

FORAMINIFERA BIOSTRATIGRAPHY AND PALEOENVIRONMENT OF SEDIMENTS FROM WELL AM-2, NIGER DELTA.

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ABSTRACT

Ditch cutting samples from depth interval 1440 – 2720 metres in Well AM-2, onshore Niger Delta were studied for their lithology and foraminiferal content with the aim of determining the age and paleoenvironment of the strata penetrated by the well. Standard foraminiferal preparation technique involving sample disaggregation and washing through a 63 micron mesh sieve, drying and picking of the foraminifera and accessory fauna were employed. The well sequence penetrated the alternating sand and shale sequence of the Agbada Formation at the upper part, while the predominantly shaly lower part corresponded to the Akata Formation. A Middle - Late Eocene age was assigned to the strata penetrated by the well based on age diagnostic planktic foraminifera species including *Globigerina eocaena*, *Pseudobastigerina micra*, *Hastigerina cf. bolivariana*, *T. cerroazulensis cerroazulensis*, *T. pseudomayeri* and *T. cerroazulensis pomeroli*. The occurrence of the benthic foraminiferal species – *Hopkinsina bourqi* and *Nonion oyae* which were characteristic species for the Middle to Late Eocene in the Niger Delta also supported the assigned age to the well section. Four informal benthonic foraminiferal assemblage zones - *Altistoma tenuis* zone, *Eponides africana* zone, *Uvigerina peregrina/Lenticulina grandis* zone, *Bolivina ihuoensis/Hopkinsina bourqi* zone corresponding to the P12, P13/P14, P15 and P16 and younger planktic foraminiferal zones were erected for the studied interval of the well. The four major Condensed Sections identified had been dated 35.9 Ma, 36.8 Ma, 38.0 Ma and 39.4 Ma. Paleoenvironmental interpretation based on recovered benthic foraminiferal association revealed that the sequences were deposited in the Inner to Middle Neritic environments.

Keywords: Foraminifera, Eocene, Neritic, Paleoenvironment, Niger Delta.

INTRODUCTION

Several biostratigraphic studies have been carried out in the onshore and shallow offshore areas of the Niger Delta with only few of such works on foraminifera documented in the literature for proprietary reasons. Initial studies and investigations on the southern Nigeria Tertiary rocks included the works of Reyment (1959, 1965) who established a zonal scheme for the Tertiary strata of southern Nigeria on the basis of identified *Bolivina spp*, *Afrobolivina afra*, *A. bantu*, *Bolivina ihuoensis* and *B. owerri*.

Frankl and Cordry (1967) provided the first set of information on the subsurface distribution of stratigraphic units in the Niger Delta while Parkinson (1967) proposed an estuarine to freshwater paleoenvironment of deposition for the sediments in the basin. Short and Stauble (1967) presented a detailed work on the subsurface stratigraphy of the Niger Delta and subdivided the sequences into three lithostratigraphic units;

Akata, Agbada and Benin Formations.

Evamy *et al.* (1978) established that the development of the Niger Delta from early Cretaceous to Recent had been dependent on the interplay between the rate of sedimentation and subsidence which was also influenced by the structural evolution of the Niger Delta. Peters (1979) in his work on Parabe-1 Well in the Western Niger Delta established two biostratigraphic horizons. The upper *Globorotalia tumida* horizon was dated Pliocene while the lower *Globorotalia opima-nana* horizon was assigned an Oligocene age. Salami (1982) established four distinctive biofacies: Upper, Middle, Upper-Lower and Lower-Lower biofacies in the Gulf of Guinea area. His division was based on the abundance and depth distribution as well as last appearance of bathyal benthic foraminifera from deep-water samples. Ogbe (1982) suggested the presence of three marine transgressions from the late Cretaceous to the Pleistocene based on the

microfossil assemblages he recovered from the Niger Delta sequences studied. Nwachukwu *et al.* (1992) recognized the absence of the Danian Stage from the upper Cretaceous and lower Tertiary of Bodashe-1 and Illepaw-1 Wells, Southwestern Nigeria. They used the last occurrence of *Afrolivina afra*, *Othokarstenia parva*, *Orthokarstenia oveyi* and *Globotruncana* species to mark the top of the Maastrichtian.

Edebiri (1992) carried out paleoecological and microbiostratigraphic studies of the sequences penetrated by Magna - 1 in the Niger Delta. He assigned a Middle Miocene age to the strata based on the occurrence of *Globorotalia peripheronda*, *G. peripheroacuta*, *G. fohsi* and *Globigerinoides subquadratus* which corresponded to the N9 - N13. He concluded that the sediments were deposited in a warm neritic to upper bathyal environment.

Olusoji (1995) subdivided the studied interval of Ajapa - 2 Well into biostratigraphic zones based on the associated benthic foraminiferal species and the diagnostic planktic foraminifera. The benthic zones are *Aleoelophragmium crassum*, *Marginulina costata/Lenticulina inornata* and *Ammonia beccarii/Florilus atlanticus* zones. He also delineated two informal planktic foraminiferal zones - the *Globorotalia tumida* and *Globigerinoides nepenthes* corresponding to the N19 and N18 of Blow (1979).

Fadiya (1999) carried out integrated studies on foraminiferal and calcareous nannofossil biostratigraphy and well log sequence stratigraphic analysis of the strata penetrated by Opolo - 5 and Opolo - 9 Wells, offshore, western Niger Delta. He identified 28 planktic, 72 benthic foraminiferal species and 33 calcareous nannofossil species. Two informal planktic foraminiferal zones were established (*Globigerinoides obliquus* and *G. ruber*). These corresponded to the N17 - N19 of Blow (1969). He assigned a Late Miocene to Early Pliocene age to the studied sequence of both wells on the basis of the foraminiferal zones and the calcareous nannofossil assemblage. Four informal benthic zones of *Ammobaculites stratbearnensis*, *Cyclammina cf. minima*, *Marginulina costata* and *Quinqueloculina lamarckiana* were also established.

