Biostratigraphy, Depositional Environment and Sequence Stratigraphy of Akata Field (Akata 2, 4, 6 and 7 Wells), Eastern Niger Delta, Nigeria.

E.A. Okosun and J.N.Chukwu
Department of Geology, Federal University of Technology, Minna, Nigeria

E.O. Ajayi
National Geological Survey Agency, Abuja, Nigeria

O.A. Olatunji
Sanol Engineering Consultants, 470A Aminu Kano Crescent,Wuse II, Abuja, Nigeria

Abstract
Foraminiferal biostratigraphy and sequence stratigraphic analysis were carried out in the Akata Field from Akata-2, Akata-4, Akata-6 and Akata-7 wells in the eastern Niger Delta. Three planktic foraminiferal zones *Globorotalia continuosa*, *Globorotalia obesa/Globorotalia mayeri,* and *Globorotalia peripheroacuta* together with three benthic zones of *Spirosigmoilina oligocaenica, Uvigerina sparsicostata*, and *Eponides eshira/Brizalina mandorovensis* were established in both Akata-2 and Akata-4 wells. One planktic foraminiferal zone of *Praeorbulina glomerosa was* proposed for Akata-6 and Akata-7 wells. One benthic zone of *Brizalina mandorovensis*/*Eponides eshira* and *Poritextularia panamensis* are proposed for Akata-6 and Akata-7 wells respectively. Calcareous nannofossil analysis was also carried out in Akata-6 and Akata-7 wells, *Sphenolithus heteromorphus* Zone was established in both wells. Miocene age has been assigned to the studied intervals of the four wells based on the foraminiferal assemblages. The studied wells were correlated using the established biostratigraphic zones. A littoral (deltaic) to marine (outer neritic) environments of deposition has been inferred for the four wells based largely on the presence of environmentally restricted benthic foraminifera species. Three third order maximum flooding surfaces were recognized in Akata-2 and 4 while two were recognized in Akata-6 and 7 wells. The wells have been divided into sequences and systems tracts.

Keywords: Akata field, Benthic foraminifera, Biostratigraphy, Calcareous nannofossils, Depositional Environment, Niger Delta, Planktic foraminifera, Sequence stratigraphy.

1 INTRODUCTION

The importance of Niger Delta lies in its hydrocarbon resources and is among the world's most prolific petroleum provinces. It has been rated as the sixth largest oil producer and twelfth giant hydrocarbon province. Thousands of wells have been drilled across the delta penetrating the sediments, in which petroleum generation, migration and accumulation have occurred.

Foraminferal biostratigraphic information of some wells in Niger delta has been published by [1], [2], [3], [4]. Ozumba and Amajor [5] carried out a high resolution foraminiferal biostratigraphy of four wells (Kanbo-5, Egbedicreek-1, Angalalli-1 and Opukushi-5) located in the coastal and central swamp in the western Niger Delta. They defined six foraminiferal zones (Assemblage/Partial range zones) for the middle to late Miocene Niger Delta namely; *Globigerina* cf *ciperoensis* Zone, *Nonion centrosulcatum/Chiloguembelina victoria* Zone, *Eponides eshira* Zone, *Uvigerina sparsicostata* Zone, *Spirosigmoilina oligoceanica* Zone, and *Florilus ex. gr. costiferum* Zone.

The advantages of calcareous nannofossils in the recognition of Marine Flooding Surfaces in the Niger Delta most especially in the Late Miocene to Late Pliocene time was discussed by [6]. He recognized four delta wide flooding surfaces based on the *Discoaster quinqueramus*, *Ceratholithus* species *and Gephyrocapsa* species and *Sphenolithus* species. This was confirmed by [7] who also observed the influx of *Sphenolithus abies* in the Late Miocene of the Niger delta. The unpublished research work of [8] comprises systematic calcareous nannofossil biostratigraphic studies of some Niger delta wells which were subdivided using globally recognized zones of [9], [10]. Information on calcareous nannofossils biostratigraphy of some wells in Niger delta has also been published by [11], [12], [13].

Ladipo [14] employed seismic and well-log data in the sequence stratigraphic study of five wells in the North western Niger Delta. He established a strong correlation between hydrocarbon occurrences and the lowstand systems tracts. However, [15] reported that some reservoir sequences were deposited as mainly highstand and transgressive systems tracts on a more proximal shallow swamp setting. Ozumba [16] carried out foraminiferal and wireline well log sequence stratigraphic analysis on three offshore wells (EP-1, HB-1 and KC-1) in the Niger Delta. He recognized five third-order Maximum Flooding Surfaces derived from peak foraminiferal abundance and diversities.

The focus of this study is on the foraminiferal and calcareous nannofossils biostratigraphy, sequence stratigraphy and environment of deposition of the strata penetrated by Akata 2, Akata 4, Akata 6 and Akata 7 wells (figure 1).

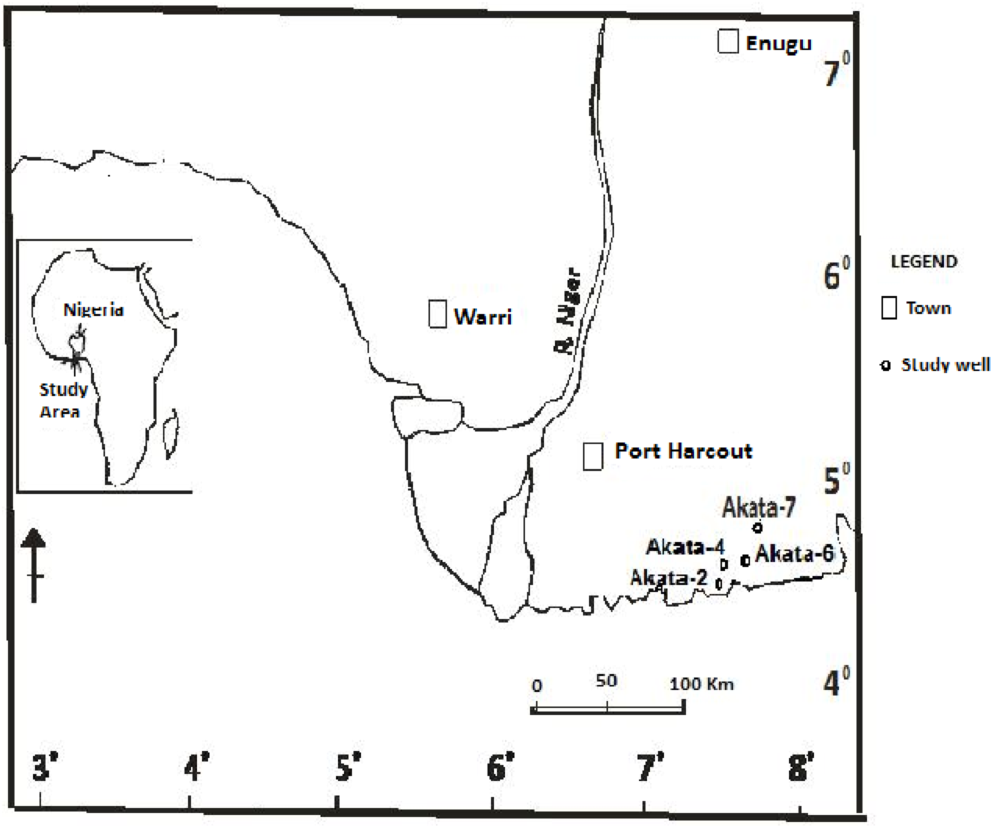

Fig. 1. Location map of Akata-2, Akata-4, Akata-6 and Akata-7 wells, Eastern Niger Delta, Nigeria.

2 MATERIALS AND METHODS

The ditch cuttings, Spontaneous Potential (SP) and Resistivity logs of the wells were obtained from NGSA, Kaduna. Other materials used include 63 micron sieve, hot plates, weighing balance, binocular microscope, slides and cover slides, water, gum, sample envelopes, liquid soap, a set of 3 stacked sieves, toothpick, picking tray, hydrogen peroxide, kerosene, oven, beakers, hand lens and Norland Optical adhesive mounting medium.

