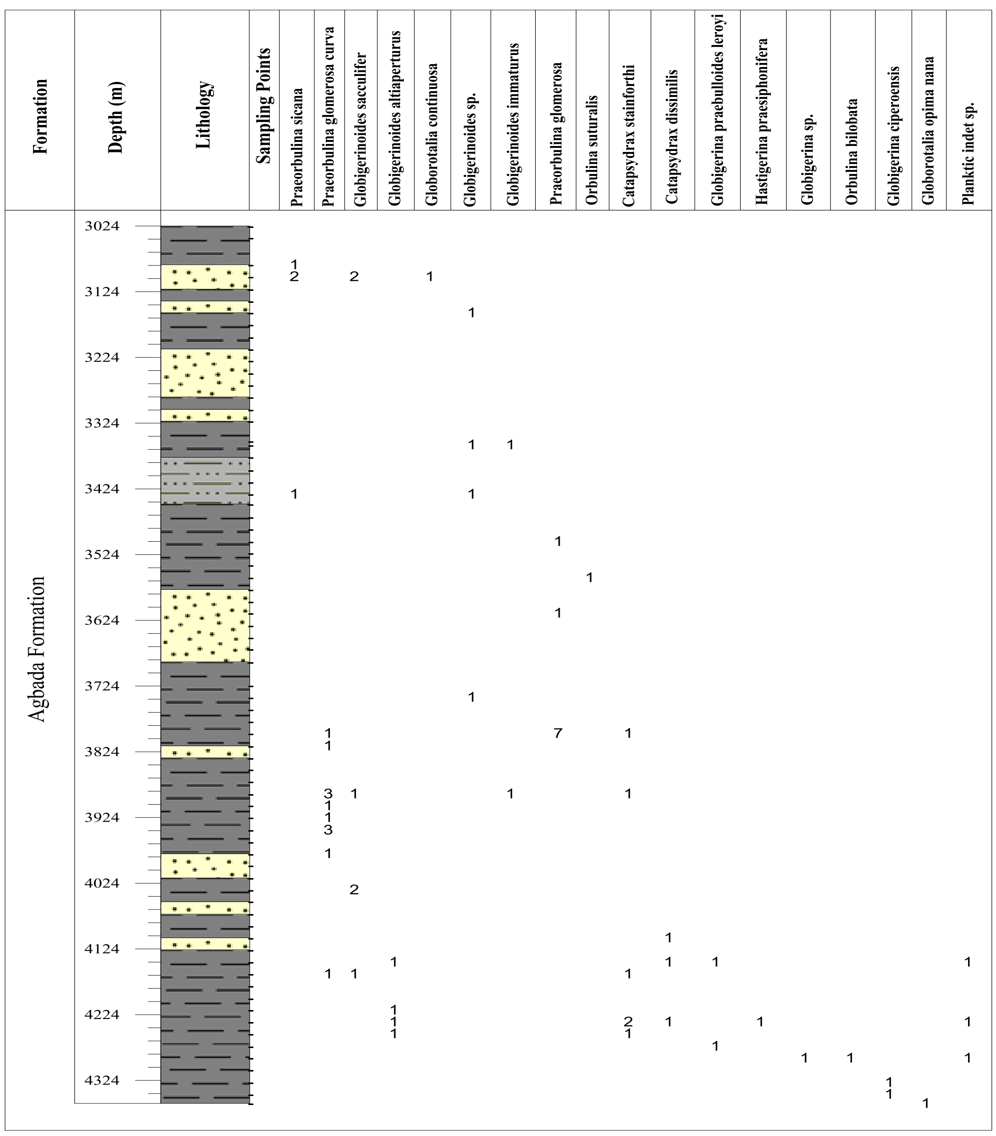


Figure 4. Planktonic foraminiferal distribution chart of the study well.

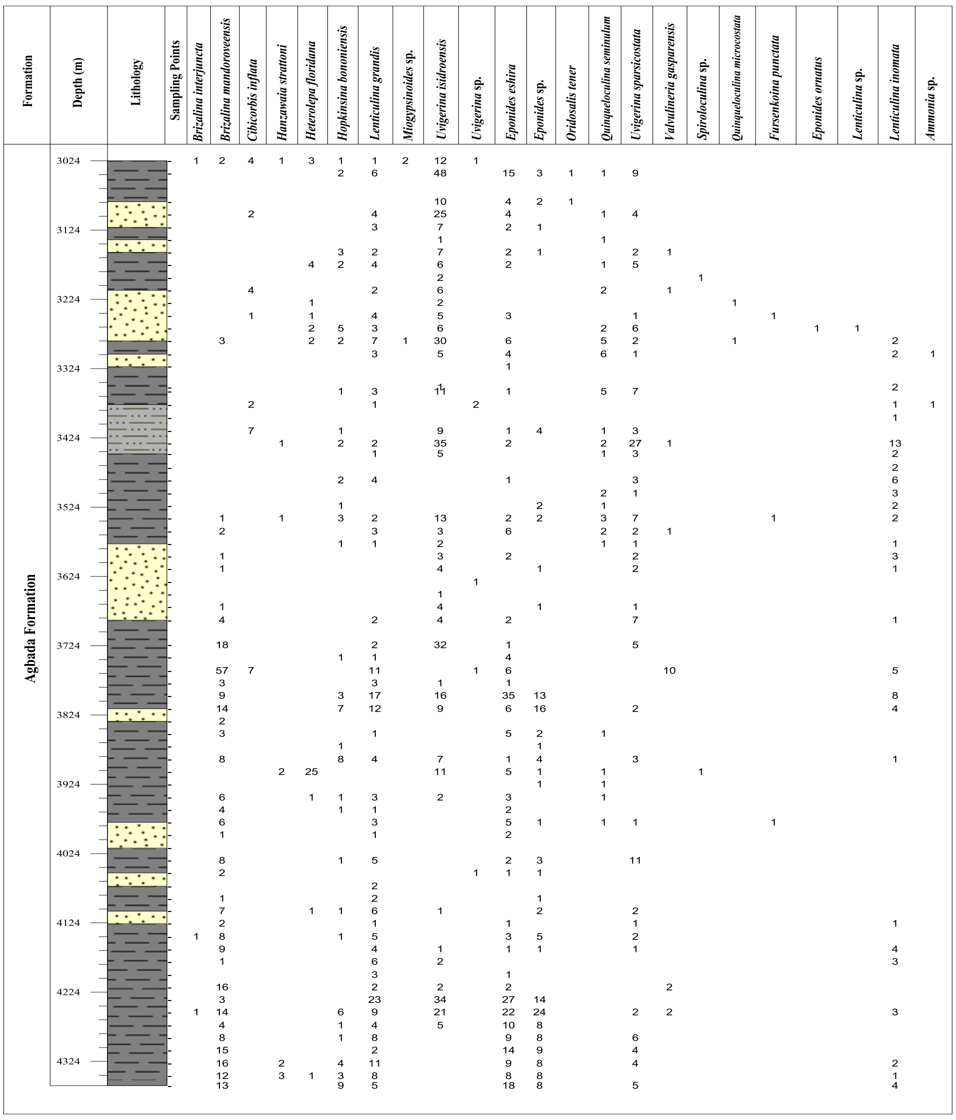


Figure 5. Benthonic foraminiferal distribution chart of the study well.