Recent biostratigraphic works in the Niger Delta

included those of Fadiya (2008) on calcareous nannofossils biozonation scheme for the deep offshore Niger Delta. He subdivided the Early Miocene to Early Pliocene sequences studied into zones and subzones based on diagnostic calcareous nannofossils in the Niger Delta. Fadiya and Salami (2012) observed a dearth of nannofossils spanning a period of approximately 5 million years between 10.9 Ma – 15.6 Ma within the Middle Miocene Serravalian age of the deep offshore Niger Delta. This, they linked with the globally recognised Middle Miocene 'carbonate crash' first described from the Caribbean. Fajemila (2012) worked on deep offshore samples from two wells in the Niger Delta. He recognized five informal foraminiferal zones and was able to mark an unconformity that cut across the two wells as a result of abrupt changes in the paleobathymetric signatures of some selected benthic foraminifera species.

A robust biostratigraphic knowledge of a well is vital in the subdivision of the well sequence into correlatable units through dating and erection of biozones. The interpretation of the environment of deposition is important in the reconstruction of the burial history as well as in sequence stratigraphic studies. This work is therefore focussed on the dating and subdivision of the sequences penetrated by AM-2 Well, using the globally recognised planktic foraminiferal zonation scheme of Blow (1969, 1979) as well as a zonal subdivision of the well section based on recovered benthic foraminifera. The environmental interpretation of the well will employ a combination of the sedimentological description of the ditch cuttings and environmental diagnostic benthic foraminiferal species.

MATERIALS AND METHODS

One hundred and twenty eight (128) ditch cuttings samples obtained from interval 1440 – 2720 metres of Well AM-2, onshore Niger Delta were employed for this study. The approximate location of the well is as shown in Figure 1. Cuttings were prepared for lithological description by gently washing off the drilling mud after soaking for few minutes in liquid detergent. The samples were then dried and described under the stereo-binocular microscope. The lithology (sand and shale) were carefully described and the accessory minerals

recorded for environmental interpretation. The samples were processed for their foraminifera and other microfaunal accessories using standard foraminiferal processing procedures. Thirty (30) grams of cuttings were weighed and soaked in detergent to facilitate sample disaggregation. The soaked sample was then washed through a 63 micron sieve, dried and the residue sieved into three fractions (coarse, medium and fine) to allow for convenient picking of the foraminifera and other microfauna accessories. The foraminifera

and microfauna contents were then carefully picked out of the residue with the aid a stereo-binocular microscope and transferred into cellulose in readiness for identification. The recovered foraminifera were studied and identified to specie level using relevant bibliography including Loeblich and Tappan (1964, 1988); Cushman (1933, 1969) and Agip S. P. A. Foraminifera Padani (1982). The identified foraminifera were recorded in the analysis sheet and transferred to the Stratabug biostratigraphic software for charting.

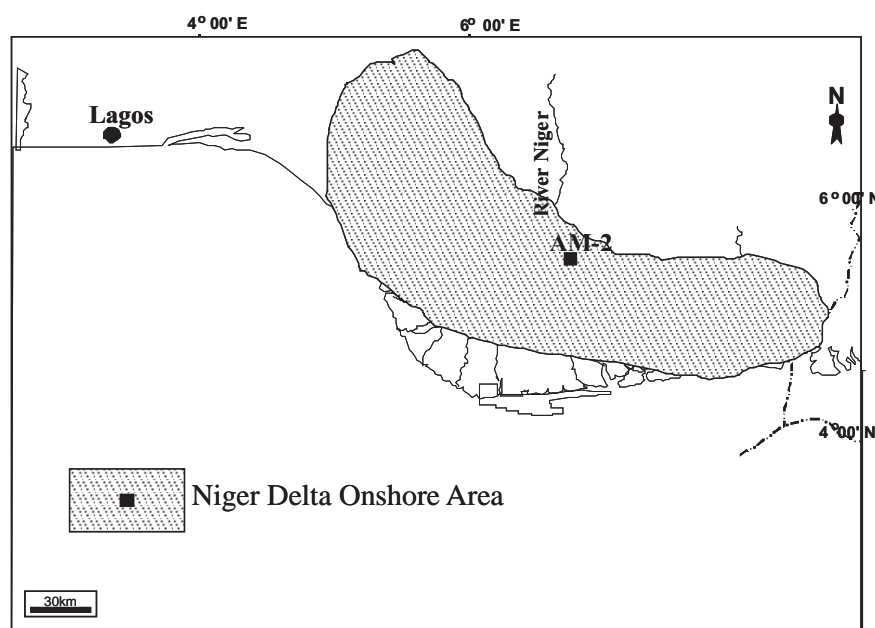


Figure 1: Niger Delta Map Showing the Approximate Location of Study Area

RESULTS

Lithological description of the analysed section of AM-2 Well revealed a clastic sequence composed of sands and shales. Sandy intervals were found intercalated within shales in the upper 1720 – 1440 m while interval 1720 – 2720 m was composed of a monotonous hemipelagic shales with few silty sands. The sands were predominantly coarse to very coarse-grained and granular, occasionally medium to fine-grained, moderately to poorly sorted. The shales were grey to darkish grey, flaggy to platy and moderately hard.

