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FORAMINIFERA BIOZONATION OF WELLS "AMAMA-1 WELL" AND "BARA-1 WELL" OF THE CAMPANIAN – MAASTRITCHIAN AGES IN THE ANAMBRA BASIN

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ABSTRACT

The study aims at Delineation of Biostratigraphic Zones based on recovered index fossils and/or diagnostic fossil assemblages of sedimentary strata penetrated by Wells "Amama-1 Well" and "Bara-1 Well" of the Campanian – Maastritchian ages of the Anambra Basin. . The two study wells are located in the Anambra Basin with geographic co-ordinates of latitudes 6°10' to 6°22'N and longitude 7°02' to 7°16' E. The scope of this study involves the evaluation of the Well analysis and biostratigrapical analysis of the samples. It covers an area of the Nkporo Group from Abia, Nkporo, Ajali and Mamu, Agbogwugwu, Enugu, Emene and Ikem-Uruaram in Enugu State. The results of the Biostratigraphic study have shown that the sediments encountered in the analysed intervals of Wells A and B penetrated the Late Campanian through Late Maastrichtian to Early Paleocene (Danian) age. Two biozones were recognized from Well A namely: Biozone A-Globotruncanella havanensis zone: Late Campanian – Maastrichtian (695 – 1829m), Biozone B-Morozovella velascoensis zone:Early Paleocene (165 – 695m), while three biozones were recognized from Well B belonging to Biozone A-Globotruncanella havanensis zone: Late Campanian (1512m), Biozone B-Bolivinaafra, B. explicate zone: Maastrichtian (634 – 1204m), Biozone C- Indeterminate (305 – 634m). Paleoenvironmental interpretation of the sections of the Anambra Basin penetrated by the study wells indicated that the sediments were deposited in Non-Marine to Outer Neritic paleo-water depths as flood plain, distributary channel, interdistibutary bay as well as Distal bay facies.

Keywords: Foraminifera, Biozonation, Wells, Campanian, Maastrichtian, Anambra Basin

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INTRODUCTION

The Anambra Basin has been identified as one of the major inland sedimentary basins in Nigeria (Agagu et al, 1985) and has been described by many authors either on the basis of its sedimentological or biostratigraphic attributes. It is a Cretaceous Basin with a total sediment thickness of about 9km. The roughly triangular shaped basin covers an area of about 40,000 sq. km, and is located in south-central part of Nigeria (Nwajide, 2006).

The Basin is dominantly filled with clastic sediments constituting several distinct lithostratigraphic units ranging from Upper Campanian to Recent in age. The lithostratigraphic units have a thickness of up to 2500m and consist of Nkporo Shale, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Shale, Ameki Formation, Nanka Sands, and Ogwashi-Asaba Formation (Reyment, 1965).

The stratigraphy of the Campano-Maastrichtian Anambra Basin consists of the Nkporo Group (Nkporo/Enugu/Owelli Formation), Mamu Formation, Ajali Sandstones and the Nsukka Formation which is believed to have terminated sedimentation of the Anambra Basin (Nwajide, 2005).

The Enugu and the Nkporo Shales represent the brackish marsh and fossiliferous pro-delta facies of the Late Campanian-Early Maastrichtian depositional cycle (Reijers and Nwajide, 1998). Deposition of the sediments of the Nkporo/Enugu Formations reflects a funnel-shaped shallow marine setting that graded into channeled low energy marshes and accumulated during the regression of the Nkporo cycle (Obaje, 2009). However, the Mamu Formation occurs as a narrow strip trending north–south from the Calabar Flank, swinging west around the Ankpa plateau and terminating at Idah near the River Niger. It is made up of different lithologic units which include shales, siltstones, sandstones and coal. The shales of the Mamu Formation are generally interbedded with chamositic carbonates and overlain by bioturbated siltstones, sandstones and coal units in coarsening upward cycles towards the north (Akande *et al*, 1992). However, the coal deposits of the Mamu Formation are of fluvio-deltaic to fluvio-estuarine environments. Overlying this is the Ajali Formation and the Nsukka Formation of Middle – Late Maastrichtian age. The Ajali Formation is characterized by unconsolidated to poorly consolidated sandstones with thin siltstone interbeds that exhibit profuse cross-bedding; and marks the height of the overall regression in this epoch. The Nsukka Formation on the other hand, consists of dark shale, sandstones, with thin coal seams (Nwajide and Reijers, 1996), marking the beginning of the transgression that led into the formation of the Niger delta basin in the Early Paleogene. The post-Santonian sea level movement was transgressive, and lasted well into the Maastrichtian while the succeeding regression ended in the Danian.

The study aims at Delineation of Biostratigraphic Zones based on recovered index fossils and/or diagnostic fossil assemblages of sedimentary strata penetrated by two wells of the Campanian – Maastritchian ages of the Anambra Basin.