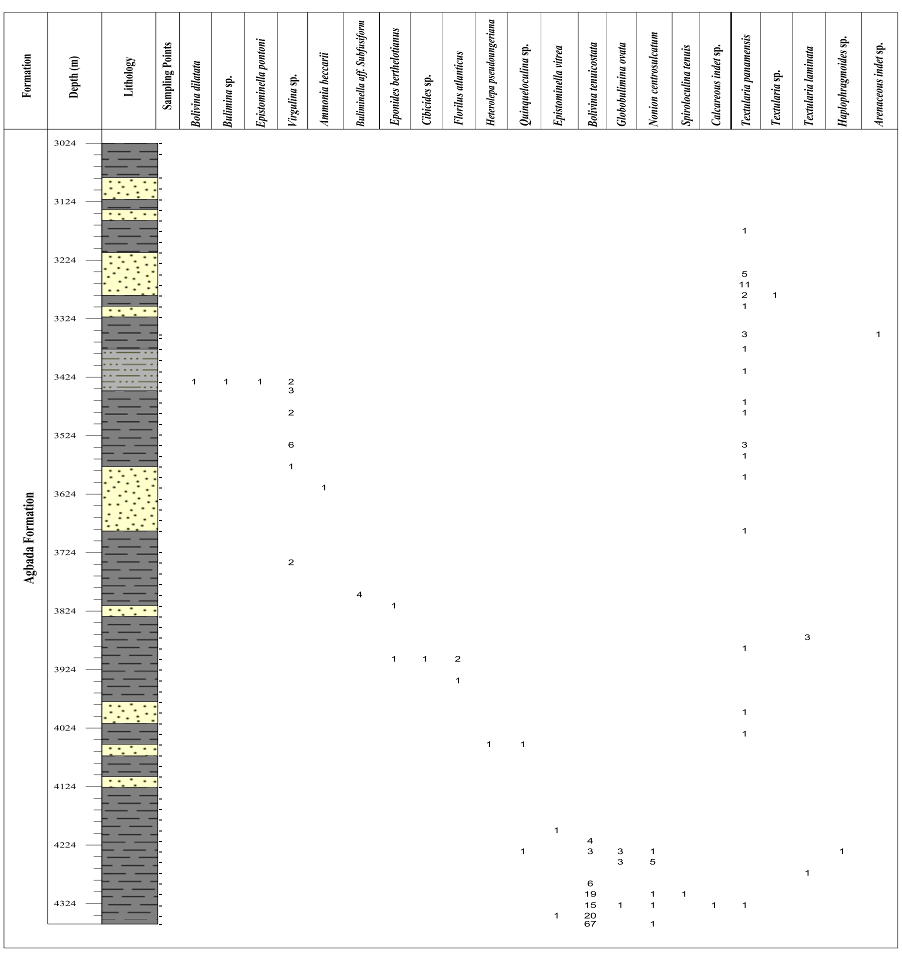


Figure 5. Cont.

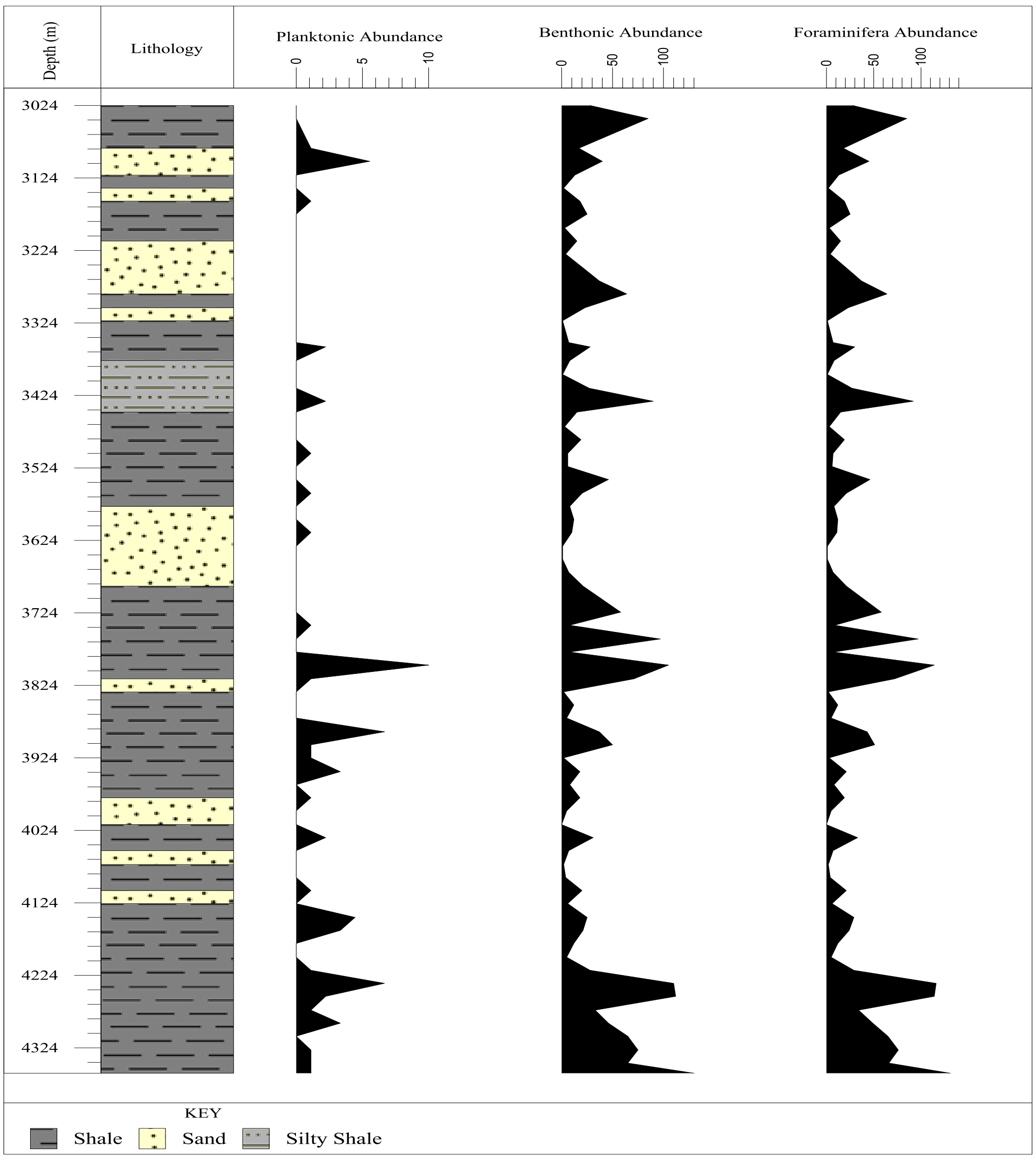


Figure 6. Abundance of benthonic, planktonic and total foraminiferal species recovered from the study well.

Discussion

Age Determination

From the planktonic foraminifers that were recovered during the study, the following index species were identified: *Praeorbulina glomerosa, Praeorbulina sicana, Globigerina ciperoensis, Catapsydrax dissimilis, Globigerinoides altiaperturus* and *Catapsydrax stainforthi* (Fig. 7). Using the index forms as defined by Postuma (1971); Bolli and Saunders (1985) and Petters (1983), the age of the studied section (Well – 004) has been interpreted to be of Late – Oligocene to Early – Middle Miocene (Fig. 7). The boundary of Oligocene and Miocene was picked at 4,327 m based on the first downhole occurrence (FDO) of Oligocene species *Globigerina ciperoensis* and occurrence of *Globigerinoides* ssp. above the FDO of the Late – Oligocene index species. The occurrence of *Globigerinoides* has widely been accepted as the datum for the Oligocene/Miocene boundary (Bolli, 1966; Bolli and Saunders, 1985) (Fig. 7).