Twenty grammes of each sample were processed for their foraminiferal content using the standard preparation technique. The hydrogen peroxide method was employed. The washed residues were dried over hot plate and then sieved into coarse, medium and fine fractions, using a set of 3 stacked sieves. Each fraction was examined under binocular microscope. All the foraminifera, ostracodes, shell fragments and other microfossils observed were picked with the aid of picking needle/tooth pick, counted, placed in foraminifer's slides and covered with cover slide for safety and future reference. The slides were properly labelled with well name and sample depth. Foraminifera identification was made to genus and species levels where possible using the taxonomic scheme of [17] and other relevant foraminiferal literature [1], [2], [4], [18], [19], [20], [21].

The ten samples each were selected from foraminifera-rich depth intervals from Akata-6 and Akata-7 wells which indicate periods of high marine influence in the area penetrated by the well. The samples were processed for calcareous nannofossil recovery using the standard preparation technique of [22]. The prepared slides were examined for their calcareous nannofossil content under a high power Olympus light microscope in cross-polarized and transmitted lights. Detailed abundance counts of the assemblages were made at x1000 magnification. Identification of species was made by consulting the works of [8], [11], [13], [23], [24].

3 RESULTS AND DISCUSSION

The results of this analysis are presented in the foraminifera distribution chart of Akata-4, Akata-2, Akata-6 and Akata-7 wells (figures 2, 3, 4 and 5). A lithologic log was prepared by integrating lithologic description data with the available SP and resistivity log. Some diagrams of the recovered specimens are presented in plates 1, 2 and 3.

3.1 Foraminifera Biosratigraphy

The stratigraphic intervals studied in the wells have been characterized or subdivided into biostratigraphic zones based on their foraminiferal contents (planktics and benthics). The established planktic and benthic foraminifera biostratigraphic zones in the four wells have been correlated (figure 6)

3.2 Akata-2 and Akata-4 wells

A total of 19 planktic, 43 calcareous benthic, and 6 arenaceous benthic foraminiferal species were identified from Akata-2 well (figure 3). Also 23 Planktic, 33 calcareous benthic, and 5 arenaceous benthic foraminiferal species were identified from the studied samples of Akata 4 well (figure 2).

3.2.1 Planktic Foraminiferal Zones

The planktic foraminiferal preservation in the two wells is poor. Some stratigraphically important species (index planktic forms) were not identifiable to specific/generic level. They are thus treated as indeterminate. However within the recognised planktic foraminiferal species, three foraminiferal zones are recgonised namely: *Globorotalia continuosa* zone, *Globorotalia mayeri* zone and *Globorotalia peripheroroacuta* zone. These zones were based on the continuous occurrence and the abundance of diagnostic species.

Globorotalia continuosa Zone

Stratigraphic intervals: 6500 – 5180 ft (Akata 4)

6290 – 4990 ft (Akata 2)

Age: Middle Miocene (11.6 – 10.5 M.A).

This zone is defined by the last stratigraphic occurrences (FDO) of *Spirosigmoilina oligocaenica* and *Globorotalia continuosa* recorded at 5660 ft and 5180 ft respectively in Akata 4 well. The same species were recorded at 4990 ft in Akata-2 well. Planktic forms associated with this zone include

Globigerina bulloides, Orbulina universa, Globigerinoides trilobus, and *Globigerina praebulloides*. This zone is equivalent to the Upper N14 and Lower N15 zones of [25], [26]. This is the N15 zone as correlated with the standard planktic foraminiferal zone of [25], [26].

Globorotalia obese - Globorotalia mayeri Zone
The Stratigraphic intervals: 7600 – 6500 ft (Akata 4)
7840 – 6290 ft (Akata 2)
Age: Middle Miocene (13.8 – 12.5 M.A).
Diagnosis: The base of this zone is placed at the 13.8 M.A sequence boundary at 7600 ft while the upper boundary is placed at 12.5 M.A sequence boundary at 6500 ft. *Globorotalia obesa* and *Globorotalia mayeri* were last seen at 6500 ft and 6290 ft in Akata-4 and Akata-2 wells respectively.
Planktic forms associated with this zone include *Globigerina praebulloides, Globigerinoides immaturus, Praeorbulina transitoria* and *Cassigerina chipolensis.* This zone is equivalent to the Upper N10, N11, N13 and Lower N14 zones of [27].
Globorotalia peripheroacuta Zone
Stratigraphic intervals: 7790 – 7600 ft (Akata 4)
7840 – 8184 ft (Akata 2)
Age: Middle Miocene (15 M.A)
Diagnosis: *Globorotalia fohsi peripheroacuta* and *Globorotalia fohsi peripheroronda* made their last stratigraphic occurrence within this zone at the depth of 7790 ft. This is indicative of Lower N11 zone for Akata 4.
In Akata 2 well, *Globorotalia fohsi peripheroacuta* made its first appearance at the depth of 7840 ft. Planktic forms associated with this zone include *Globigerinoides quadrilobatus, Globoquadrina dehiscens, Globigerinoides bilobata*, *Globorotalia fohsi peripheroronda, Globoquadrina altispira* and *Globigerina bulliodes*. Equivalent planktic foramineral zones is N10, Lower N11 zones of [27]

3.2.2 Benthic Foraminifera Zones

The benthic foraminiferal assemblages found in the wells are well preserved in contrast to the planktic forms. Three informal benthic foraminiferal zones are common to both Akata-2 and Akata-4 wells. The zones were established based on the stratigraphic range, abundance and association of diagnostic species. The three zones are *Spirosigmoilina oligocaenica* Zone*, Brizalina mandoroveensis/Uvigerina Sparsicostata* Zone *and Eponides eshira* Zone.

Spirosigmoilina oligocaenica Zone
Stratigraphic intervals: 4990 ft – 6290 ft (Akata 2)
5180 ft – 6500 ft (Akata 4)
The top of the zone is defined by the First Downhole Occurrence of *Spirosigmoilina oligocaenica* at 4990 ft depth in Akata 2 and at the depth of 5180 ft in Akata-4. Other commonly occuring benthic forms are

Lenticulina inornata, Cibicorbis inflata, Bolivina scalprata miocenica, Hopkinsina bononiensis, *Hanzaiwai strattoni* and *Poritextularia aff panamensis*. This zone is equivalent to Upper N14 and Lower N15 zones of [25], [27]. These foraminiferal occurences confirms that, the Age is of middle Miocene.

Brizalina mandoroveensis/*Uvigerina sparsicostata* Zone
Stratigraphic intervals: 6290 ft – 7840 ft (Akata 2)
6500 ft – 7720 ft (Akata 4)
Benthic foraminifera such as *Uvigerina sparsicostata* and *Brizalina mandoroveensis* made their first occurrence (FO) at 6930 ft and 7050 ft respectively in Akata-4. The last occurrence of *Brizalina mandoroveensis* at depth 7720 ft is indicative of Lower N11 zone in the Akata-4 well. Presence of *Cibicorbis inflata, Orbulina universa, Hazawaia strattoni, Uvigerina* spp. and *Florilus costiferum* in this zone establishes zone range from N11, N12 to N13. This zone correlates with the Upper N11, N12 and N13 of [25], [28]. The zone's age is of Middle Miocene.

Eponides eshira Zone
Stratigraphic interval: 7840 ft – 8184 ft (Akata 2)
7720 ft – 7790 ft (Akata 4)
Eponides eshira Zone is a taxon range zone.Other important benthic species in this zone include *Lenticulina inornata*, *Spirosigmoilina oligocaenica* and *Poritextularia aff panamensis*.

3.3 Akata-6 and Akata-7 wells

A total of eleven planktic, twenty-nine calcareous benthic, and two arenaceous benthic foraminiferal species were identified from the studied samples of Akata-6 well. A total of twelve planktic, thirty calcareous benthic and seven arenaceous benthic foraminiferal species were recovered from Akata-7 well.