The sediments of AM-2 Well yielded fairly abundant and diverse foraminifera population. Fifty two (52) foraminiferal species were recorded in all. Twenty five species (48%) were planktics, twenty four (46%) were calcareous benthics while the remaining three (6%) were arenaceous

benthics. Gastropod, ostracod and pelecypod constituted the accessory microfauna assemblages. Figures 2 and 3 showed the taxa distribution of the recovered planktic and benthic foraminifera respectively. The upper interval (1440 – 1920 m) was characterised by rare and scattered occurrences of planktic foraminiferal species as compared to the rich and diverse assemblage in the lower 1940 – 2720 m. Zonal delineation of the well section was however, made easy with the abundant occurrence of calcareous benthic species as well as the presence of diagnostic index planktic foraminiferal species. Criteria employed for the biozonation of the well section included the First and Last Appearance Datum s (FAD and LAD) of chronostratigraphically significant planktic foraminiferal species, First and Last Appearance Datum of chronostratigraphically significant

benthic foraminifera whose stratigraphic ranges were well established in the Niger Delta and worldwide. Another criterion employed in the zonation of the well was the characteristic foraminifera assemblage of stratigraphically important planktic and benthic foraminifera species well established in the Niger Delta and Worldwide.

The delineated zones were carefully compared to the revised Cenozoic geochronologic and chronostratigraphic schemes of Berggren *et al.*, (1995) and the standard planktic foraminiferal

zonal scheme of Blow (1969, 1979). On the basis of the stated criteria above, the analysed section of the AM-2 Well had been found to penetrate the Early to Middle Miocene P12, P13/P14, P15 and P16 and younger planktic foraminiferal zones of Berggren *et al.*, (1995). Four (4) informal benthic foraminiferal zones were delineated for the studied section of AM-2 Well. These are - *Altistoma tenuis* zone, *Eponides africana* zone, *Uvigerina peregrina/Lenticulina grandis* zone, *Bolivina ibuoensis/Hopkinsina hourqi* zone.

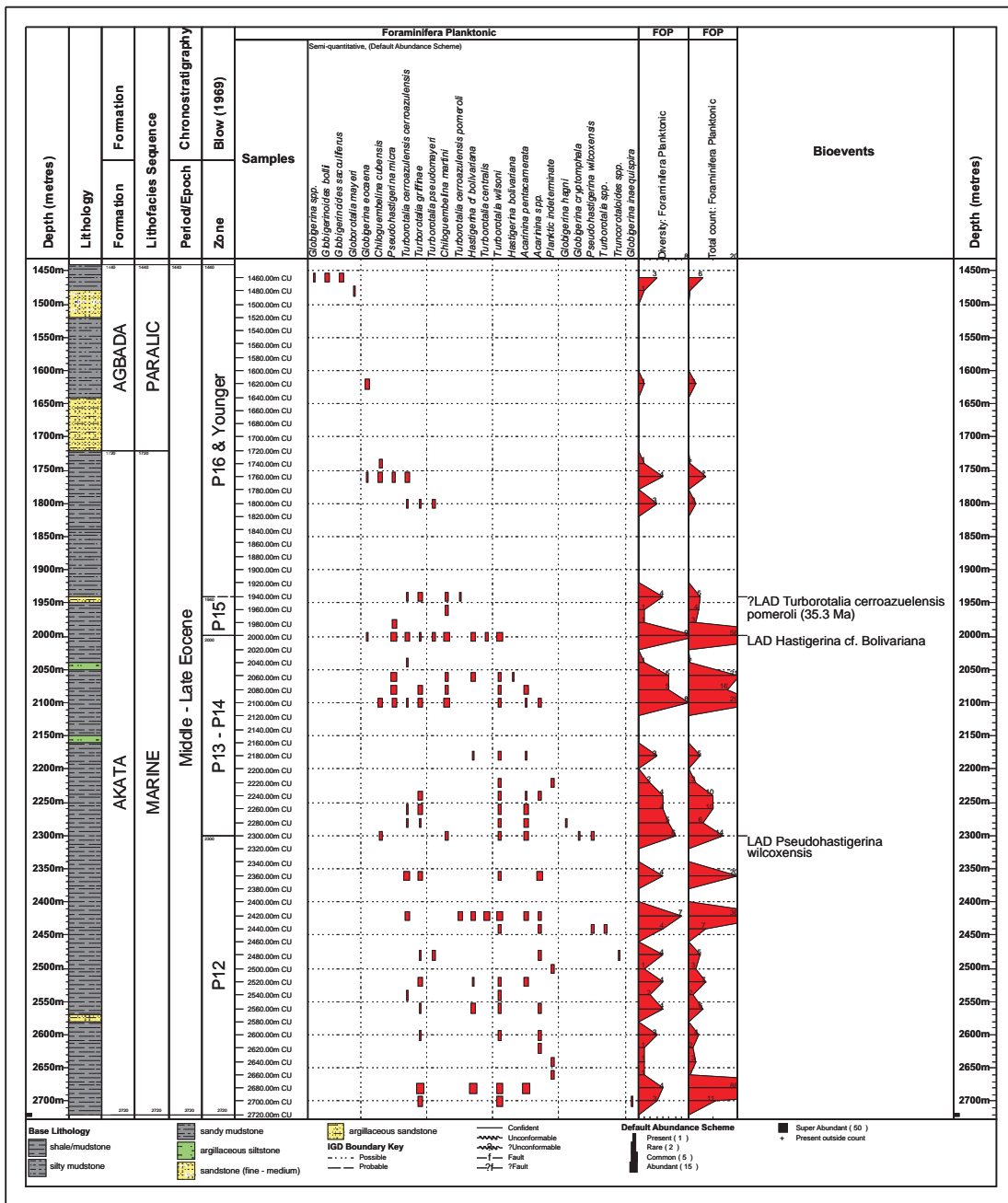


Figure 2: Stratigraphic Distribution and Zonation of the Planktic Foraminifera Recovered from AM-2 Well