The presence of *Globigerina ciperoensis, Globorotalia opima nana* and the absence of *Globigerinoides* spp. is indicative of Late – Oligocene age and occurs between the depth of 4,359 m and 4,327 m**.** According to Postuma (1971); Bolli and Saunders (1985) and Petters (1983), these planktonic foraminifers are both valuable index species for Late - Oligocene. Petters (1979) used *Globorotalia opima nana* to define late Oligocene age in Parable – 1 well in the Niger Delta Basin. Hewaidy *et al*. (2014) used the presence of *Globigerina ciperoensis* in addition to the absence of *Globigerinoides* spp. to defined Late – Oligocene age in west Central Sinai, Egypt (Fig. 7). The lower limit of Early – Miocene is marked at 4327 m based on FDO of *Globigerina ciperoensis*. The upper limit is marked at 3796 m based on last downhole occurrence (LDO) of *Praeorbulina glomerosa* and FDO of *Catapsydrax stainforthi*. This interval is characterized by the presence of other Early – Miocene index species which include *Catapsydrax* *dissimilis*, *Globigerinoides altiaperturus* (Fig. 7). The lower limit of Early – Middle Miocene is marked at 3,796 m based on LDO of *Praeorbulina glomerosa* and FDO of *Catapsydrax stainforthi*.

The upper limit of Early – Middle Miocene is not within the interval studied (Fig. 7).

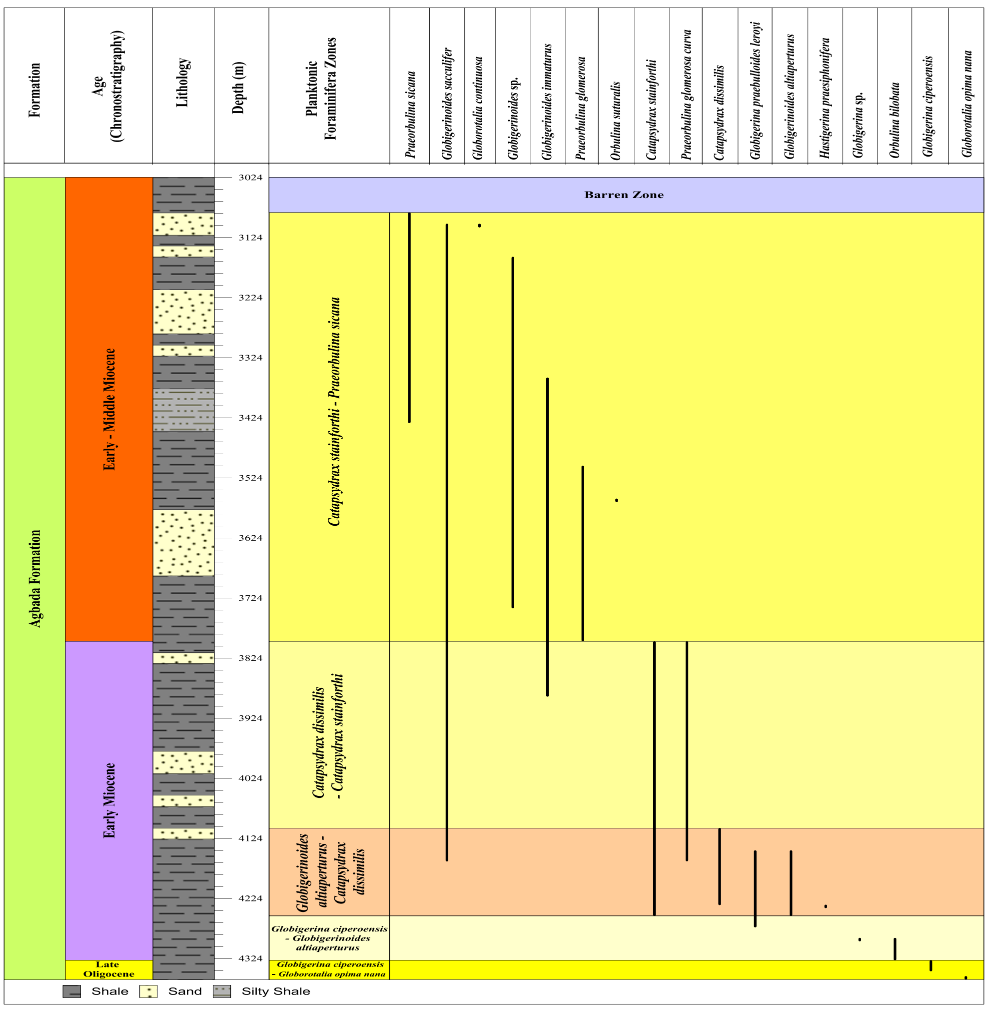


Figure 7. Range chart and proposed Planktonic foraminifera zones of the study well.

Planktonic Foraminifera Biozonation
In this study, five planktonic foraminiferal zones were identified in line with the work of Murphy and Salvador (1999): one zone for the Late Oligocene; *Globigerina ciperoensis* - *Globorotalia opima nana* Interval zone (P22/N3). Three for the Early Miocene; *Globigerina ciperoensis* - *Globigerinoides altiaperturus* Interval zone (N4), *Globigerinoides altiaperturus* – *Catapsydrax dissimilis* Interval zone (N5 – N6), and *Catapsydrax dissimilis* - *Catapsydrax stainforthi* Interval zone (N7). One for the Early – Middle Miocene; *Catapsydrax stainforthi* - *Praeorbulina sicana* Interval zone (N8 – N9) (Fig. 7). A comparison of the zones proposed in this study with the zonal schemes described by Blow (1969), Bolli and Saunders (1985), and Medina (2001) is shown in Figure 8.

***Globigerina ciperoensis* - *Globorotalia opima nana* Interval zone (P22/N3)**
This zone is defined by FDO of *Globigerina ciperoensis* (top), the lower boundary of this zone is defined by LOD of *Globorotalia opima nana* (Fig. 7). The top of the zone is marked at 4,327 m. species restricted to this zone are *Globorotalia opima nana* and *Globigerina ciperoensis*. The presence of the mentioned index species suggest Late Oligocene age for this zone (Fig. 7). *Globigerina ciperoensis* - *Globorotalia opima nana* Interval zone correlates with zone P22/N3 of Blow (1969) and can be compared with *Globigerina ciperoensis*

zone of Stainforth *et al.* (1975) and *Globigerina ciperoensis ciperoensis* zone of Medina (2001). Bolli and Saunders (1985) subdivide this zone into *Globigerina ciperoensis ciperoensis* zone and *Globigerina kugleri* zone (Fig. 8).

***Globigerina ciperoensis- Globigerinoides altiaperturus* Interval zone (N4)**

The base and top boundaries of this zone are defined by the FDO of *Globigerina ciperoensis* and LDO of *Globigerinoides altiaperturus* respectively (Fig. 7). This zone is demarcated between depths of 4,253 m and 4,327 m. The FDO of *Globigerina ciperoensis* coincide with LDO of *Orbulina bilobata* while the LDO of *Globigerinoides altiaperturus* coincide with LDO of *Catapsydrax stainforthi*. Species restricted to this zone are *Orbulina bilobata* and *Globigerina* sp. species of *Globigerinoides praebulloides leroyi* ranged beyond this zone (Fig. 7). *Globigerina ciperoensis-Globigerinoides altiaperturus* Interval zone as identified in this study correlates with zone N4 of Blow (1969) and may be compare with *Globorotalia kugleri* of Stainforth et al. (1975) and *Globorotalia primordius* of Bolli and Saunders (1985) (Fig. 8).