Location of the study area

The two study wells are located in the Anambra Basin with geographic co-ordinates of latitudes 6°10′ to 6°22′N and longitude 7°02′ to 7°16′ E as shown on the map below (Figure 1).

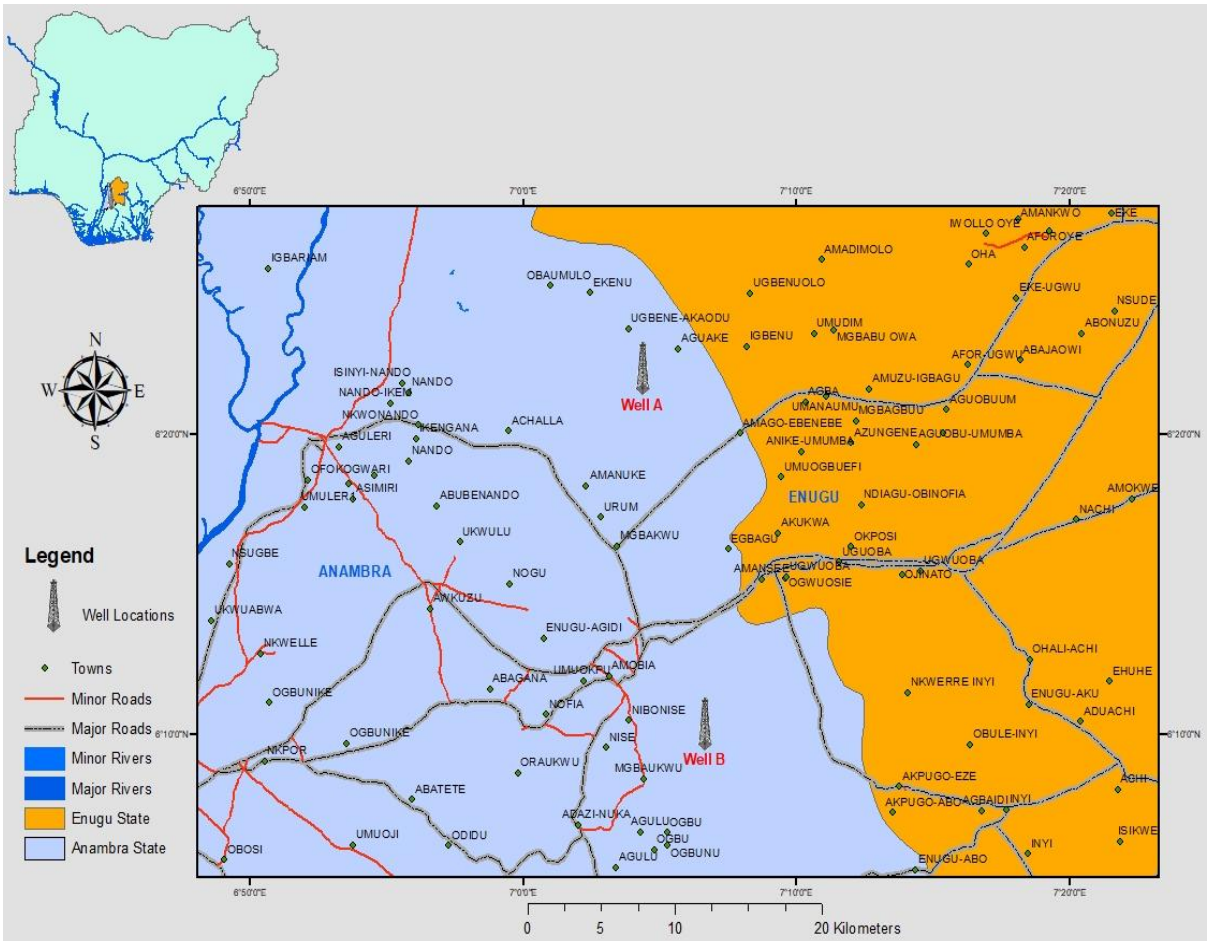


Figure 1. Map of the study area showing Location of the wells used in this study (Modified NGSA, 2004)

METHODOLOGY

Micropaleontological Standard Processing Procedures

The samples are variously composited at intervals varying from 5 - 20m for foraminiferal investigation for high resolution purposes.

The ditch cutting samples were subjected to standard laboratory procedures (Armstrong and Brasier, 2005) where samples were soaked overnight in Anhydrous Sodium Carbonate (Na_2CO_3) to disaggregate the clays, washed using a 63µ sieve, and collected on filter paper.

Thereafter, the samples were dried in an oven at a room temperature. The dried samples were further separated into three (3) size fragments; that is, coarse, medium and fine fragments for easy picking. Each size fragment sample is spread evenly in a picking tray and viewed under the binocular microscope following grid pattern on the tray in a rhythmic pattern. All relevant fossil faunas are picked with aid of a wet brush and stored in a well-labelled slide.