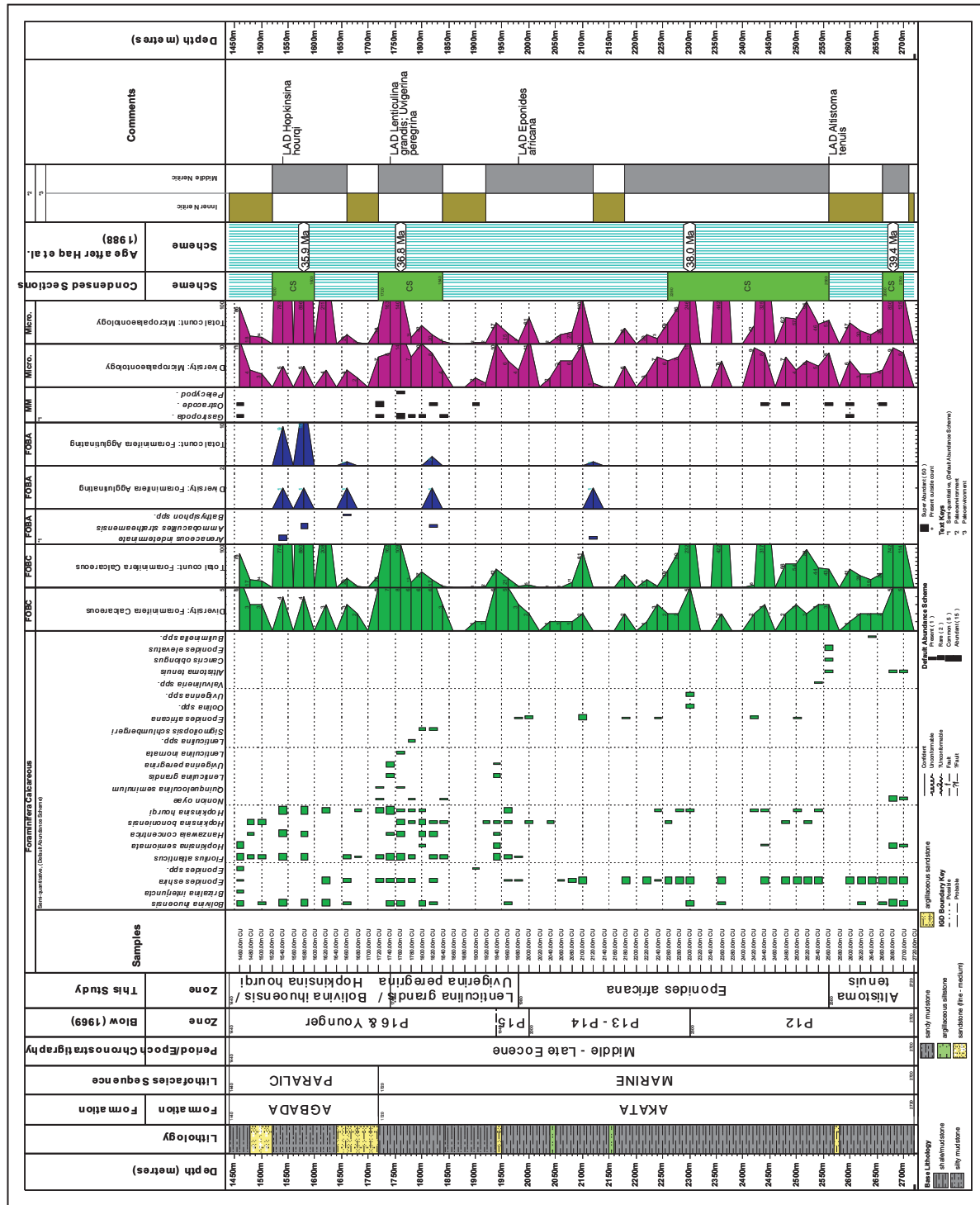


Figure 3: Stratigraphic Distribution and Zonation of the Benthic Foraminifera Recovered from AM-2 Well

DISCUSSION

AGE OF AM-2 WELL

The analysed section of Well AM-2 yielded characteristic markers and associated planktic foraminiferal species such as *Globigerina eocaena*, *G. bagni*, *G. cryptomphala*, *G. inaequispira*, *Chiloguembelina cubensis*, *C. martini*, *Pseudobastigerina micra*, *P. wilcoxensis*, *Turborotalia cerroazulensis*, *T. griffinae*, *T. pseudomayeri* and *T. cerroazulensis pomeroli*. This assemblage is typical of

the P12 – P16 planktic foraminiferal zones of the Middle - Late Eocene age. The presence of a characteristic Late Eocene foraminifera species in the Niger Delta – *Hopkinsina hourqi* and *Nonion oyae* also confirms the age of the well.

PLANKTIC FORAMINIFERAL ZONATION

A good number of diagnostic planktic foraminiferal species were recovered in the studied

section of AM-2 Well. These are *Globigerina eocaena*, *G. bagni*, *G. crytomphala*, *G. inaequispira*, *Chiloguembelina cubensis*, *C. martini*, *Pseudobastigerina micra*, *Pseudobastigerina wilcoxensis*, *Turborotalia cerroazulensis cerroazulensis*, *T. griffinae*, *T. pseudomayeri*, *T. cerroazulensis pommeroli*, *T. centralis*, and *T. wilsoni*. This assemblage permitted the zonal subdivision of the well section based on the zonation scheme of Berggren *et al.* (1995) as follows:

Stratigraphic Interval: 2720 - 2300 m

Zone: P12

Age: Middle Eocene.