***Globigerinoides altiaperturus – Catapsydrax dissimilis* Interval zone (N5 – N6)**

The base of this zone is recognized by the LDO of *Catapsydrax stainforthi* and *Globigerinoides altiaperturus*. The top coincides with the FDO of *Catapsydrax dissimilis* (Fig. 7). This zone is recognized at the depth of 4,107 m to 4,253 m. Species that are restricted to this zone are *Hastigerina praesiphonifera*, *Globigerinoides altiaperturus*, and *Catapsydrax dissimilis* (Fig. 7). *Globigerinoides altiaperturus – Catapsydrax dissimilis* zone correlates with zone N5 – N6 of Blow (1969). Stainforth *et al.* (1975) and Bolli and Saunders (1985) defined boundary between zone N5 and N6 of Blow (1969) by the LDO of *Globigerinatella insueta* an event that could not be determined in this study. This zone may be correlated with *Catapsydrax dissimilis* zone (N5) – *Catapsydrax stainforthi* zone (N6) of Stainforth et al. (1975); Bolli and Saunders (1985). Medina, (2001) called zone N4, N5 and N6 *Catapsydrax dissimilis* zone because of the absence of index species that separate the zones (Fig. 8).

***Catapsydrax dissimilis - Catapsydrax stainforthi* Interval zone (N7)**

The base and top boundaries of this zone are defined by the FDOs of the two nominate taxa; *Catapsydrax dissimilis* and *Catapsydrax stainforthi* (Fig. 7). This zone is marked at 3,796 m – 4,107 m. This zone correlates with zone N7 of Blow (1969) and maybe correlated with *Globigerinatella insueta* zone of Stainforth et al. (1975); Bolli and Saunders (1985) (Fig. 8).

***Catapsydrax stainforthi - Praeorbulina sicana* Interval zone (N8 – N9)**

The base and top boundaries of this zone are defined by the FDOs of the two nominate taxa; *Catapsydrax stainforthi* and *Praeorbulina sicana* respectively (Fig. 7). This zone is recognized at the depth of 3,083 m to 3,432 m. Species that are restricted to this zone are *Praeorbulina glomerosa, Praeorbulina sicana, Orbulina suturalis, Globorotalia continuosa* and *Globigerinoides* sp. *Globigerinoides sacculifer* and *Globigerinoides immaturus* are inherited from the previous zone (Fig. 7). *Catapsydrax stainforthi - Praeorbulina sicana* interval zone correlates with zone N8 – N9 of Blow (1969). In this study the index species that separate zone N8 – N9 is absent. This zone may be correlated with *Praeorbulina glomerosa* of Stainforth et al. (1975) and Bolli and Saunders (1985) (Fig. 8).

Age	This Work	Blow (1969)	Bolli and Saunders (1985)	Medina (2001)
Early - Middle Miocene	*Praeorbulina glomerosa*	N8 - N9	*Praeorbulina glomerosa*	*Praeorbulina glomerosa - Globigerinoides bisphericus*
Early Miocene	*Catapsydrax stainforthi*	N7	*Globigerinatella insueta*	
	Globigerinoides altiaperturus - Catapsydrax dissimilis	N5 - N6	*Catapsydrax stainforthi* *Catapsydrax dissimilis*	*Catapsydrax dissimilis*
	Orbulina bilobata	N4	*Globorotalia kugleri*	
Late Oligocene	*Globigerina ciperoensis*	P22 / N3	*Globigerina ciperoensis*	*Globigerina ciperoensis ciperoensis*

Figure 8. Comparison of the Zones identified in this study with other Zonal Scheme.

Palaeoenvironmental Study

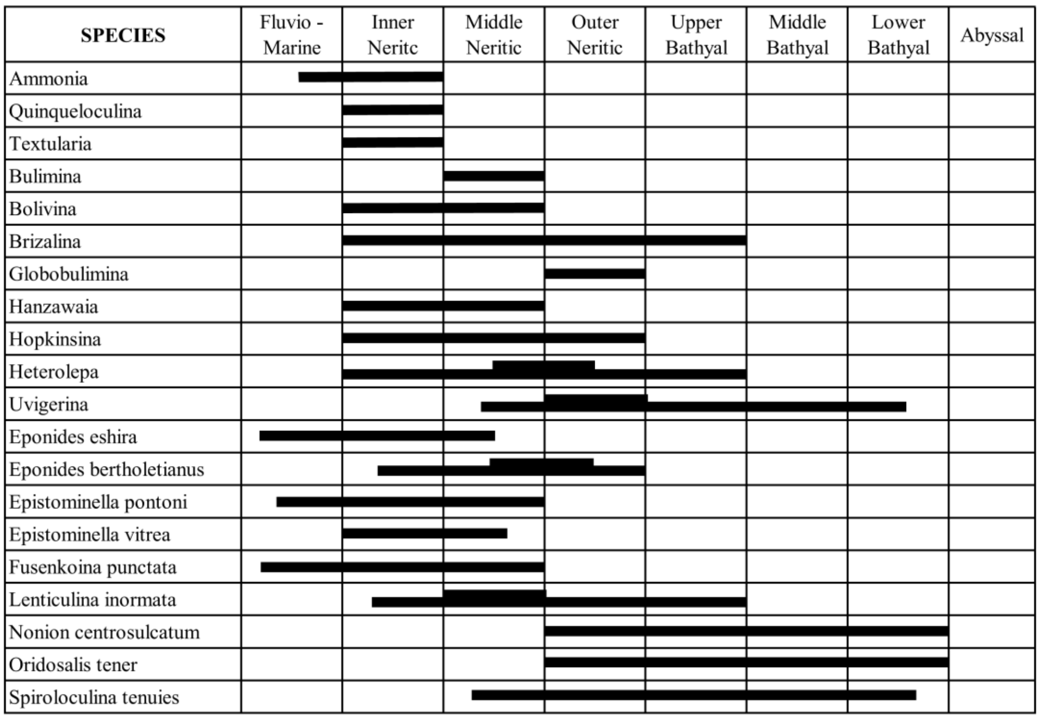
The methods used in this study include:

1. Foraminiferal species assemblages (biofacies) and bathymetric ranges of the dominance genera and species.
2. Miliolina – Textularia – Rotaliina triangular plot (Murray, 1973).
3. Relative planktonic percentages (P/B ratio)

Palaeobathymetry

Palaeobathymetry is the paleoenvironmental interpretation most widely used in petroleum exploration because of its value in determining the depositional history of a basin. Benthonic foraminifera are usually used for this purpose. As bottom dwellers, they provide information about conditions at the sea floor (Fleisher and Lane, 1999). The approach adopted by Petters (1982, 1995), where various biofacies were styled after bathymetric features was used in this study. This approach was based on previous studies by Harris (1981) and Culver (1988), from which the bathymetric zonation for the offshore Niger Delta was derived. This interpretation took into consideration the total foraminiferal assemblages characteristics and the presence of particular foraminiferal genera and species in the samples. The palaeobathymetric ranges of some genera and species used in this study are presented in Table 1. In the study well the Paleobathymetry ranged from non-marine to outer neritic environment (Figure 9).

Table 1. Palaeobathymetric ranges of selected benthonic foraminiferal genera and species in the study well (the bathymetric ranges are from Petters, 1995; Murray, 2006).