Foraminiferal Micropaleontology Analysis

The picked faunawere subjected to species identification using standard manuals Petters, (1979, 1982), Bolli and Saunders, (1985), Adegoke *et al*, 2017, etc. Subsequently, the abundance and diversity counts were recorded. Also, photomicrographs of significant foraminiferal taxa are documented as Plates.

Age determination and microzonation of the wells were based on the careful use of First Downhole Occurrences (FDO) as well as Last Downhole Occurrences (LDO) of age diagnostic planktic and benthic foraminiferal species. Also, known age diagnostic benthic foraminiferal assemblages were used where possible

RESULTS

Fossil Distribution In Amama-1 Well

The microfaunal distribution of the well shows an uneven distribution and composition (Figure. 4.3). It appears to be a progressive increase in the abundances and diversities of microfauna from the base to the top, so there is a variation of the forms from one formation to the other. These changes in diversity and dominance of microfauna, particularly foraminifera tend to indicate shifting depositional environment with time. For example, from (Figure 4.3), showing the foraminiferal ecological distribution chart, the percentage of the assemblage benthonics with those of the calcareous test dominated the assemblage followed by those with agglutinated test and planktonics are very scanty in their distribution. The basal interval (Nkporo Shale), there is a general increase in diversity but a decrease in abundance of microfauna. This interval recorded very few calcareous benthonic forms, few macro fossils which were mostly poorly preserved.

The middle interval is comprised of the Mamu Formation between 1152m to 1573m and it is dominated by poorly preserved agglutinated forms. There appears to be a general decrease in diversity and abundance. This interval is barren of plantonic foraminifera.

The upper interval which comprised the Ajali Formation is generally marked by paucity of microfauna and also devoid of any planktonic specie.

The Nsukka Formation overlies that of the Ajali Sandstone and corresponds to the interval between 622m to 1152m, there appears to be a sudden increase in the diversity and abundance of the benthonic forms with few planktonic forms occurring at the top within the interval. The bulk of the foraminifera assemblage is the calcareous benthonics forms. Beginning from the base between 622m to 1152m. There is a general increase in the benthic foraminiferal forms.

Fossil Distribution in Bara-1 Well

The well B penetrated four major lithostratigraphic units. The Nkporo Formation, Mamu Formation, Ajali Sandstones, and the Nsukka Formation. The microfaunal distribution shows an uneven distribution (Figure. 4.4). It appears to be a progressive increase in the abundances and diversities of microfauna from the base to the top, so there is a variation of the forms from one formation to the other. These changes in diversity and dominance of microfauna, particularly foraminifera tend to indicate shifting depositional environment with time. For example, from (Figure 4.4), showing the foraminiferal ecological distribution chart, the percentage of the assemblage benthonics with those of the calcareous test dominate the assemblage followed by those with agglutinated test and planktonics are very scanty in their distribution. The basal interval (Nkporo Shale), there is a general increase in diversity but a decrease in abundance of microfauna. This interval recorded very few calcareous benthonic forms, few macro fossils which were mostly poorly preserved.

The middle interval is comprised of the Mamu Formation between 591 m to 878m and it is dominated by poorly preserved agglutinated forms. There appears to be a general decrease in diversity and abundance. This interval is barren of plantonic foraminifera.

The upper interval which comprised the Ajali Formation is generally marked by paucity of microfauna and also devoid of any planktonic specie.

The Nsukka Formation overlies that of the Ajali Sandstone and corresponds to the interval between384m to 591m, there appears to be a sudden increase in the diversity and abundance of the benthonic forms with few planktonic forms occurring at the top within the interval. The bulk of the foraminifera assemblage is the calcareous benthonics forms. Beginning from the base between 384 m to around 591 m. There is a general increase in the benthic foraminiferal forms.

DISCUSSION

Foraminiferal Zonation for Amama-1 Well

This study utilized the basis of the first and last stratigraphic occurrence (Last downhole occurrence and first downhole occurrence respectively), the biozones were deliminated base on the first appearances of two or more species (Table 1).

Biozone A-Globotruncanellahavanensis zone: Late Campanian – Maastrichtian (695 – 1829m)

The occurrences of *Haplophragmoides sahariense, H. saheliense, H. hausa, H. talokaense, Spiroplectam minahausorum, Ammobaculites coprolithiformis, A. amabensis, Miliammina onyeamensis, M. petila, M. telemaquensis, M. tsogaensis,* in association with *Bolivinaafra, B. explicata, Praebulimina opima, P. robusta and Nonionella cretacea* are typical of the Late Campanian – Maastrichtian (Petters, 1979, 1982).

The single occurrence of *Globotruncanella havanensis* at 1512m (if *in-situ*), is an indication of the penetration of sediments of this zone (Late Campanian – Late Maastrichtian age). This planktic species occurs in the Late Campanian – Late Maastrichtian (Hardenbol, *et al*., 1998).The F1700 Zone is an equivalent of the KS28 – KS31 planktic zone (Sliter, 1989); of a Late Cretaceous epoch / Late Campanian – Maastrichtian age on a global scale (Hardenbol, *et al*., 1998).