Description: The top of this zone is placed at the observed Last Appearance Datum (LAD) of *Pseudobastigerina wilcoxensis* at depth 2300 m. This datum is commonly found within the P12 zone. The base is taken as the base of the studied interval at depth 2720 m. The associated species in this zone include *Turborotalia cerroazulensis cerroazulensis*, *T. griffinae*, *T. pseudomayeri*, *T. cerroazulensis pommeroli*, *T. centralis*, *T. wilsoni*, *Hastigerina cf. bolivariana*, *Acarinina pentacamerata*, *Acarinina spp* and *Pseudobastigerina wilcoxensis*.

Stratigraphic Interval: 2300 - 2000 m

Zone: P13/14

Age: Middle - Late Eocene.

Description: The top of this zone is marked by the presumed Last Appearance Datum (LAD) of *Hastigerina cf. bolivariana* at depth 2000 m. The base is marked by the last appearance of *Pseudobastigerina wilcoxensis* at depth 2300 m. The associated species in this zone include: *Globigerina eocaena*, *G. bagni*, *G. crytomphala*, *Chiloguembelina cubensis*, *C. martini*, *Pseudobastigerina micra*, *P. wilcoxensis*, *Turborotalia cerroazulensis cerroazulensis*, *T. griffinae*, *T. pseudomayeri*, *T. cerroazulensis pommeroli*, *T. centralis*, *T. wilsoni*, *Hastigerina cf. bolivariana*, *H. bolivariana*, *Acarinina pentacamerata*, *Acarinina spp*.

Stratigraphic Interval: 2000 - 1940 m

Zone: P15

Age: Late Eocene.

Description: The top of this interval is tentatively placed at the presumed Last Appearance Datum (LAD) of *Turborotalia cerroazulensis pommeroli* at depth 1940 m. The base is marked by the First Downhole Occurrence of *Hastigerina cf. bolivariana* at depth 2000 m. The interval is characterised by fairly

abundant and diverse planktic species. This include *Globigerina eocaena*, *Pseudobastigerina micra*, *Turborotalia cerroazulensis cerroazulensis*, *T. griffinae*, *T. pseudomayeri*, *T. cerroazulensis pommeroli*, *Chiloguembelina martini*, *T. centralis* and *T. wilsoni*.

Stratigraphic Interval: 1940 -1440 m

Zone: P16 & Younger

Age: Late Eocene.

Description: The top of this interval is tentatively placed at the depth of the shallowest sample analysed at 1440 m. The base is tentatively placed at the presumed Last Appearance Datum (LAD) of *Turborotalia cerroazulensis pommeroli* at depth 1940 m. It is however believed that the base of the zone may be up within the interval but cannot be confidently delineated due to the absence of zonal marker species. The interval is characterised by scattered occurrence of planktic foraminiferal species including *Globigerina eocaena*, *Turborotalia cerroazulensis cerroazulensis*, *T. griffinae*, *T. pseudomayeri*, *Chiloguembelina cubensis*, *Globorotalia mayeri*, *Globigerinoides sacculiferus*, *Globigerinoides bolli* and *Globigerina spp*.

INFORMAL BENTHIC FORAMINIFERAL ZONES

Twenty - six (26) benthic foraminiferal species were recovered from the samples of AM-2 well analyzed. These include *Bolivina ibuoensis*, *Eponides eshira*, *Florilus atlanticus*, *Hopkinsina semiornata*, *Hopkinsina bononiensis*, *Hanzawaia concentrica*, *Hopkinsina bourqi*, *Nonion oyae*, *Quinqueloculina seminulum*, *Lenticulina grandis*, *Lenticulina inornata*, *Sigmoilopsis schlumbergeri*, *Eponides africana*, *Oolina spp.*, *Uvigerina peregrina*, *Uvigerina spp.*, *Valvulineria spp.*, *Alitostoma tenuis*, *Cancris oblongus*, *Eponides elevatus* and *Buliminella spp.* Others are *Brizalina interjuncta*, *Eponides spp.*, *Lenticulina spp.*, *Ammobaculites stratbearnensis* and *Bathysiphon spp.* Four informal benthic foraminiferal assemblage zones were erected based on the stratigraphic distribution of the recovered benthic foraminifera. These delineated zones are: *Alitostoma tenuis* zone, *Eponides africana* zone, *Uvigerina peregrina/Lenticulina grandis* zone and *Bolivina ibuoensis/Hopkinsina bourqi* zone. These zones are described as follows:

Stratigraphic Interval: 2720 - 2560 m

Zone: *Altistoma tenuis*

Equivalent Planktic Foraminiferal Zone: Lower P12.

Age: Middle Eocene.

Description: The top of the zone is defined by the Last Appearance Datum of *Altistoma tenuis* at depth 2560 m, while its base is tentatively placed at 2720 m, the depth of the deepest sample studied. It is characterized by the occurrence of abundant to super abundant distribution of calcareous benthic foraminifera species such as *Bolivina ihuoensis*, *Eponides eshira*, *E. africana*, *E. elevatus*, *Hopkinsina semiornata*, *Valvulineria spp.*, *Nonion oyaie*, *Altistoma tenuis*, *Cancris oblongus*, and *Buliminella spp.* Accessory microfauna recovered within the interval include shell fragments, gastropod and ostracod. It is worthy of note to mention that arenaceous benthic foraminifera are totally in this interval. This interval has been correlated to the Lower part of the P12 planktic foraminiferal zone of Blow (1969, 1979). The condensed section over interval 2660 – 2700 m is thought to be associated with the 39.4 Ma Condensed Section of Haq *et al.* (1988) Sequence Cycle Chart based on their position below the proposed 38.0 Ma Condensed Section.