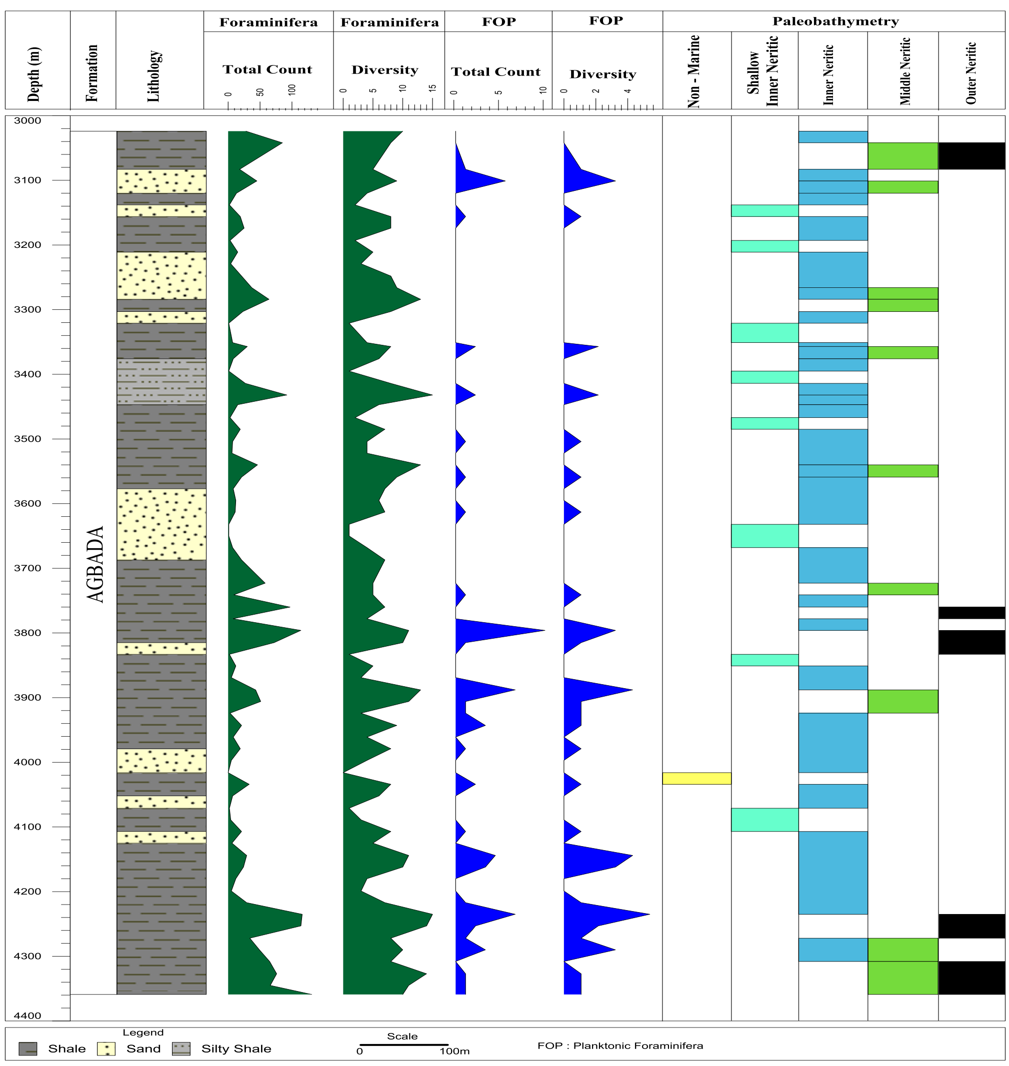


Figure 9. Palaeobathymetric interpretation of the study well.

Non – Marine

Non marine palaeobathymetry is observed between 4,016 m to 4,034 m (Figure 9). This interpretation is based on absence (barren) of foraminiferal species and high percentage occurrence of sand.

Shallow Inner Neritic

Boersma, (1978) included shallow inner neritic in subdivision of the neritic environment. The shallow inner neritic is characterized by a numerically small fauna dominated by a few species, very few of which are agglutinated and none of which are pelagic (Boersma, 1978). In this study, the interval inferred to be shallow inner neritic ranges from the following; 4,107 m – 4,071 m, 3,851 m – 3,833 m, 3,668 m – 3,632 m, 3,485 m – 3,467 m, 3,414 m – 3,395 m, 3,351 m – 3,321 m, 3,266 m – 3,211 m, 3,156 m – 3,138 m (Figure 9) . The intervals are characterized by fine to medium grained sand, contain very few shallow water benthonic foraminifera species e.g. *Textularia panamensis*, *Quinqueloculina seminulum*, *Eponides eshira*, *Eponides* sp.

Inner Neritic

This is a subdivision of marine environment that lies within 0 – 20m on the continental shelf (Allen, 1965). According to Boersma, (1978) the inner neritic is usually characterized by coarse-grained, clean sand containing abundant rounded shell fragments; A few species usually dominate the benthic faunas; Tests are small and weakly ornamented. Agglutinated species with simple wall structure are common foraminifera. Common taxa are arenaceous forms (e.g. *Textularia* sp., *miliolids* (e.g. *Quinqueloculina*), *Nonion* sp., and *Ammonia beccarii*).

The ranges of intervals inferred to be inner neritic environment are 4,235 m – 4,107 m, 4,016 m – 3,924 m, 3,888 m – 3,851 m, 3,796 m – 3,778 m, 3,760 m – 3,741 m, 3,741 m – 3,668 m, 3,632 m – 3,559 m, 3,540 m – 3,485 m, 3,467 m – 3,447 m, 3,421 m – 3,414 m, 3,395 m – 3,376 m, 3,357 m – 3,351 m, 3,321 m – 3,303 m, 3,321 m – 3,303 m, 3,266 m – 3,211 m, 3,211 m – 3,156 m, 3,138 m – 3,120 m, 3,101 m – 3,083 m, 3,042 m – 3,024 m (Fig. 9). The inner neritic environments of the above intervals are characterized by the following;

1. Low species abundance and diversity of both planktonic and benthonic foraminifera
2. Presence of exclusively inner neritic benthonic foraminiferal species; *Quinqueloculina seminulum*, *Textularia panamensis*, *Textularia laminata*, *Ammonia beccarii* and *Ammonia* sp. (Bandy and Anal 1957; Bandy and Anal, 1960; Haywick and Henderson, 1999; Petters, 1995). The occurrence of the above mentioned species was also used by Bassey and Alalade, (2005) and Chukwu *et al*., (2012) to infer inner neritic environment of deposition in the Niger Delta Basin.
3. The occurrence of *Eponides eshira*, *Eponides* sp., *Epistominella vitrea*, *Fursenkoina punctata* which are considered to be fluvio marine to middle neritic species by Petters (1995).
4. *Lenticulina grandis* and *Lenticulina inomata* are considered to be characteristics of Inner neritic environment but they ranged up to outer neritic environment (Petters, 1995, Murray 2006). Okosun *et al*., (2012) used the presence of *Lenticulina grandis*, *Lenticulina inomata* to inferred inner neritic environment for sediments of Niger Delta Basin.

Inner Neritic – Middle Neritic

The environment of deposition here fluctuated from inner neritic to middle neritic. Benthonics foraminifera occurring within this environment include *Textularia* sp., *Ammonia beccarii*, *miliolids*, *Lenticulina* sp., *Eponides* sp. and *Nodosariids* (Boersma, 1978). Lithologically, it is composed of fine to medium grained sand, clays silts and some shale intervals (Chukwu, 2012).