Biozone B-Morozovella velascoensis zone:Early Paleocene (165 – 695m)

The single occurrence of *Morozovella spp* at 219m, is an indication of the penetration of this zone. This planktic genus is not known to occur in sediments older than the Paleocene (Tourmakine and Lutherbacher, 1975).

The occurrences of *Ammobaculites excavata, A. coprolithiformis, Anomalinoides midwayensis, A. umboniferus, Cibicides succedens, Planulina nacatochensis, Elphidiella africana, Eponides elevatus, E. pseudo elevatus, Gavelinella danica, G. guineana* and *Lenticulina midwayensis* constitute the foraminiferal assemblage in this interval and affirm a Paleocene Epoch (Petters, 1982).Also, the FDO of *Ammobaculites coprolithiformis* at 274m is an indication of the Paleocene; as this taxon is not known to be younger than the Paleocene. Adegoke *et al*., 2017, indicate that this taxon ranges from Maastrichtian – Paleocene. This F3100 zone as defined by Dim *et al*. (2017) is an equivalent of the P1 planktic zone of Sliter (1989); an Early Paleocene epoch / Danian age on a global scale (Hardenbol, *et al*., 1998).

Table 1: Biozonation and Age interpretation of Well Amama-1 Well

Depth Interval	Epoch / (Age)	Foram Zone (Present study)	Foram. Zones (Dim, et al., 2017) / Equivalent Planktic Zone (Sliter, 1989)	Foram. Events
165 – 695m	Early Paleocene (Danian)	Morozovella velascoensis	F3100 / (P1)	-Single occurrence: *Morozovella spp* at 219m -FDO: *Ammobaculite scoprolithiformis* at 274m -Top occurrences of *Haplophragmoides sahariense, H. saheliense and Spiroplectam minahausorum* at 695m
695 – 1829m	Late Cretaceous (Late Campanian – Maastrichtian)	Globotruncanella havanensis	F1700 / (KS28 – KS31)	-Single occurrence: *Globotruncanella havanensis* at 1512m

Foraminiferal Zonation for Bara-1 Well

Foraminiferal recovery was low to moderately high; with a significant barren interval in the upper section. Benthic taxa are predominant with a few planktic taxa. A summary of the interpretation indicating the age and biozones encountered in the analysed interval of the Well are presented in the Table 2.

Biozone A-Globotruncanella havanensis zone: Late Campanian (1512m)

Single occurrence of *Globotruncanella havanensis* at 1512m marked the penetration of this zone. The co-occurrences of *Ammodiscus kiowensis, Haplopragmoides hausa, Anomalinoides midwayensis, A. madrugensis, Bolvina afra, Planulinanacatochensis, Praegublerinarobusta* and *Nonionellacretacea* define the foraminiferal assemblage in this interval.

The regular and abundant occurrences of *Globotruncaellahavanensis*to the base of this interval, is an indication that this foraminiferal zone is not older than the Late Campanian. The LDO of this planktonic taxon is recorded in the Late Campanian (Hardenbol *et al*., 1998).

This F1700 foraminiferal zone of Dim *et al*, 2017 is an equivalent of the KS28 – KS30 of Sliter, 1989; calibrated as Late Campanian age on a global scale (Hardenbol, *et al*, 1998).

Biozone B-Bolivinaafra, B. explicatazone: Maastrichtian (634 – 1204m)

The Co-occurrences of *Globotruncanella havanensis* in association with *Bolivina afra, B. explicata* and *Textularia hockleyensis* from 634m and within the interval and the LDOs of *Textularia hockleyensis* and *Miliammina telemaquensis* at 1204m defines this biozone.

The co-occurrences of *Bolivina afra, B. explicata, Gabonitalata, Anomalinoides midwayensis, Cibicides succedens, C. H arperi, Textularia hockleyensis, Miliammina telemaquensis, Haplophragmoides excavata, H. saheliense* etc define the foraminiferal assemblage in this interval (Petters, 1982).

The LDOs of *Textularia hockleyensis and Miliammina telemaquensis* at 1204m were used to mark the base of this foraminiferal zone. These two arenaceous taxa define the Late Campanian / Maastrichtian boundary (Petters, 1982).

The age of this interval is dated Early – Late Maastrichtian by calibration to the global time scale of Hardenbol, *et al*; 1998.

Biozone C- Indeterminate (305 – 634m)

This interval is completely barren of foraminifera and other ancillary microfossils. Therefore, neither the biozones nor the chronology of the sediments in this interval could be evaluated.