3.3.1 Planktic foraminiferal zones

The planktic foraminiferal preservation in the two wells is poor. Some stratigraphically important species (index planktic forms) were not identifiable to generic/species levels. Therefore, they are treated as planktic indeterminate. However, based on the recognized planktic foraminiferal species, one concurrent ranges zone was recognized for both wells. The zone is the *Preaorbulina glomerosa* Zone. Above this zone is an indeterminate zone/interval and above the indeterminate zone is the barren zone because there was no foraminiferal recovery in the zone.

Preaorbulina glomerosa Zone
Stratigraphic intervals: 8420 – 6210 ft (Akata-7)
8250 – 7670 ft (Akata-6)
The zone is characterized/defined by the FDO (First Downhole Occurrence) of *Preaorbulina glomerosa* at the top and LDO

(Last Downhole Occurrence) of *Preaorbulina glomerosa* /*Orbulina universa* at the base. Other planktic forms occurring within the zone are *Globigerina praebulloides, Globigerinoides immaturus, Globigerinoides sacculiferus, Globigerinoides ruber, Globorotalia mayeri and Orbulina bilobata.*
The zone is equivalent to the N8-N9 zone of [25], [26].
Age: Base of middle Miocene.

The stratigraphic interval above this zone is assumed to be equivalent to N9/N10 of [25], [26] because of its stratigraphic position above the positively assigned zone of *Preaorbulina glomerosa*. The age is also assumed to be middle Miocene for the same reason.

3.3.2 Benthic Foraminifera Zones

The benthic foraminiferal assemblages found in the studied wells are moderately well preserved. The poorly preserved are treated as benthic indeterminate. A concurrent range zone was established in Akata-6 well on the basis of stratigraphic range, abundance and association of diagnostic species. The zone is *Brizalina mandorovensis/Eponides eshira* Zone. Owing to the absence of (marker) index benthic species in Akata-7, a taxon/range zone of *Poritextularia panamensis* was established.

Brizalina mandorovensis/*Eponides eshira* Zone
Stratigraphic interval: 8270 ft – 7930 ft /8170 ft (Akata-6)
The benthic foraminifera *Eponides eshira* and *Brizalina mandorovensis* made their First Downhole Occurrence (FDO) at 8130 ft and 7930 ft respectively in Akata-6 well. The Last Downhole Occurrence (LDO) of *Brizalina mandorovensis* at 8270 ft defines the base of the zone. Other important benthic species in this zone include *Bulimina fusiformis* and *Lenticulina inornata*. The age of the zone is Middle Miocene.

Poritextularia panamensis Zone
Stratigraphic interval: 8440 – 3450 ft (Akata-7)
The zone is characterized by the first and last downhole occurrences of *Poritextularia panamensis.* Other benthics associated with it include: *Lenticula inornata, Quinqueloculina microstata, Quinqueloculina seminulum, Textularia laminata, Textularia soldani, Heterolapa bellincionii* and many others.
Age: Miocene.

4 Calcareous Nannofossil Biostratigraphy

The results of the identified calcareous nannofossils for samples selected at critical horizons (condensed sections) are shown in the foraminifera and calcareous nannofossils distribution chart for Akata-6 and Akata-7 wells (figures 4 and 5). Out of 10 samples each that were analyzed, some samples were barren. The calcareous nannofossils observed were used for accurate age determination and correlation of the two wells (figure 7)

A total of eight and nine nannofossils species in Akata-6 and 7 wells respectively were recovered. The flora assemblage comprises mainly of *Sphenolithus heteromorphus, Reticulofenestra pseudoumblicus, Pontosphaera multipora, Sphenolithus moriformis, Coccolithus pelagicus, Coccolithus miopelagicus,* and *Helicosphaera carteri.* Most of the species observed show a rare to common occurrences within the studied intervals. Straigraphically important zonal markers of chronostratigraphic values recorded include *Sphenolithus heteromorphus* and *Reticulophenesatra pseudoumbilicus.* Both species occur within same interval in Akata-7 well. This could be as a result of sediment reworking or sediment mixing during drilling and sampling. Hence the older specie is used in zoning and age determination.

4.1 CALCAREOUS NANNOFOSSIL BIOZONATION

The calcareous nannofossils assemblages found in the critical horizons were compared with the previously established zones (NN - Neogene Nannofossil) of [9] which is a globally recognized zonal scheme. Based on this, one major zone (*Sphenolithus heteromorphus* Zone) belonging to the middle Miocene was established in both wells. The zoning was also based on the assemblages of diagnostic specie and notable calcareous nannofossils event.

Sphenolithus heteromorphus Zone**.**

Stratigraphic interval: 7730 – 8210 ft (Akata-6)

8440 - 8230 ft (Akata-7)

The top and bottom of the zone in Akata-6 was defined by the FDO and LDO of *Sphenolithus heteromorphus* placed at 7730 ft and 8210 ft, making the zone a range zone. The top of the zone in Akata-7 is marked by the FDO of *Sphenolithus heteromorphus* in association with *Helicosphaera carteri.* The based is undefined. The zone is equivalent to the *Sphenolithus heteromorphus* Zone, NN5 of [9].

Age: Middle Miocene (15.0 Ma).

Above the top of the FDO of *Sphenolithus heteromorphus* Zone is also indeterminate owing to absence of index calcareous nannofossil species in the interval.