Depth intervals of the study well that are inferred to belong to this environment are; 4,308 m – 4,272 m, 3,559 m – 3,540 m, 3,376 m – 3,357 m, 3,284 m – 3,266 m, 3,120 m – 3,101 m (Figure 9). Deposition in the Inner – middle neritic environment of the above intervals is suggested based on the occurrence of typical forms from inner and middle neritic environment. The inner neritic forms includes; *Textularia laminata*, *Quinqueloculina seminulum*, *Textularia panamensis* (Bandy and Anal 1957; Bandy and Anal, 1960; Haywick and Henderson, 1999; Petters, 1995) while *Eponides eshira*, *Eponides ornatus*, *Eponides* sp., *Fursenkoina punctata*, *Hanzawaia strattoni*, occurs in both inner and middle neritic environments (Petters 1995; Okosun *et al*., 2012). There is increase in the foraminiferal species abundance and diversity when compared with inner neritic intervals. *Bolivina tenuicostata* is considered as inner neritic to upper bathyal species (Murray, 2006).

Middle Neritic

This environment lies between 20 – 100m in the marine environment within the continental shelf (Allen 1965; Boersma 1978). Lithologically, it is composed of clay, silt, poorly sorted sands, and abundant glauconite. Large and robust species that are often highly ornamented are present. Species dominance is low and the number of species (diversity) is high. The planktic types constitute from 15 – 30% of the total fauna (Boersma, 1978). In the study well the %planktonics of the intervals inferred to be middle neritic ranges from 0 to 11.11. Common taxa are *Bolivina* sp., *Lenticulina* sp., *Uvigerina* sp., *Eponides* sp., *Nodosariids* and *Cibicides* sp.

This environment is recognized in the study well from the following intervals 3926 – 3888m, 3,741 m – 3,723 m, 3,303 m – 3,284 m (Figure 9). The criteria used for recognition of the middle neritic environment are the presence of *Brizalina mandoroveensis*, *Spiroloculina* sp., *Lenticulina grandis*, *Lenticulina inomata*, *Hopkinsina bononiensis* and *Eponides berthelotianus*. Petters (1995) consider *Brizalina mandoroveensis, Spiroloculina* sp. as middle neritic to upper bathyal species while *Lenticulina grandis*, and *Lenticulina inomata* range in terms of depth from inner neritic to outer neritic environment but dominate in the middle neritic environment. The presence of *Eponides eshira*, *Eponides* sp. *Hanzawaia strattoni* also suggest middle neritic environment (Petters, 1995) as they are not found beyond middle neritic environment. Chukwu *et al*., (2012) used the occurrence of *Hopkinsina bononiensis*, *Lenticulina inomata*, and *Spiroloculina* sp. to suggest middle neritic environment while Okosun *et al*., (2012) suggested the same environment based on the association of *Brizalina mandoroveensis*, *Uvigerina isidroensis*, *Uvigerina sparsicostata*, *Eponides* sp. and *Hopkinsina bononiensis*.

Middle Neritic – Outer Neritic

The intervals inferred to be middle neritic – outer neritic environment are 4,359 m – 4,308 m, 3,083 m – 3,043 m (Figure 9). Deposition in middle neritic – outer neritic water depth is suggested based on high abundance (65 to 131 individual per sample) of the foraminiferal species, presence of deep water benthonic foraminiferal species such as; *Bolivina tenuicostata*, *Brizalina mandoroveensis*, *Globobulimina ovata*, *Nonion centrosulcatum*, *Spiroloculina tenuis*, *Uvigerina sparsicostata* and *Heterolepa floridana*. The deep water benthonic foraminiferal species occur in association with inner to middle neritic species (i.e. they do not occur beyond middle neritic); *Eponides eshira*, *Eponides* sp., *Hanzawaia strattoni*, *Epistominella vitrea* and inner to outer neritic species (i.e. they do not occur beyond outer neritic); *Hopkinsina bononiensis*, *Lenticulina inomata* and *Lenticulina grandis*. Bandy and Anal (1960) reported the occurrence of *Hanzawaia*, *Epistominella* in the middle to outer shelf/neritic.

Outer neritic

This environment lies between 20m – 200m in the marine environment within the continental shelf (Allen 1965; Boersma 1978). The outer shelf is characterized by fine grained sediments such as clays and some glauconite. The abundance of the foraminiferal species is high and ornamentation is strong. Planktonics constitute approximately 50% of the faunas (Boersma, 1978). In this study P/B ratio is not used as proxy for palaeobathymetry because of poor abundance of the planktonic foraminiferal species in well – 004.

Sediments deposited in the outer neritic environment were observed from the following intervals 3,833 m – 3,796 m, 3,778 m – 3,760 m and 3,447 m – 3,432 m (Figure 9). Deposition in the outer neritic environments is suggested by: high abundance of the foraminiferal species (65 to 114 individual per sample); presence of planktonic foraminifera such as *Globigerinoides* sp. *Praeorbulina glomerosa*, *Catapsydrax stainforthi*; presence of deep water benthonic foraminifera species including *Uvigerina sparsicostata*, *Uvigerina isidroensis*, *Uvigerina* sp., *Brizalina mandoroveensis*; the presence of *Lenticulina grandis*, *Lenticulina inormata*, *Eponides berthelotianus* and *Hopkinsina bononiensis*, which are considered to be characteristics of Inner to outer neritic environment (Petters, 1995) and would appear to limit the intervals to no greater than outer neritic environment. Petters, (1995) reported the occurrences of *Hopkinsina bononiensis*, *Eponides berthelotianus*, *Uvigerina sparsicostata*, *Eponides berthelotianus* in outer neritic environment of the Nigerian rift and continental margin deltas. Bassey and Aladede (2005) used the presence of the above benthonic foraminifera species coupled with high P/B ratio and high foraminiferal species abundance to infer outer neritic environment. Gibson (2007) suggested outer neritic environment by the presence *Uvigerina* and *Lenticulina*. Bandy and Anal (1957) reported the occurrence of *Uvigerina* in outer shelf/neritic water depth off the coast of Central America.

Salinity

The general composition of the foraminiferal species in terms of wall structure of the study well is shown in Figure 10. Overall the calcareous hyaline component is the most abundant with 96 %, while Porcelaneous and Arenaceous with 2.3 % and 2.1 % respectively. The relative abundance and percentage of the suborders at each sample depth is shown in Figures 11 and 12 respectively.

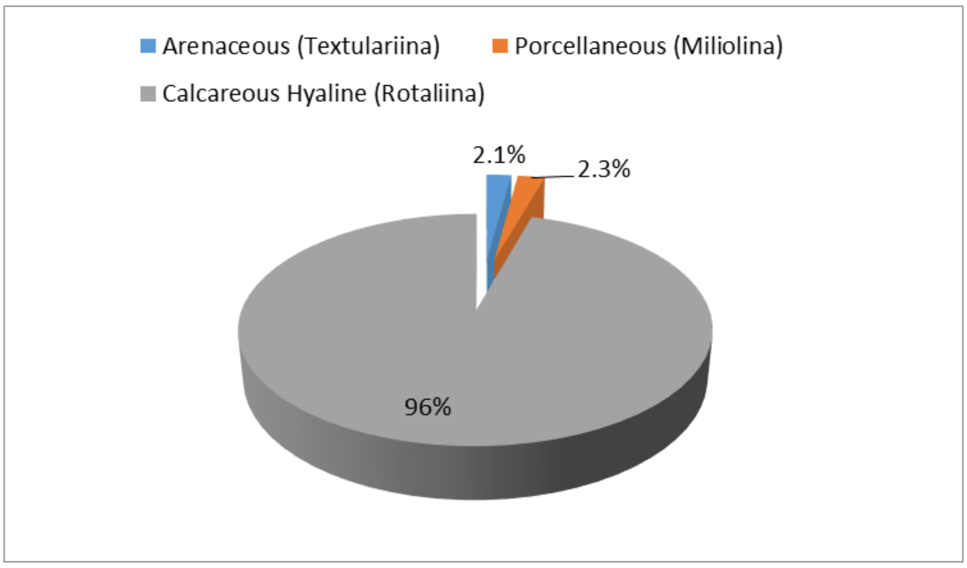


Figure 10. A pie chart showing percentages of the foraminiferal assemblages based on wall composition