Table 2: Biozonation and Age interpretation of Bara-1 Well

Depth Interval	**Epoch (Age)**	**Foram Zone (This study)**	**Foram. Zones (Dim, et al., 2017) / Equivalent Planktic Zone (Sliter, 1989)**	**Foram. Events**
305 – 634m	Indeterminate	Indeterminate	Indeterminate	-Interval completely barren of Foraminifera
634 – 1204m	Late Cretaceous (Maastrichtian)	Bolivina afra, B. explicate	F1700 / (KS30 – KS31)	-Co-occurrences of *Globotruncanella havanensis* in association *with Bolivina afra, B. explicata and Textularia hockleyensis* from 634m and within the interval -LDOs of *Textularia hockleyensis* and *Miliammina telemaquensis* at 1204m
1204 – 1478m	Late Cretaceous (Late Campanian)	Globotruncanella havanensis	F1700 / (KS28 – KS30)	-Single occurrence: *Globotruncanella havanensis* at 1512m

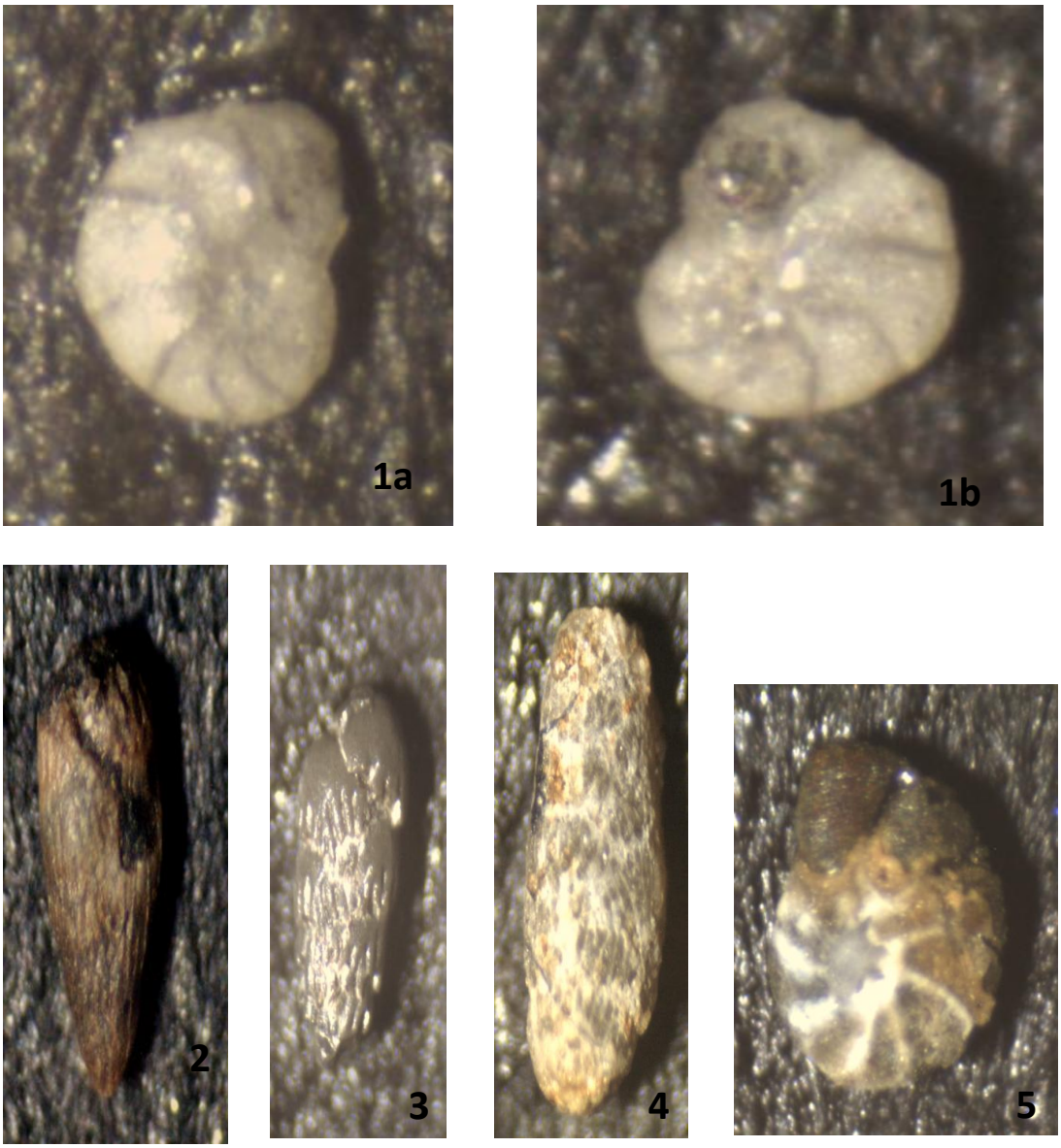


Fig 2. Photomicrograph of recovered formainiferas in the wells (1a-b) *Anomalinoides midwayensis (*PLUMMER, 1926) (a) Spiral view (x300) (b) Umblical view (x300). (2) Bolivina afra (REYMENT, 1959) Side view (x400) (3) *Bolivina explicata (*CUSHMAN & HEDBERG, 1930) Side view (x300) (4) *Uvigerina havanensis (*CUSHMAN & BERMUDEZ, 1936) Side view (x200) (5) *Cibicides succedens (*BROTZEN, 1948) Umblical view (x300)