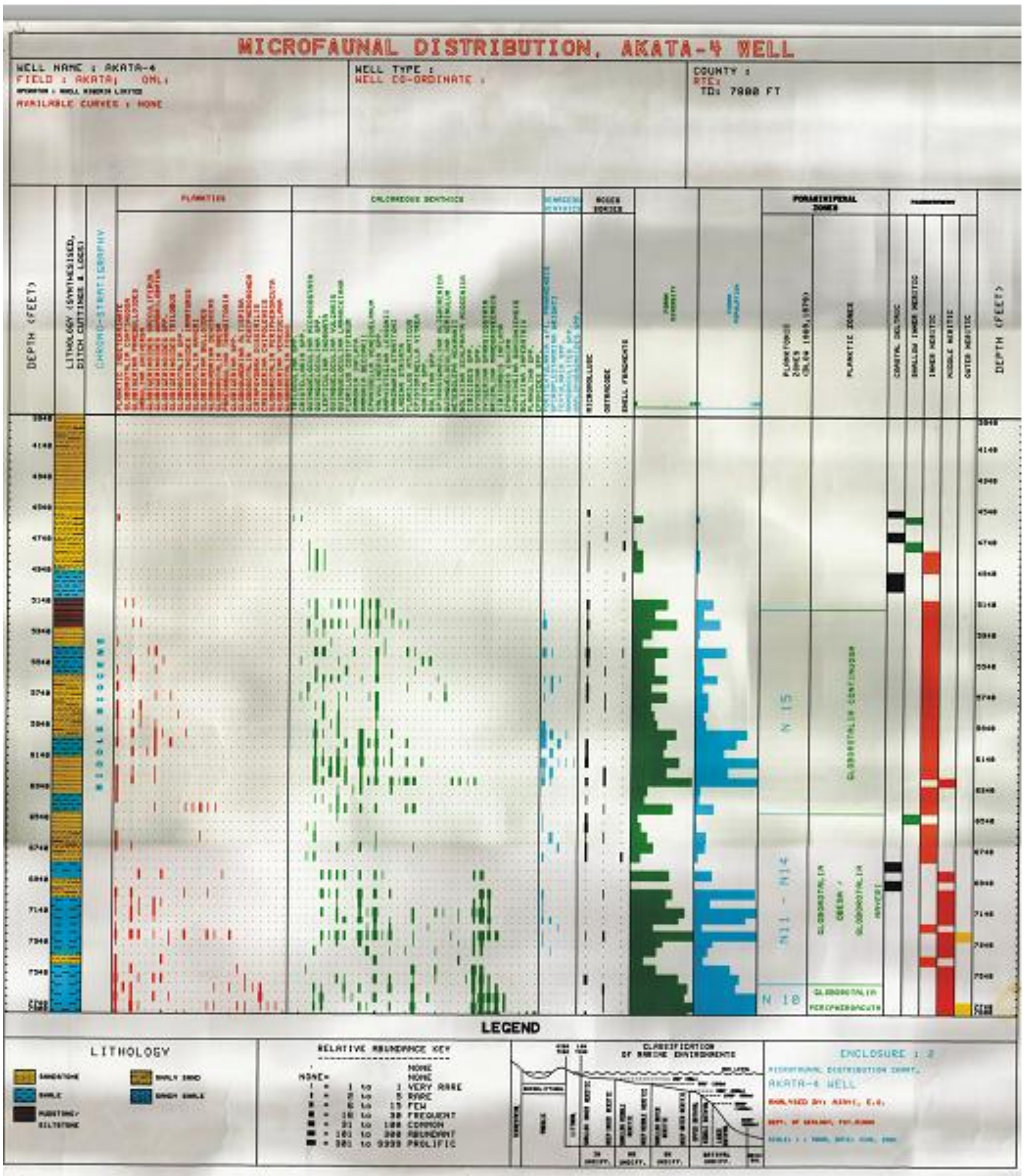

Fig. 2. Foraminifera distribution chart of Akata-4 well.

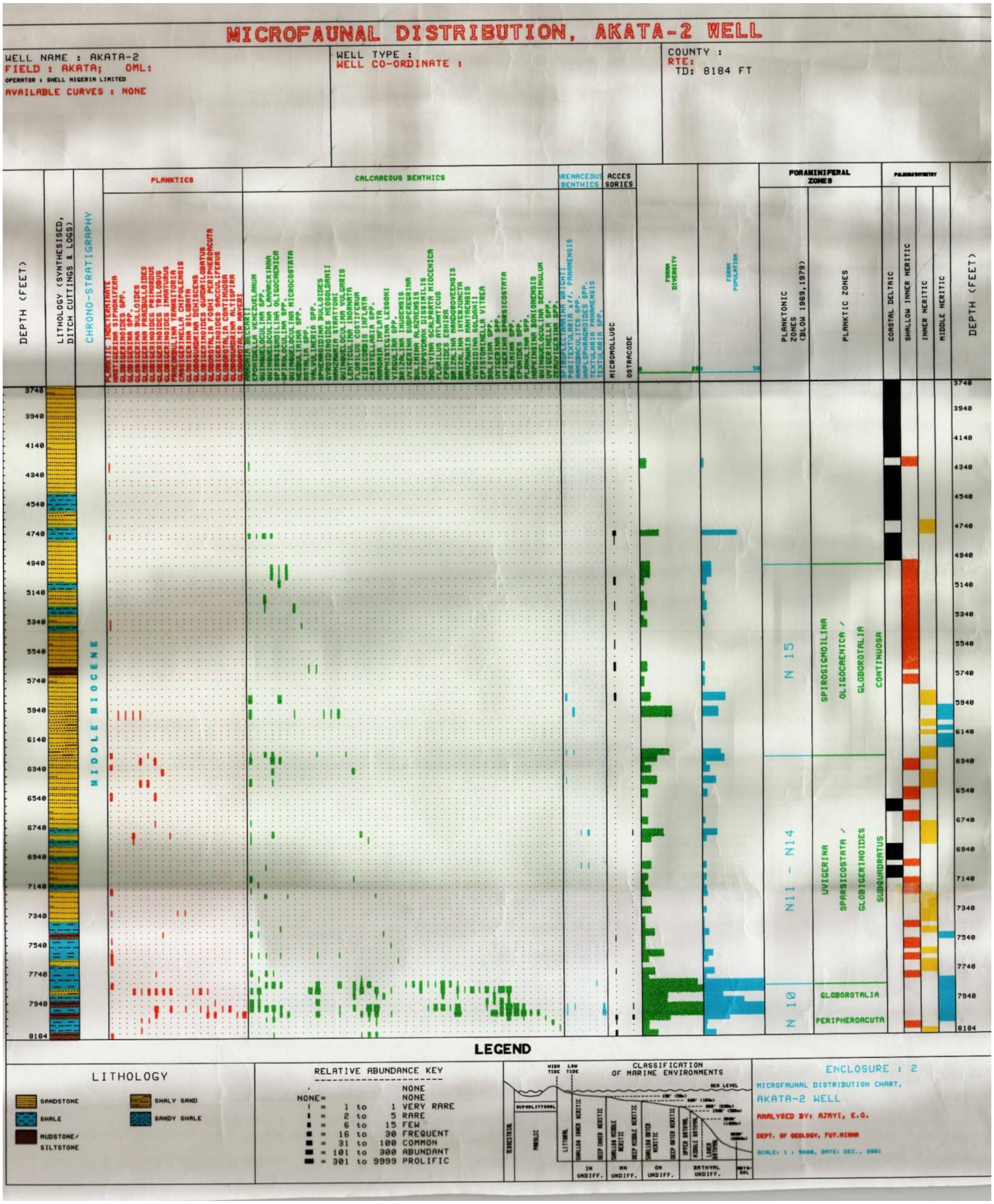

Fig. 3. Foraminifera distribution chart of Akata-2 well.

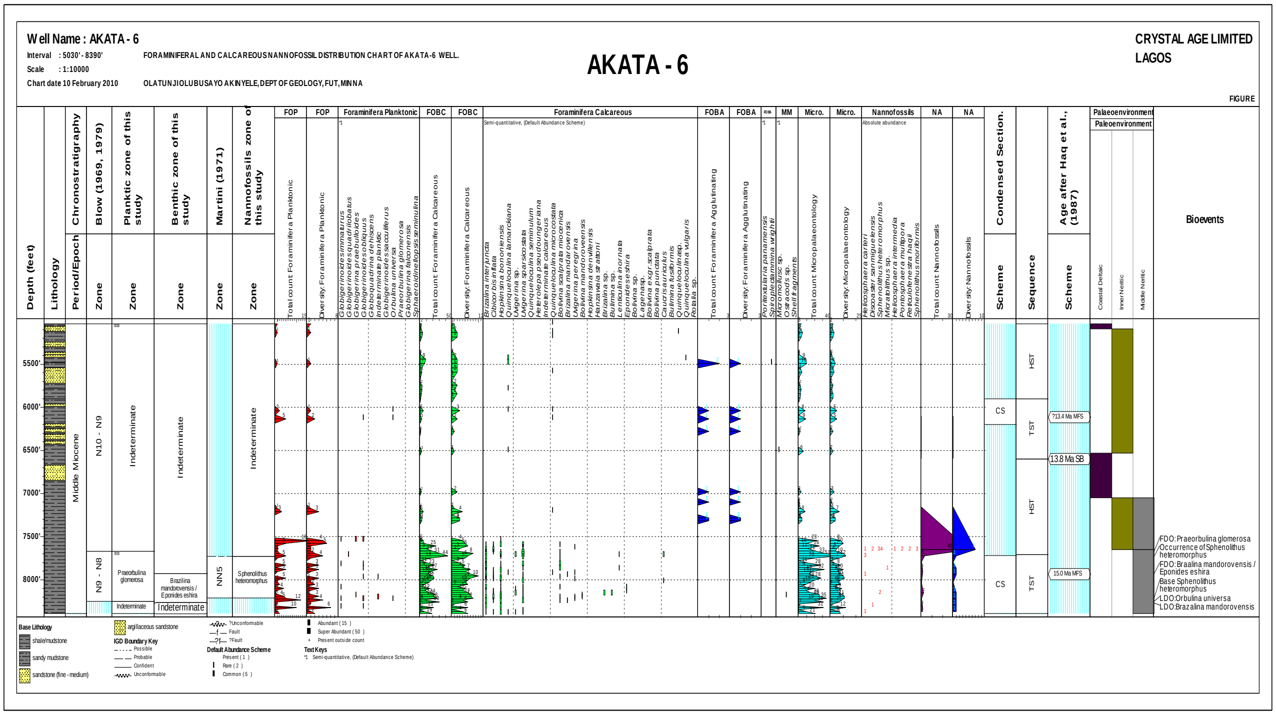

Fig. 4. Foraminifera distribution chart of Akata-6 well.