The relative abundances of the foraminiferal suborders Textulariina (arenaceous), Miliolina (porcelaneous), and Rotaliina (hyaline calcareous) were plotted on triangular diagrams on which the composition or fields for recent marine environment are shown. The triangular plot is widely used for paleoenvironmental reconstruction (Petters, 1982). This is however only applicable for distinguishing brackish from hypersaline and normal marine environments (Murray 1973 and Murray 2006).The foraminiferal suborders ratio Textulariina (arenaceous), Miliolina (porcelaneous calcareous), and Rotaliina (hyaline calcareous) (Figure 13) reveals a dominance of hyaline calcareous. Comparison with modern microfauna suggests normal salinity conditions (Murray, 1991).

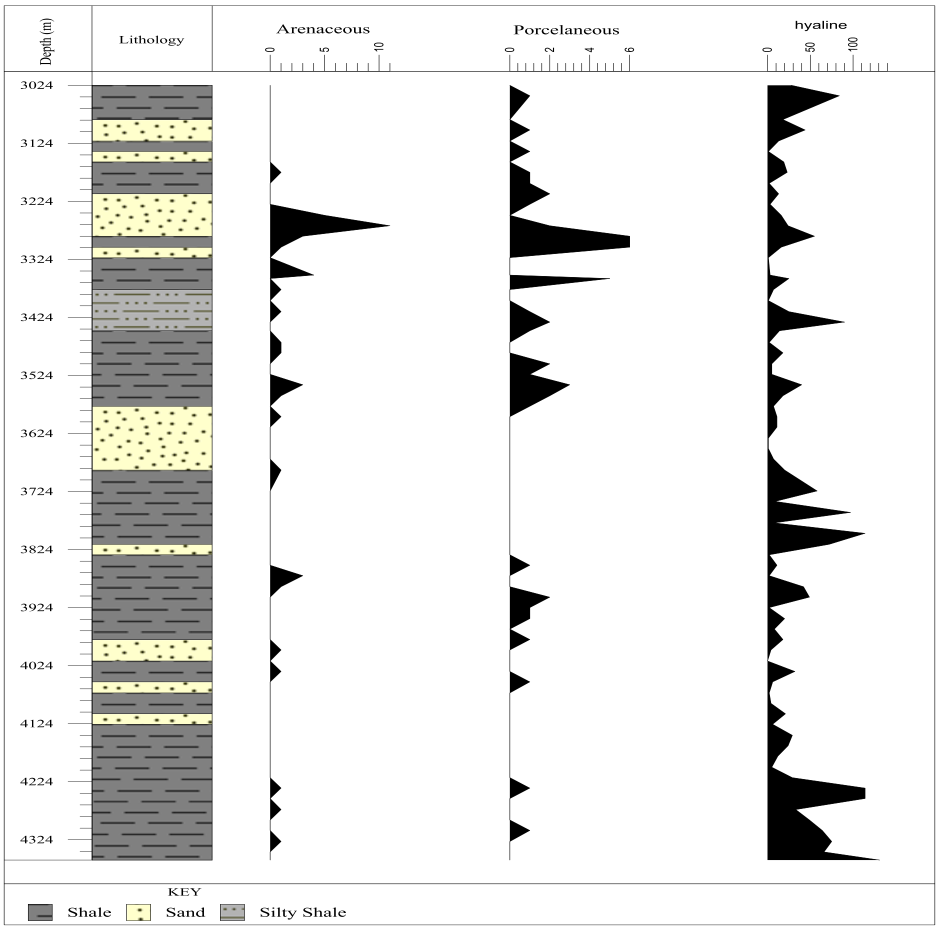


Figure 11. Relative abundances of the three foraminiferal wall composition types at each depth

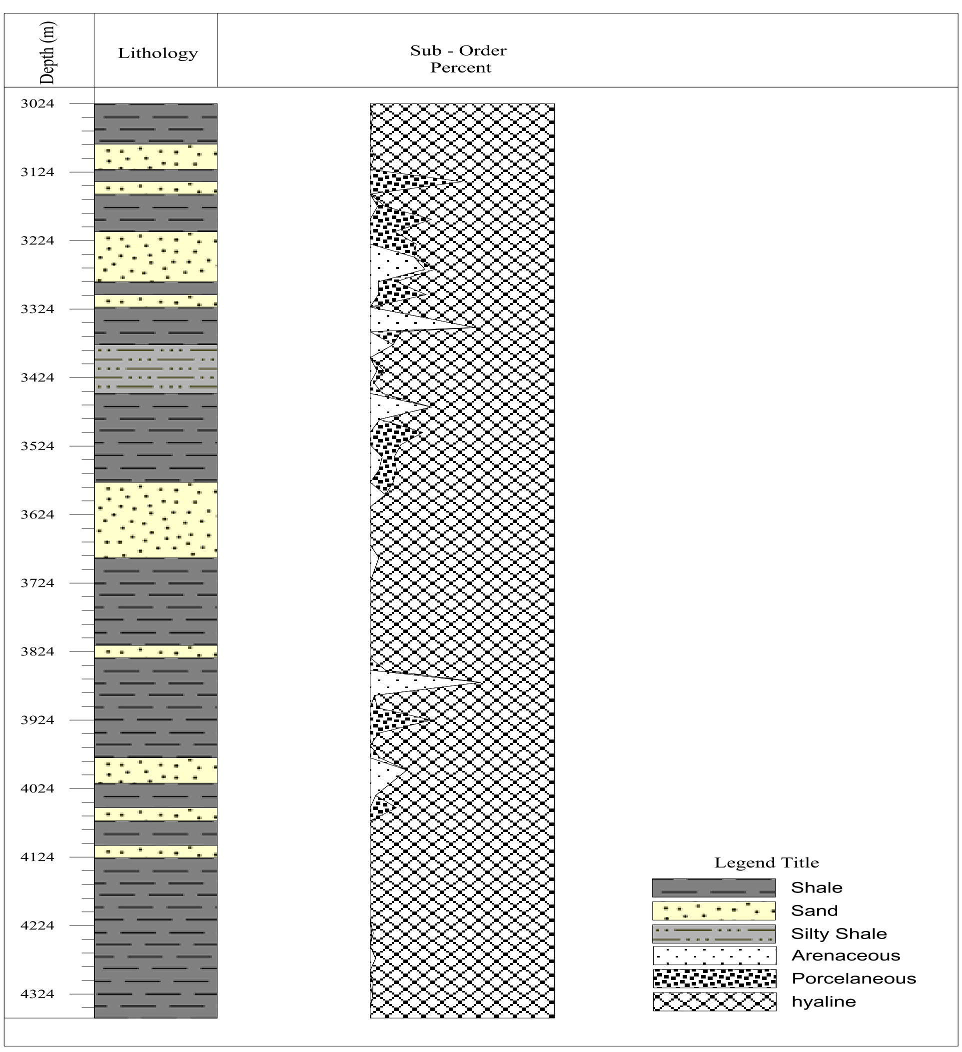


Figure 12. Relative Percentages of the three foraminiferal wall composition types at each depth