Paleoenvironmental Analysis of Amama-1 Well

Paleoenvironmental characterization of Amama-1 Well was based on the lithological, microfauna and flora properties. The basal interval of the well is composed of shale, and shale and sandstone intercalations. This suggested deposition in low energy environment such as intertidal zones and swampy environment (Petters 1983). This interval is dominated by arenaceous benthic foraminifera and spares occurences of macrofossils like ostracodes and gastropods. Planktonic foraminifera are completely barren of this interval. This shows deposition in a nearly shore environment, example lagoons and estuariene environment. The middle intervals also lack the calcerous benthics but dominated by the arenaceous forms and spares occurrence of planktonic foraminifera. The upper interval which is made of shales in

the upper units is dominated by benthonc foraminifera of both the arenaceous and calcerous group. The lower units are made up of am alternation of shale and sandstone unit. This interval also contains remains of macrofossils like ostracodes and gastropods. This shows deposition in a littoral to sublittoral environment. A plot of foraminiferal population/diversity aided this interpretation (Figure 3). During the Maastrichtian there was an episodic warm depositional environment with a restricted bottom condition. These anoxic conditions were probably caused by the abundant supply of organic matter from the land, and poor circulation which resulted to a stagnant bottom water condition in the transgressive Campano-Maastrchtian sediments of the Nkporo Formation and the regressive Maastrichtian Mamu Formation (Akaegbobi and Boboye 1999). The Nsukka Formation marks the onset of another Transgression in the Paleocene and within a shallow environment. Foraminifera like *Haplophragmoides* and *Textularia* indicate a warm shallow marine environment. The rarity of planktic foraminifera and the dominance of argillaceous sediments in the Well section also indicate a shallow nearshore environment (Mode, 1991). Foraminiferal analysis results reveal that the study area is rich in benthic forams, but devoid of planktics. The absence of planktic foraminifera in the samples may attest to shallow and probably harsh ecologic factors (Agagu *et al*., 1985). Ammobaculites is an infaunal deposit feeder that lives in muddy sediments with brackish to normal-marine salinities from marsh to bathyal environments. It also tolerates low oxygen levels. This genus is present in all niches of modern seas (Murray, 1991). *Haplophragmoides* is a probable infaunal, detritivore that is commonly found in muddy to sandy substrates in environments ranging from marsh to bathyal. It is a primarily marine genus but has also been reported from hyposaline lagoons and estuaries. Miliammina inhabits a wide range of environments from brackish to hypersaline marshes to upper bathyal depths. It is an infaunal deposit feeder that settles in muddy and silty sediments. Textularia species inhabit normal marine environments ranging from lagoonal to bathyal. They live epifaunally on hard substrates, muddy silts, and sands (Murray, 1991; Bronnimann *et al*., 1992). Haplophragmoides saheliense is an index of Campanian-Maastrichtian age (Petters 1982). Nonionella is an infaunal, probable detritivore, dwelling in muds of marine waters. The genus occurs from inner shelf (inner neritic) to upper bathyal depths (Murray, 1991;). Foraminiferal characteristics indicates **shallow marine** environment of deposition for the Mamu and Nkporo Formations.