Stratigraphic Interval: 2560 - 1980 m

Zone: *Eponides africana*

Equivalent Planktic Foraminiferal Zone: Upper P12 - Lower P15

Age: Middle Eocene.

Description: The top of this zone is defined by the Last Appearance Datum (LAD) of *Eponides africana* at 1980 m, while its base is defined by the Last Appearance Datum of *Altistoma tenuis* at 2560 m. The Last Appearance Datum of the planktic marker specie - *Hastigerina cf. bolivariana*, at depth 2000 m and the Last Appearance Datum of *Pseudobastigerina wilcoxensis* at depth 2300 m were notable bioevents within this zone. The zone is further characterized by abundant to super abundant calcareous benthic foraminifera including *Bolivina ihuoensis*, *Eponides eshira*, *Hopkinsina semiornata*, *Hopkinsina hourqi*, *Eponides africana*, *Oolina spp.*, *Uvigerina spp.*, *Hopkinsina spp.*, *Valvulineria spp.*, *Altistoma tenuis*, *Cancris oblongus*, and *Eponides elevatus*. A few indeterminate arenaceous forms were recovered within the interval. A correlation of the zone to the Blow

(1969, 1979) scheme indicated that the zone falls within the Upper P12 to Lower P15 planktic zones. The condensed section over interval 2260 – 2560 m is believed to be associated with the 38.0 Ma Condensed Section of Haq *et al.* (1988) Sequence Cycle Chart, based on its stratigraphic position below the positively recognised 36.8 Ma Condensed Section.

Stratigraphic Interval: 1980 - 1740 m

Zone: *Uvigerina peregrina*/*Lenticulina grandis*

Equivalent Planktic Foraminiferal Zones: Upper P15 – Lower P16

Age: Late Eocene

Description: The top of this zone is defined by the Last Appearance Datum (FAD) of *Uvigerina peregrina* and that of *Lenticulina grandis* at 1740 m while its base is tentatively placed at 1980 m. The FDO of the index planktic marker - *Chiloguembelina martini* was recorded at depth 1940 m within this interval. The zone is further characterized by the co - occurrence of *Bolivina ihuoensis*, *Florilus atlanticus*, *Hopkinsina semiornata*, *Hopkinsina spp.*, *H. hourqi*, *Hanzawaia concentrica*, *Eponides eshira*, *Nonion oyaie*, *Quinqueloculina seminulum*, *Lenticulina grandis*, *Lenticulina spp.*, *Lenticulina inornata*, *Uvigerina peregrina*, *Sigmioilopsis schlumbergeri*, *Nonion oyaie*, *Eponides spp.* and *Eponides africana*. *Ammobaculites stratbeamensis* represent the only agglutinated foraminifera found within the interval while the microfaunal accessories are characterised by shell fragments, gastropods, ostracods and pelecypod. This interval corresponds to the Upper P15 to Lower P16 planktic zone of Blow (1969, 1979). The condensed section over interval 1720 – 1840 m is believed to be associated with the 36.8 Ma Condensed Sections of Haq *et al.* (1988) Sequence Cycle Chart. This is based on its association with P16 planktic foraminiferal zone and the presumed Last Appearance Datum of the foraminiferal species – *Turborotalia cerroazuelensis pomeroli* (35.3 Ma) at the depth of 1980 m.

Stratigraphic Interval: 1740 - 1440 m

Equivalent Planktic Foraminiferal Zone: P16 & Younger

Zone: *Bolivina ihuoensis*/*Hopkinsina hourqi*

Age: Late Eocene

Description: The top of the zone is placed at the shallowest sample analysed at 1440 m. Its base is

tentatively placed at the first downhole occurrence (FDO) of *Lenticulina grandis* and *Uvigerina peregrina* at depth 1740 m. The FDO of the benthic marker specie - *Hopkinsina bourqi* at depth (1540 m) is an important bioevent within the zone. The zone is further characterized by the co - occurrence of *Bolivina ibuoensis*, *Eponides eshira*, *Florilus atlanticus*, *Hopkinsina semiornata*, *H. hourqi*, *Hopkinsina spp*, *Hanzawaia concentrica*, *Noion oya*, *Quinqueloculina seminulum* and arenaceous benthic foraminifera such as *Ammobaculites stratbearnensis* and *Bathysiphon spp*. This interval has been correlated to the P16 and Younger planktic foraminiferal zone of Blow (1969, 1979). The condensed section over interval 1520 – 1600 m is believed to be associated with the 35.9 Ma Condensed Sections of Haq *et al.* (1988) Sequence Cycle Chart. This is based on its association with P16 planktic foraminiferal zone.

LITHOSTRATIGRAPHY AND PALEOENVIRONMENTS

Paleoenvironmental interpretation of the analysed section of AM-2 Well was based on the integration

of paleobathymetric and sedimentological data obtained over the analysed section. The sedimentological data was derived from ditch cutting samples while paleobathymetric deductions were guided by varied micropaleontological criteria including the occurrence of environmental diagnostic benthic foraminifera species (Adegoke *et al.*, 1976; Van Morkhoven, 1986; Murray, 1991). Others include the abundance and diversity of foraminifera, planktic/benthic ratio and the nature and type of accessory microfauna.