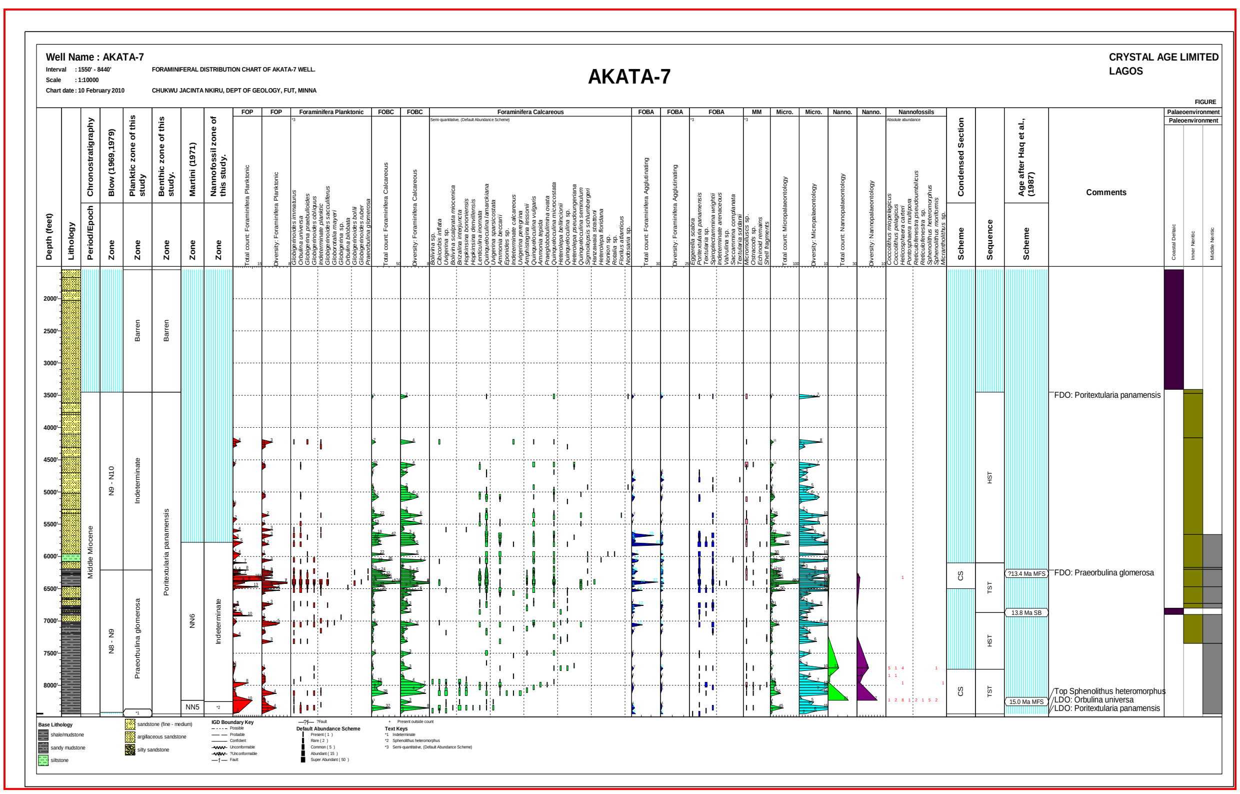

Fig. 5. Foraminifera distribution chart of Akata-7 well.