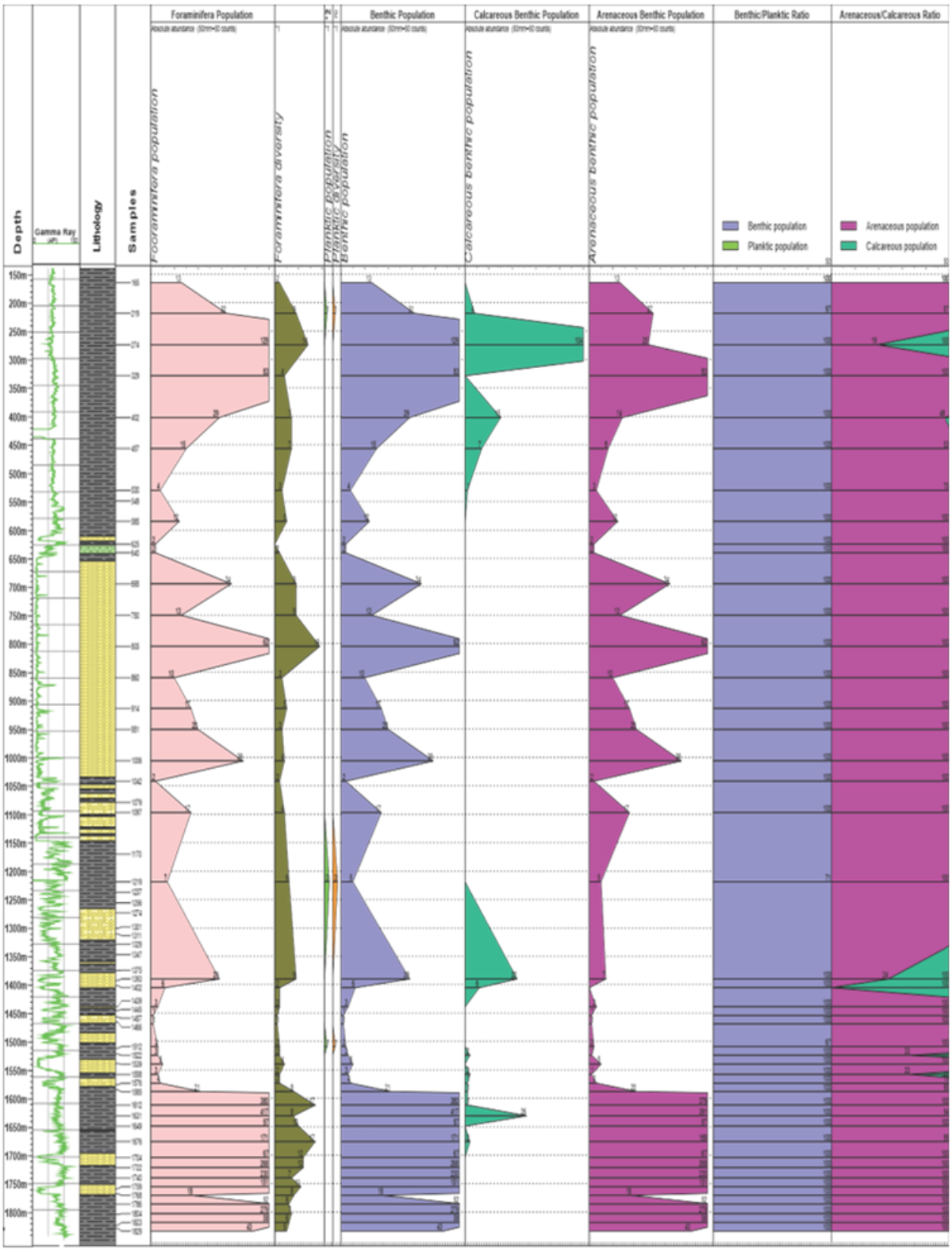


Figure 3. Foraminifera Diversity/Population plot of Well Amama-1 Well

Paleoenvironmental Analysis of Bara-1 Well

Paleoenvironmental characterization of Bara-1 Well was based on the lithological, microfauna and flora properties. The basal interval of the well is composed of shale, while the upper units are made of an alternation of shales and sandstones and sandstones interval. The upper units are mostly barren of Foraminifera while the basal units are dominated by the

bethic foraminifera (Table 2). This suggested deposition in a non marine environment for the upper units and a low energy environment such as intertidal zones and swampy environment for the lower units (Petters 1995). The basal interval which is made of of shales is dominated by benthonc foraminifera of both the arenaceous and calcerous group. This interval also contains remains of macrofossils like ostracodes and gastropods. This shows deposition in a littoral to sublittoral environment. A plot of foraminiferal population/diversity aided this interpretation (Figure 4). During the Maastrichtian there was an episodic warm depositional environment with a restricted bottom condition. These anoxic conditions were probably caused by the abundant supply of organic matter from the land, and poor circulation which resulted to a stagnant bottom water condition in the transgressive Campano-Maastrchtian sediments of the Nkporo Formation and the regressive Maastrichtian Mamu Formation (Akaegbobi and Boboye 1999). The Nsukka Formation marks the onset of another Transgression in the Paleocene and within a shallow environment. Foraminifera like *Haplophragmoides* and *Textularia* indicate a warm shallow marine environment. The rarity of planktic foraminifera and the dominance of argillaceous sediments in the Well section also indicate a shallow nearshore environment (Mode, 1991). Foraminiferal analysis results reveal that the study area is rich in benthic forams, but devoid of planktics. The absence of planktic foraminifera in the samples may attest to shallow and probably harsh ecologic factors (Agagu *et al*., 1985). Ammobaculites is an infaunal deposit feeder that lives in muddy sediments with brackish to normal-marine salinities from marsh to bathyal environments. It also tolerates low oxygen levels. This genus is present in all niches of modern seas (Murray, 1991). *Haplophragmoides* is a probable infaunal, detritivore that is commonly found in muddy to sandy substrates in environments ranging from marsh to bathyal. It is a primarily marine genus but has also been reported from hyposaline lagoons and estuaries. Miliammina inhabits a wide range of environments from brackish to hypersaline marshes to upper bathyal depths. It is an infaunal deposit feeder that settles in muddy and silty sediments. Textularia species inhabit normal marine environments ranging from lagoonal to bathyal. They live epifaunally on hard substrates, muddy silts, and sands (Murray, 1991; Bronnimann *et al*., 1992). *Haplophragmoides saheliense* is an index of Campanian-Maastrichtian age (Petters 1982).Nonionella is an infaunal, probable detritivore, dwelling in muds of marine waters. The genus occurs from inner shelf (inner neritic) to upper bathyal depths (Murray, 1991; Sliter and Baker 1972). Foraminiferal characteristics indicates **shallow marine** environment of deposition for the Mamu and Nkporo Formations.