Sedimentological criteria including sand/shale ratios supported by micropaleontological data aided the lithostratigraphic subdivision of the entire studied section (1440 - 2720 m) of AM-2 well into the Agbada and Akata Formations. These criteria supported by paleobathymetric data, further enabled the recognition of two (2) lithofacies sequences – the paralic and marine sequences with characteristics as follows:

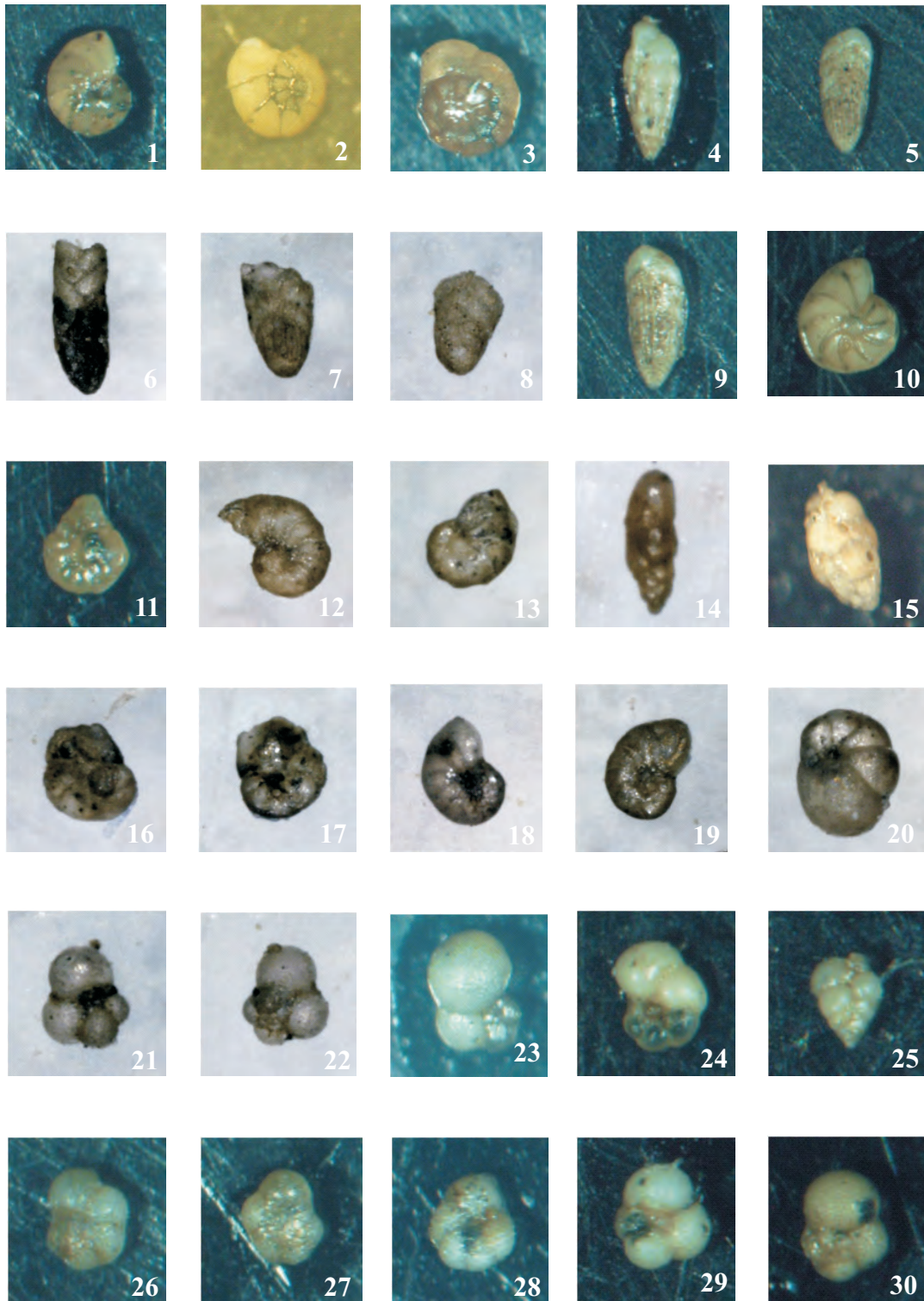
Interval (m)	Formation	Lithofacies Sequence	Lithological characteristics
-	AGBADA	PARALIC	<ul style="list-style-type: none"> • Sub-equal proportions of sands and shales • Sands are predominantly coarse to very coarse-grained and granular, occasionally medium to fine -grained, moderately to poorly sorted. • Association with inner to middle neritic biofacies
1720 – 2720	AKATA	MARINE	<ul style="list-style-type: none"> • Monotonously shaly with occasional thin silty sand intervals • Sands are very fine to fine, occasionally medium to coarse -grained and well sorted • Association with predominantly middle neritic biofacies.