ISSN 2229-5518

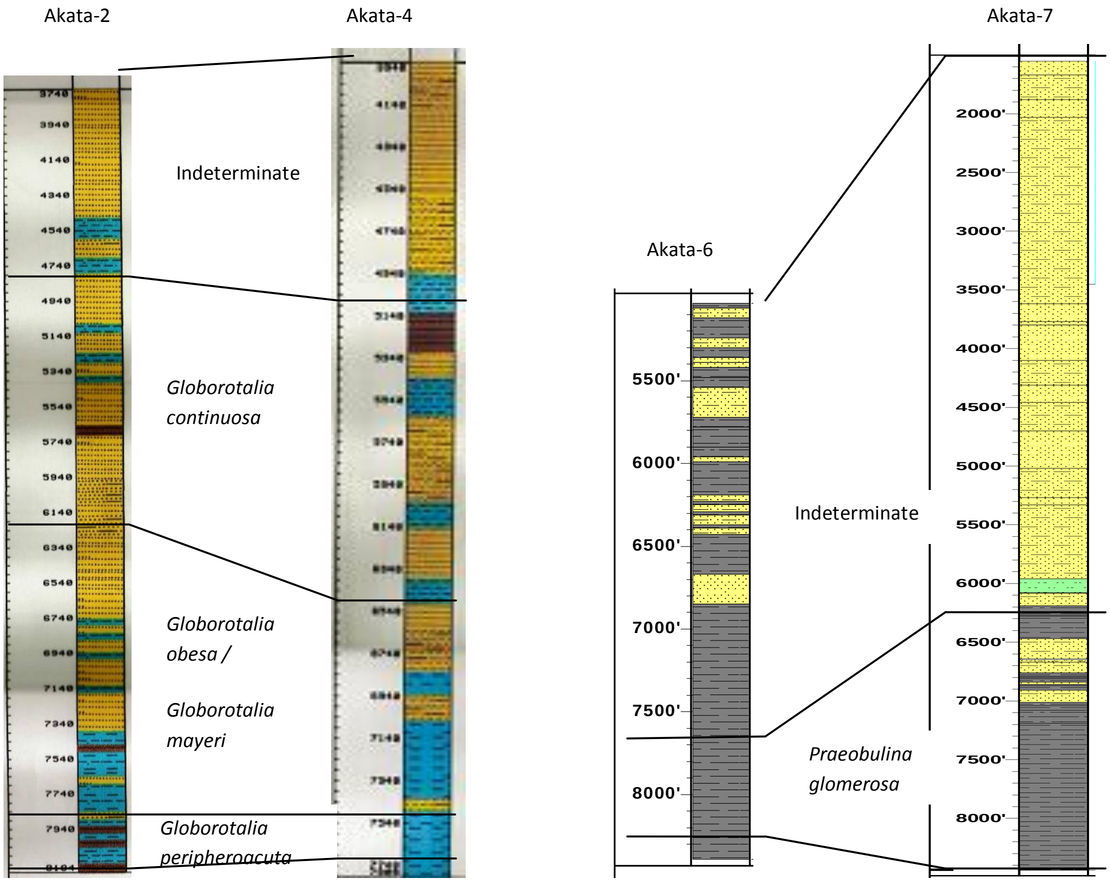

Fig. 6**(a).** Planktic foraminiferal zones correlation of the wells

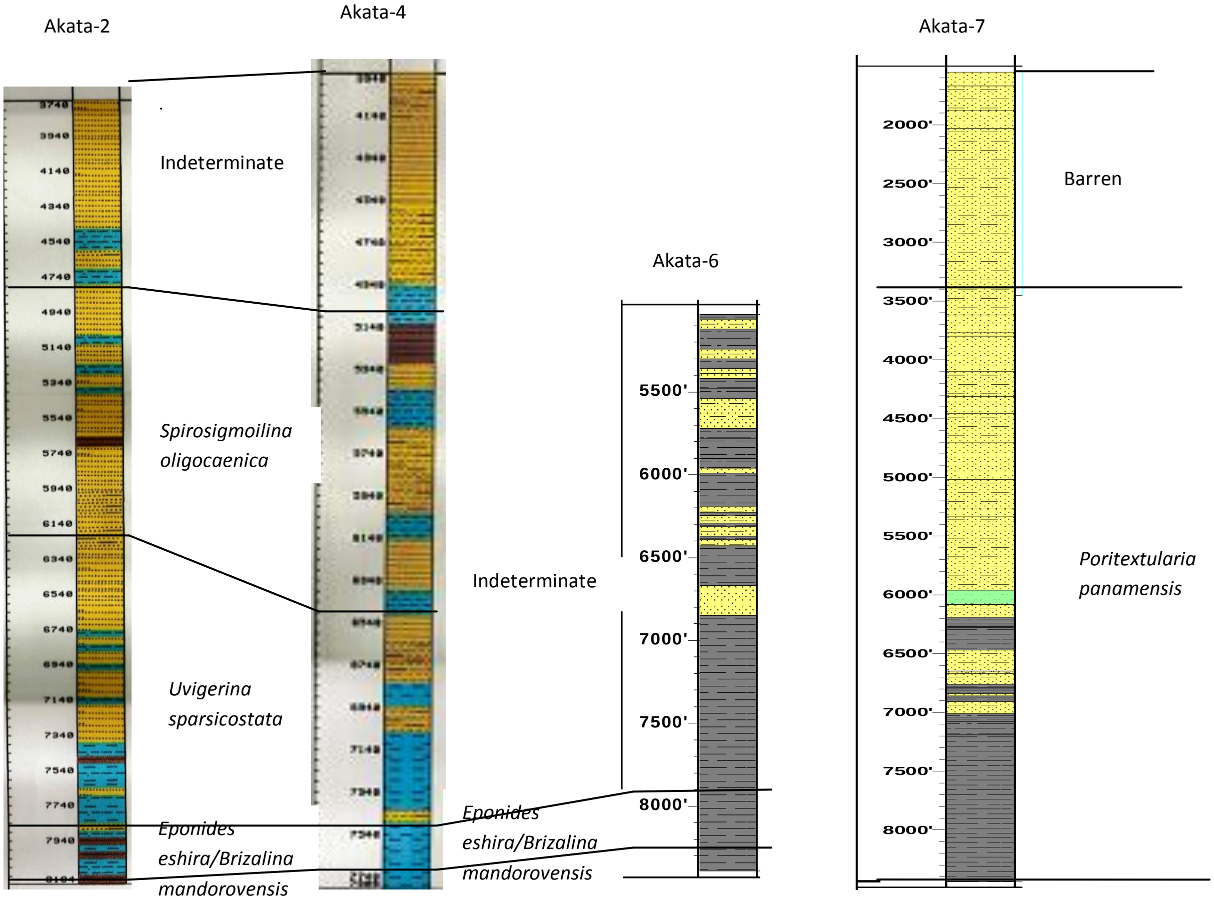

Fig. 6**(b).** Benthic foraminiferal zones correlation of the wells

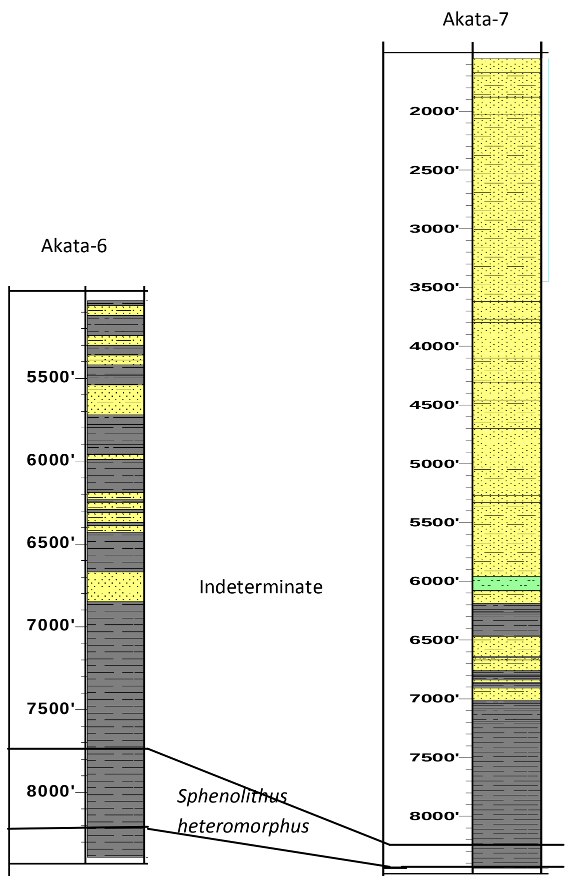

Fig. 7. Calcareous nannofossils zone correlation of Akata-6 and Akata-7 wells.

5 DEPOSITIONAL ENVIRONMENT

Inference of the paleodepositional environment of the studied wells was made based on the biofacies information interpreted from the qualitative and quantitative evaluation of the benthic foraminiferal assemblages. This has been integrated with the lithologic description of the wells, the planktic/benthic foraminifera ratio and presence/absence of ostracode. The criteria outlined for the reconstruction of marine paleoenvironment by [29] were also considered. It is on these bases, that the sequences of the wells are interpreted to have fluctuated from coastal deltaic to marine (inner neritic, inner to middle neritic and middle neritic).

5.1 Coastal Deltaic (Marginal-Marine) Environment

The intervals inferred to be coastal deltaic environment from the study in both wells ranges from 3740 – 4290, 4340 –

4690, 4790 – 4940, 6590 – 6690, 6940 – 7140 ft in Akata-2 and 4540 – 4500, 4690 – 4790, 4940 – 5040, 6540 – 6590 and 6840 – 6990 ft in Akata-4 well, 5030 ft-5050 ft and 6580 ft-7050 ft in Akata 6, 3450 -1550 ft and 6870 – 6810 ft in Akata-7. This inference is based on the following reasons:

1. The intervals are characterized by fine to medium through coarse grained sand or mudstone.
2. The intervals are completely barren of microfauna or contain very few benthic and planktic foraminifera e.g. *Textularia* sp, *Quinqueloculina* sp, *Globigerina* sp, *Globigerinoides obliquus* and planktic indeterminate.

5.2 Inner Neritic Environment

The intervals inferred to be inner neritic environment ranges from 3740 – 4290, 4340 – 4690, 4790 – 4940, 6590 – 6690, 6940 – 7140 ft in Akata 2 and 4540 – 4500, 4690 – 4790, 4940 – 5040, 6540 – 6590 and 6840 – 6990 ft in Akata 4 well, 5650-3450 ft and 9500-7400 ft in Akata-7 and Akata-6 wells respectively. This inference is based on the following criteria:

1. The indicator fauna found here are the miliolids e.g *Quinqueloculina microstata, Quinqueloculina vulgaris, Quinqueloculina seminulum, Quinqueloculina* sp *and Quinqueloculina lamarckiana* in association with *Ammonia beccarii, Lenticulina inornata, Cibcorbis inflata, Heterolepa pseudougerina, Poritextularia panamensis, Textularia soldanii and other Textularia* sp. Porcelaneous type of foraminifera are usually very common in the inner neritic environment [29], [30]. The population count of the benthic forms within these intervals is higher than that of the planktic forms. The average planktic/benthic ratio is low. The diversity is low; it ranges from 0-9 species. This is based on simple species diversity.
2. The lithology of the intervals is composed of fine to medium grained sand, silt and mudstone.

5.3 Inner-Middle Neritic Environment

Depth intervals of the studied wells that are inferred to belong to this environment are from 6810 - 5650 ft and 7350 – 6870 ft in Akata-7 well, and from 7051 ft to 7660 ft in Akata-6 well only. The criteria for this inference are based on the following:

1. The occurrence of the typical forms from inner, middle and outer neritic environments like *Ammonia beccarii, Heterolepa bellinocionii, Poritextularia panamensis, Uvigerina* sp*, Spiroplectamina wrightii, Lenticulina inornata, Hanzawaia strattoni, Amphistegina Lessonii, Saccammina complanata, Sigmoilopsis schlumbergeri, Quinqueloculina* sp *and Textularia* sp*.*
2. There is an increase in the population of the planktics and increase in species diversity (ranging from 0-20 species). Also the planktic/benthic ratio is increased.