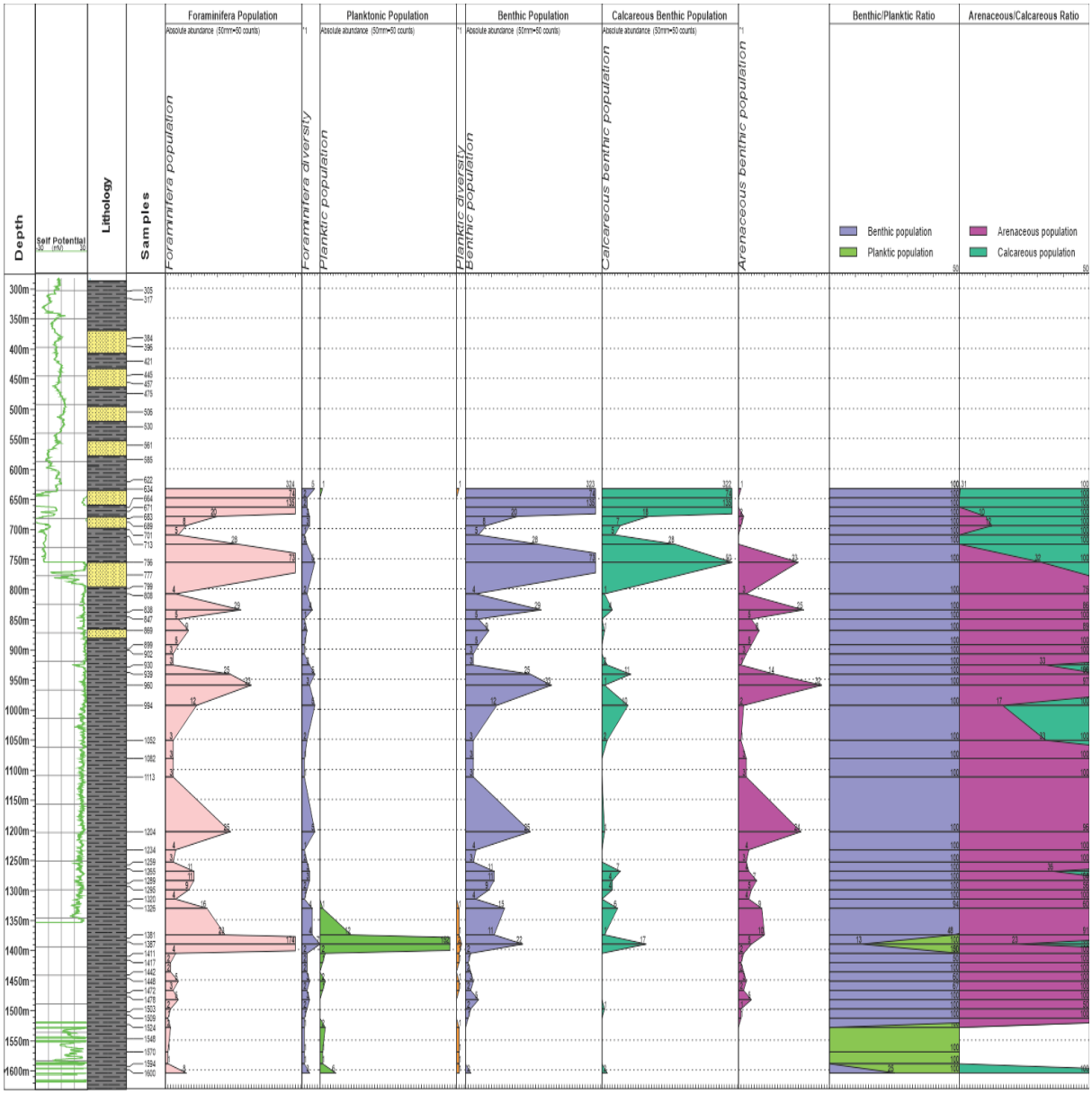


Figure. 4. Foraminifera Diversity/Population plot of Bara-1 well

CONCLUSION

The results of the Biostratigraphic study have shown that the sediments encountered in the analysed intervals of Wells A and B penetrated the Late Campanian through Late Maastrichtian to Early Paleocene (Danian) age. A total of five biozone (two from Amama-1 well and 3 from Bara-1 Well) were recognized in the study area. Paleoenvironmental interpretation of the sections of the Anambra Basin penetrated by the study wells indicated that the sediments were deposited in Non-Marine to Outer Neritic paleo-water depths as flood plain, distributary channel, interdistributary bay as well as Distal bay facies.

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