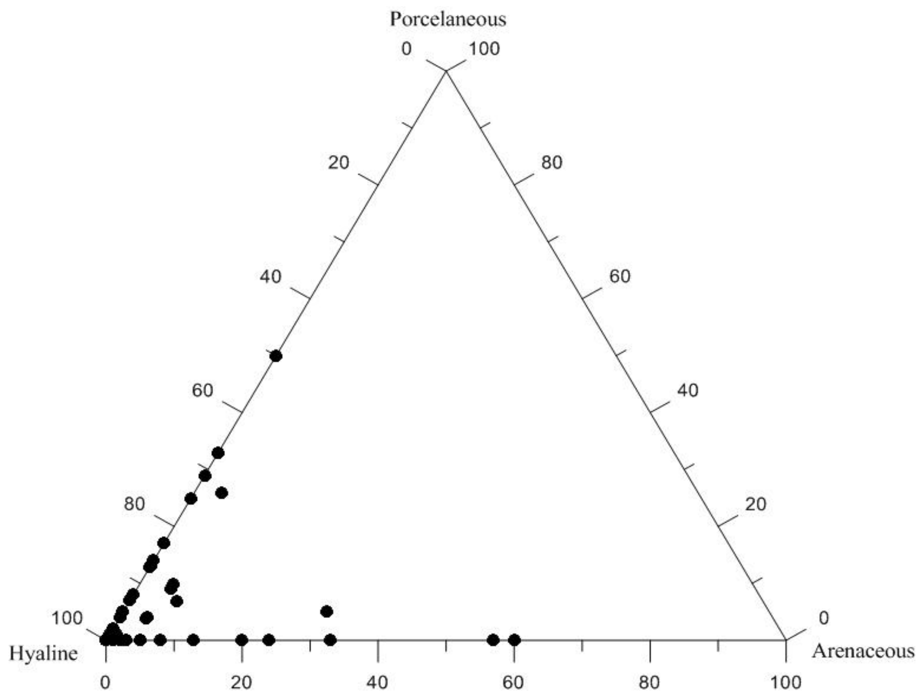


Figure 13. Triangular plot of the ratio of the three suborders showing dominance calcareous hyaline.

Oxygen

Van der Zwaan *et al.* (1999) concluded that it would be preferable to use planktonic/benthonic (P/B) ratios, or the percentage planktons in a total foraminiferal assemblages, as quantitative markers of depth. Earlier Bandy and Arnal (1960) assigned an outer shelf to upper bathyal zone to the southern end of the San Joaquin Basin, California based on the occurrence of >50% planktics (0.5 P/B ratio). However, the most sensitive applicability of the P/B ratio is the identification of oxygen deficiency (Van der Zwaan, *et al.*, 1999; Van Hinsbergen, *et al.*, 2005; Lowery *et al.*, 2014). Anoxic condition can be identified by the absence of the benthic foraminifera (particularly calcareous benthics) and the high occurrence of planktics (high P/B ratios) (Echer and Worstell, 1970; Kaiho, 1994; Van der Zwaan *et al.*, 1999). Van Hinsbergen, *et al.*, (2005) suggested that P/B ratio can only be used as proxy for bottom water oxygenation in environment prone to dysoxia.

Planktonic foraminifera have been recovered from the study well with poor abundance (0 – 6 count per sample) and diversity (0 – 5 species per sample) (Figure 14). In this study P/B ratios, i.e. the percentages of planktonic foraminifera in the total foraminiferal assemblages was calculated using $\%P = P/(P+B) * 100$. The result shows that the P/B ratio ranges from 0% to 33.33% with most frequent values of 0 to 14%.

Based on low P/B ratio (0% – 33.33%) and dominance of foraminiferal taxa that are prone to dysoxia (e.g. *Bolivina*, *Bulimina*, *Brizalina*, *Globobulimina*, *Lenticulina*, *Uvigerina*, and *Hopkinsina*) well – 004 sequence was interpreted as deposited in dysoxic to oxic condition (Fig. 14). Abubakar, (2006) interpreted low P/B ratio (10% – 30%), as dysoxic to oxic in the Pindiga Formation Upper Benue Trough. The high abundance and diversity of benthonic foraminifera as compared to planktonic is another evidence that the well sequence is not deposited in anoxic condition but rather dysoxic to oxic conditions (Fig. 14) because sediments that were deposited in anoxic condition are characterized by the absence of benthonic foraminifera and abundance of dwarf planktonic foraminifera (Petters, 1982).

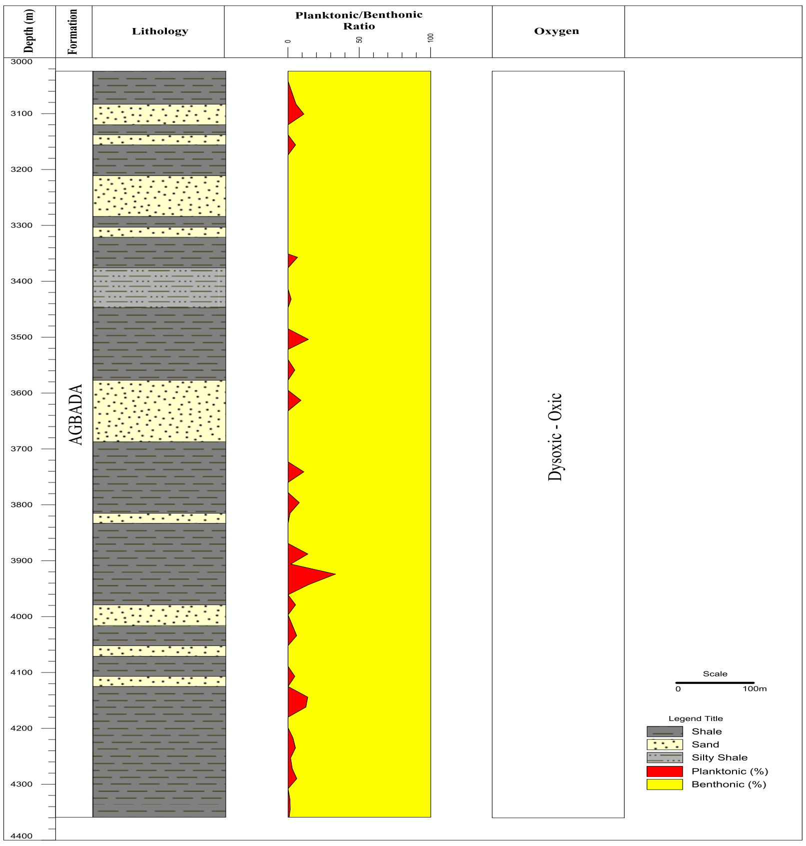


Figure 14: Planktonic/Benthonic ratios and Oxygen deficiency horizons in the study well

Conclusion

The planktonic foraminiferal species recovered from the study well suggest Late – Oligocene to Early – Middle Miocene. The boundary of Oligocene and Miocene was picked at 4,327 m based on the first downhole occurrence (FDO) of Oligocene species *Globigerina ciperoensis* and occurrence of *Globigerinoides* ssp. above the FDO of the Late – Oligocene index species.

On the basis of the planktonic foraminiferal species, biozones from *Globigerina ciperoensis* - *Globorotalia opima nana* Interval zone (P22/N3) to *Catapsydrax stainforthi* - *Praeorbulina sicana* Interval zone (N8 – N9) have been identified. Biostratigraphic zonal boundaries are determined on the first downhole occurrence (FDO) and last downhole occurrence (LDO) of the index taxa. The sediments in the study well are deposited in neritic region with normal salinity and dysoxic – oxic conditions.

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