3. The lithology is composed of mudstone, sandy mud, silts, clays and sands.

5.4 Middle Neritic Environment

This environment is recognized in Akata-7 well from 8440 ft to 7350 ft and 7670 ft - 8390 ft in Akata-6,and from 5940 – 6020, 6140 – 6240, 7490 – 7540 and 7790 – 8090 ft in Akata 2 well and 6240 – 6300, 6680 – 7190, 7240 – 7340 and 7490 – 7800 ft in Akata 4 well. The criteria for recognition are:

1. The presence of indicator fauna like *Bolivina* sp*, Brizalina interjuncta, Uvigerina* sp*, Bolivina scalprata miocenica, Uvigerina sparsicostata, Eponides* sp*, Lenticulina inornata, Hopkinsina danvillensis, Hopkinsina bonomensis, and Poritextularia panamenmsis, Heterolepa pseudougerina. Spiroplectamina wrightii.*
2. Increase in the number of planktic specimens. The average planktic/benthic ratio is high about 22%. The simple species diversity is also increased, ranging from 0-13 species
3. The lithology is composed of shale, mudstone and silt.

5.5 Outer Neritic Environment

Sequences deposited in the outer neritic environment were observed only within 7240 – 7340 ft and 7720 – 7800 ft in Akata 4 well.

Here, the planktic / benthic ratio here is as high as 30%. Diverse planktic foraminiferal assemblages found here include *Globigerinoides* sp*. Glorbigerina* sp*., Orbulina* sp., *Praeorbulina* sp., *Cassigerina* sp., *Globoquadrina* sp., and *Globorotalia* sp. The main lithology of this environment is constituted by shale and mudstone. Sands are deposited at some intervals in the studied sequence. Accessory minerals are mainly pyrite and mica. There is dominance of calcareous forms over arenaceous ones.

6 SEQUENCE STRATIGRAPHY

Sequence stratigraphy is a concept that involves the integration of biostratigraphy, paleodepth data and characteristic well log signatures with seismic reflection profiles. SP and resistivity log data were available but other necessary well log and seismic data were not available in this study. The interpretation procedures of [31] were employed in this study for the identification of CS, MFS, SB and system tracts.

6.1 Condensed Sections (CS) and maximum flooding surfaces (MFS)

The candidate condensed sections are recognized at 5900 – 6200 ft and 7710 – 8380 ft in Akata-6, 8440-7730 ft and 6470-6200 ft in Akata-7 wells. The criteria used for their recognition are:

1. There are abundant and diverse planktic and benthic microfossils within the intervals.
2. The lithology is mainly shale, deduced from the ditch cutting samples and logs (low resistivity and high SP).

The candidate MFS recognized are at 7840, 6290 and 4990 ft (dated 15 Ma, 13.4 Ma and 11.6 Ma) in Akata-2, 7800, 7290 and 5180 ft (dated 15 Ma, 13.4 Ma and 11. 6Ma) in Akata-4, 7711 and 5901 ft (dated 15 Ma and 13.4 Ma) in Akata-6, 8230 ft and 6330 ft (dated 15 Ma and 13.4 Ma) in Akata-7. By the ages, the MFS are 3-50 million years [32]. The criteria for their identification and dating are based on:

1. The condensed sections, fossil assemblage and association with significant microfossil bioevent.
2. The abundant and diverse planktic and benthic microfauna.
3. Low resistivity and high SP as deduced from the logs.

The 15 Ma was confirmed by the presence of *Sphenolithus heteromorphus* calcareous nannofossil Akata-6 and 7 wells. The 13.4 Ma was not confirmed because of non recovery of index calcareous nannofossil at that depth but was dated because of its stratigraphic position above the positively dated 15 Ma MFS and 13.8 Ma SB when compared with the global sequence cycle chart of [33]. The age range is confirmed by the characteristic middle Miocene planktic foraminifera assemblages recorded in this work. Some of these include: *Globorotalia continuosa*, *Globorotalia mayeri*, *Globorotalia peripheroroacuta, Globorotalia fohsi peripheroronda* [25], [27].

6.2 Sequence Boundaries (SB)

Sequence Boundaries were recognized at 5540 ft and 6940 ft and dated 12.5 MA and 13.8 MA respectively in Akata-2. The sequence boundaries recognised in Akata-4 are at 7600 ft and 6500 ft and dated 12.5 MA and 13.8 MA. In Akata-6 and Akata-7, sequence boundaries were recognised at 6600 ft and 6810ft and have been dated 13.8 Ma. Their recognition and dating are based on the following reasons:

1. There is decrease (few or scarce) in foraminiferal recovery at these depths.
2. From the logs (SP and Resistivity), it is the point of change (sharp lithologic contact) between coarsening upward (forestepping) HST and the fining upward (backstepping) TST.
3. 13.8 Ma SB was dated because of its stratigraphic position in the sequence. The SB immediately above the positively dated 15 Ma MFS is 13.8 Ma when compared with the global sequence cycle chart of [33].

6.3 Transgressive Systems Tracts (TST)

TST was recognized at7690 – 7740, 7190 – 7390, 6940 – 7040, 6790 – 6840 ft in Akata-2, 5900 ft-6599 ft and 7710 ft – 8390 ft in Akata-6 , 8440-7730 ft and 7810 – 6200 ft in Akata-7, because of the following;

1. From the logs, the sequence within the intervals displayed fining upward sequence.
2. The sequences are bounded at the top by MFS and below by transgressive surface.
3. The lithology is composed of sand overlain by fossiliferous pelagic shale.

6.4 Highstand Systems Tracts (HST)

HST was recognized in Akata-2 from 6290 – 6940 ft and 4990 – 5540 ft, in Akata-4 from 7290 – 7600 ft and 5180 – 6500 ft, in

Akata–6 from 5030 ft – 5900 ft and 6601 ft – 7701 ft and in Akata-7 well from 7730-6810 ft and 6200-3450 ft because of the following reasons:

1. From the logs, the lithology is composed of intervals of sand and mudstones which are indicative of shallow marine sandstones, and shelf and slope mudstones.
2. The logs showed a coarsening upwards and shallowing upward sequence.
3. The intervals are bounded by MFS at the bottom and SB at the top.

6.5 Lowstand Systems Tracts (LST)

Lowstand Systems Tracts complexes (slope fan complex and prograding complexes) were only recognized in the studied Akata 2 and Akata 4 wells.

Slope Fan Complex

A slope fan complex was mapped between 7150 and 6500 feet in Akata 2 and between 7340 and 7000 feet in Akata 4. This is essentially a sand-rich proximal slope fan deposit. The parasequences displayed spiky log motifs indicative of sand-shale interbedding.

Prograding Complex

Lowstand prograding wedges occur as follows: 6740 – 6940 ft and 7940 – 7140 ft in Akata 2, and between 6000 ft and 6400 ft in Akata 4. Each prograding complex is characterised by a regular alternation of thin sand and shale bands (incised valley fills deposits) in which the sands become relatively thicker and respectively more prominent up section.

The shelf margin systems tracts were developed at periods of falling sea level. Sediments were, therefore, not transferred as far as the basin floor or slope. The parasequence is supposed to set a display of an overall coarsening (indicated by a Christmas tree log pattern). Such Low-stand prograding Complexes have proved to be among the most rewarding exploration targets throughout the tertiary Niger Delta basin.

7 CONCLUSION

This study was carried out on ditch cutting samples of four wells namely; Akata-2, Akata-4, Akata-6 and Akata-7 wells respectively. The studied depth intervals range from 3700 – 8184 ft in Akata-2, 4080 – 7800 ft in Akata-4, 5030-8390 ft in Akata-6 and 1550-8440 ft in Akata-7 wells respectively. The Lithology of wells is composed of grey shale and mudstone/siltstone beds with intercalation of sand/sandstone beds.