THE MARINE – AKATA SEQUENCE (2720 – 1720 m)

Integration of the sedimentological and foraminiferal evidences suggest that this unit is composed essentially of marine shales with few silty sands. The shales are grey to darkish grey, flaggy to platy and moderately hard. The interbedded silty sands are milky white to buff,

predominantly fine-grained, occasionally medium to coarse-grained and well sorted. The accessory mineral suite is mostly ferruginous materials, mica flakes and carbonaceous detritus in increasing order of abundance. The abundance of shales over the sequence suggests slow deposition in a predominantly low energy, sufficiently oxygenated outer shelf settings. The recovered sands may

PLATE 1



EXPLANATION OF PLATE 1

- | | | | |
|-------|---|-------|---|
| 1-3 | <i>Eponides esbira</i> (Mboro <i>et al.</i> , 1981) | 18-19 | <i>Florilus atlanticus</i> (Cushman, 1936) |
| 4 | <i>Hopkinsina bourqi</i> (Fornasini, 1888) | 20 | <i>Valvulineria</i> spp (d'Orbigny, 1846) |
| 5-8 | <i>Bolivina ibuensis</i> (d'Orbigny, 1846) | 21-22 | <i>Globigerina eocaena</i> (Gumbel, 1868) |
| 9 | <i>Hopkinsina semiornata</i> (Howe and Wallace, 1932) | 23 | <i>Pseudobastigerina wilcoxensis</i> (Cushman & Ponto, 1932) |
| 10 | <i>Lenticulina grandis</i> (Cushman, 1921) | 24 | <i>Pseudobastigerina micra</i> (Cole, 1927) |
| 11 | <i>Nonion oyae</i> (Walker e Jacob, 1798) | 25 | <i>Chiloguembelina martini</i> (Pijpers, 1933) |
| 12-13 | <i>Hanzawaia concentrica</i> (d'Orbigny, 1846) | 26-27 | <i>Turborotalia pseudomayeri</i> (Tourmakine & Bolli, 1970) |
| 14 | <i>Bulminella</i> spp. (Cushman, 1911) | 28 | <i>Acarinina pentacamerata</i> (Subbotina, 1947) |
| 15 | <i>Uvigerina peregrina</i> (Cushman, 1923) | 29 | <i>Turborotalia cerroazuelensis pomeroli</i> (Tourmakine & Bolli, 1970) |
| 16-17 | <i>Eponides africanus</i> (Petri, 1962) | 30 | <i>Pseudobastigerina cf. bolivariana</i> (Bolli, 1957) |

represent occasional burst of energy in the otherwise quiet environments.

High abundance and diversity of deep water calcareous foraminiferal fauna characterize this interval. These include *Bolivina ibuoensis*, *Eponides eshira*, *Hopkinsina bourqi*, *Lenticulina grandis*, *Hopkinsina bononiensis*, *Uvigerina peregrina*, *Buliminella spp* and *Hopkinsina semiornata*. The above foraminiferal association is suggestive of sediment deposition in an middle neritic environment. The high occurrence of planktic foraminifera within interval 1940 – 2720 m is indicative of deposition in an environment as deep as middle to outer shelf marine settings. Intervals with lower abundance and diversity of these species (1840 – 1940 m, 2120 – 2180 m, 2560 – 2660 m and 2700 – 2720 m) has been attributed to fluctuations in the environment to a shallower (inner neritic) environment.

THE PARALIC – AGBADA SEQUENCE (1720–1440 m)

This interval is essentially a heterogenous sequence of alternating sand and shale/mudstone units. The base of the paralic lithofacies sequence is marked at 1720 m being the commencement of sand deposit within the well section. The sands are predominantly fine grained, occasionally medium to coarse-grained, well sorted and subangular. The shales (interval 1520 – 1640 m) are grey to brownish grey, flaggy to platy and moderately soft to moderately hard. The accessory mineral suite is dominated by ferruginous materials, carbonaceous detritus and pyrites. Mica flakes occur rarely within the sandy section while glauconites and shell fragments shows spotty records. The grain size which increases upward in the section as noted from the lithologic description is interpreted as a subaqueous mouth bar deposited during progradational episode in a middle to outer shelf settings. This is further confirmed by the mixture of glauconite and carbonaceous detritus. The environment of deposition within the interval fluctuates between the inner to middle neritic environment based on the recovery of characteristic paleobathymetric indicators. These include *Bolivina ibuoensis*, *Brižalina interjuncta*, *Eponides eshira*, *Hopkinsina bononiensis*, *Hopkinsina bourqi*, *Hanzawaia concentrica* and *Florilus atlanticus*. This assemblage which occurs in various

abundances has been used to subdivide the environment of deposition into inner neritic (1440 – 1520 m and 1640 – 1720 m) and middle neritic (1520 – 1640 m) environments.

CONCLUSION

The analysed sequences of AM-2 Well (1440 – 2720 m), onshore Niger Delta penetrated the Agbada and Akata Formations. The upper part of the well (1440 – 1720 m) belongs to the basal part of the Agbada Formation with alternating sand and shale sequence while the predominantly hemipelagic shale within interval 1720 – 2720 m belongs to the Akata Formation. A fairly abundant and diverse planktic foraminifera and benthic foraminifera assemblage recorded enabled the subdivision of the well section into the P12, P13/P14, P15 and P16 and younger zones. These established zones are found within the Middle to Late Eocene age. The age is further confirmed by the occurrence of characteristic Niger Delta Middle to Late Eocene benthic foraminiferal species – *Hopkinsina bourqi* and *Nonion oyaе* within the analysed interval of the well. Four informal benthic foraminiferal zones – *Altistoma tenuis*, *Eponides eshira*, *Lenticulina grandis/Uvigerina peregrina* and *Bolivina ibuoensis/Hopkinsina bourqi* were erected for the analysed section of the well. Paleoenvironmental interpretation based on the integration of paleobathymetric (from key benthic foraminifera indicator) and sedimentological data obtained over the analysed section revealed that the sequences were deposited within the inner to middle neritic environments. The four major condensed sections identified within the studied section of the well have been dated 35.9 Ma, 36.8 Ma, ?38.0 Ma and ?39.4 Ma based on the identified planktic foraminiferal zones and dated bioevent.

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