Foraminiferal biostratigraphic characteristics of the wells were analysed. Three planktic and three benthic foraminiferal zones corresponding to the N10 – N15 zones of [25], [26] were established in Akata-2 and Akata-4 wells. The planktic zones are *Globorotalia continuosa* Zone, *Globorotalia obesa* and *Globorotalia mayeri* Zone, and *Globorotalia peripheroacuta* Zone. The *Spirosigmoilina oligocaenica, Brizalina mandoroveensis* and *Eponides eshira* Zones were based on the recovered benthic foraminiferal species. The planktic foraminiferal zone established in Akata-6 and Akata-7 wells is the

Praeorbulina glomerosa Zone which corresponds to N8-N9 zone of [25], [26]. One benthic foraminifera zone, *Brizalina mandorovensis*/*Eponides eshira* was established in Akata-6 well. The benthic foraminiferal zone established in Akata-7 well is the *Poritextularia panamensis* Zone which is a taxon range zone. Calcareous nannofossil biostratigraphic analysis was also carried out in Akata-6 and Akata-7 wells, and the *Sphenolithus heteromorphus* Zone was established. This zone is equivalent or corresponds to the NN5 zone of [9]. This was used to assign an absolute age to the sequence in Akata-6 and 7 wells. This enabled correlation of the sequence with the global sequence cycle chart of [33] and has been found to correlate with geologic events ranging from about 15.0 Ma to 13.4 Ma.

The observed foramniferal assemblages especially the benthics together with other accessory microfauna indicated that the sediments of the four wells were deposited in a lithoral (beach), deltaic to marine (inner neritic, inner to middle neritic, middle neritic and outer neritic) environments.

Based on the lithologic, foraminiferal and paleoenvironmental analysis, it is inferred that the intervals penetrated by both wells correspond to Agbada Formation, and they are of Miocene age. The alternation of sands and shales/mudstones within the sequence provides the combination of source, reservoir and cap rocks essential for hydrocarbon generation, accumulation and trapping.

The Maximum Flooding Surfaces derived from foraminiferal peaks, abundance and diversities together with wireline log (Sp and Resistivity) signatures enabled the subdivision of the well into sequences and systems tracts. HST, TST and LST are the recognized systems tracts in the wells.

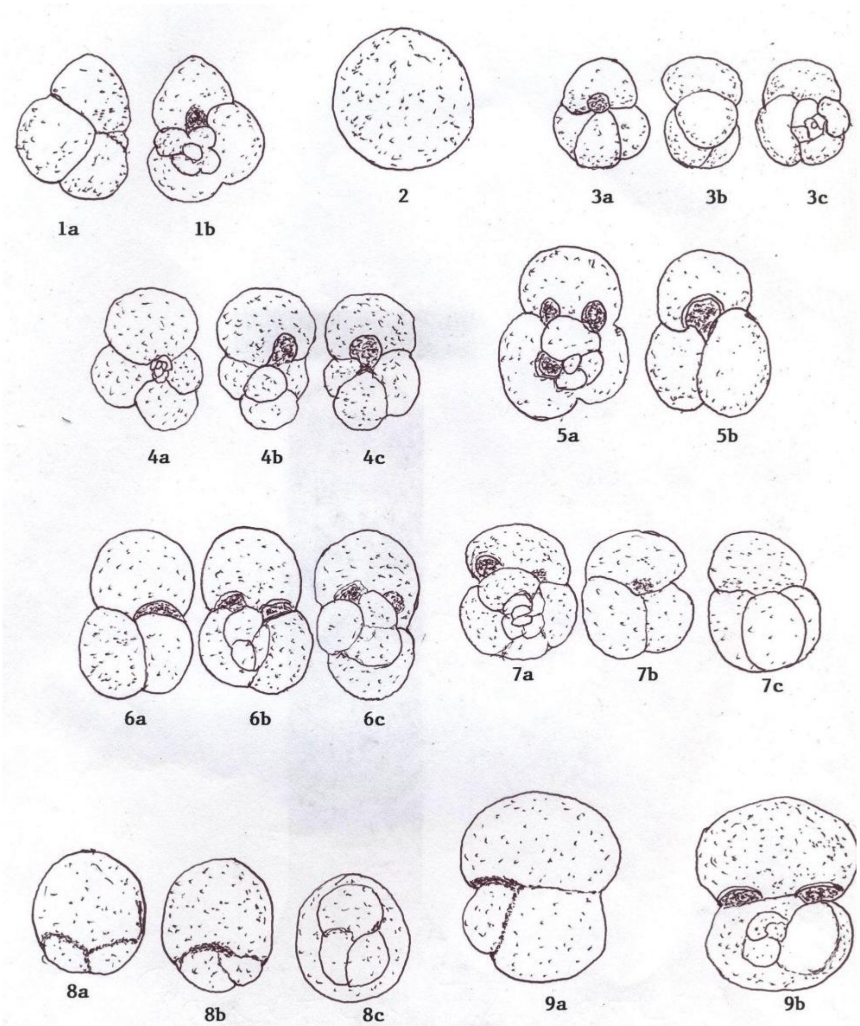

Plate 1. Planktic foraminifera

ISSN 2229-5518

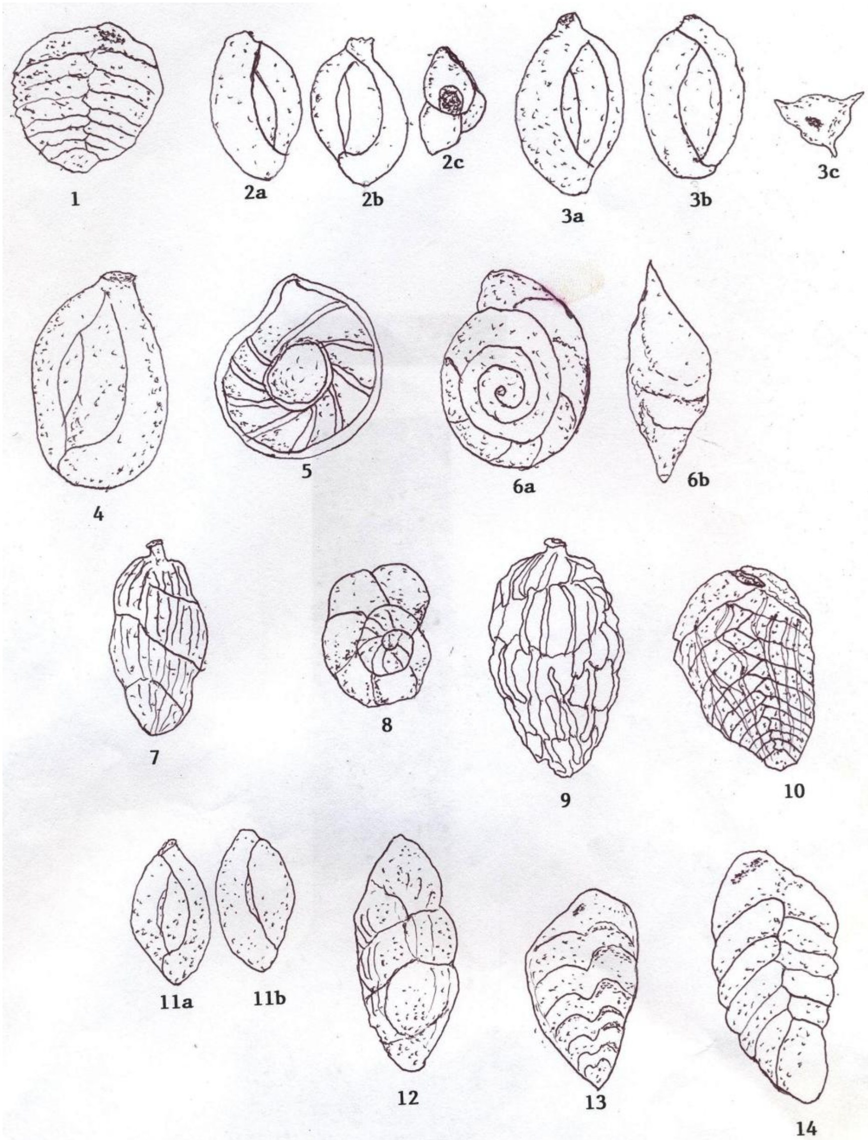

Plate 2. Benthic foraminifera

ISSN 2229-5518

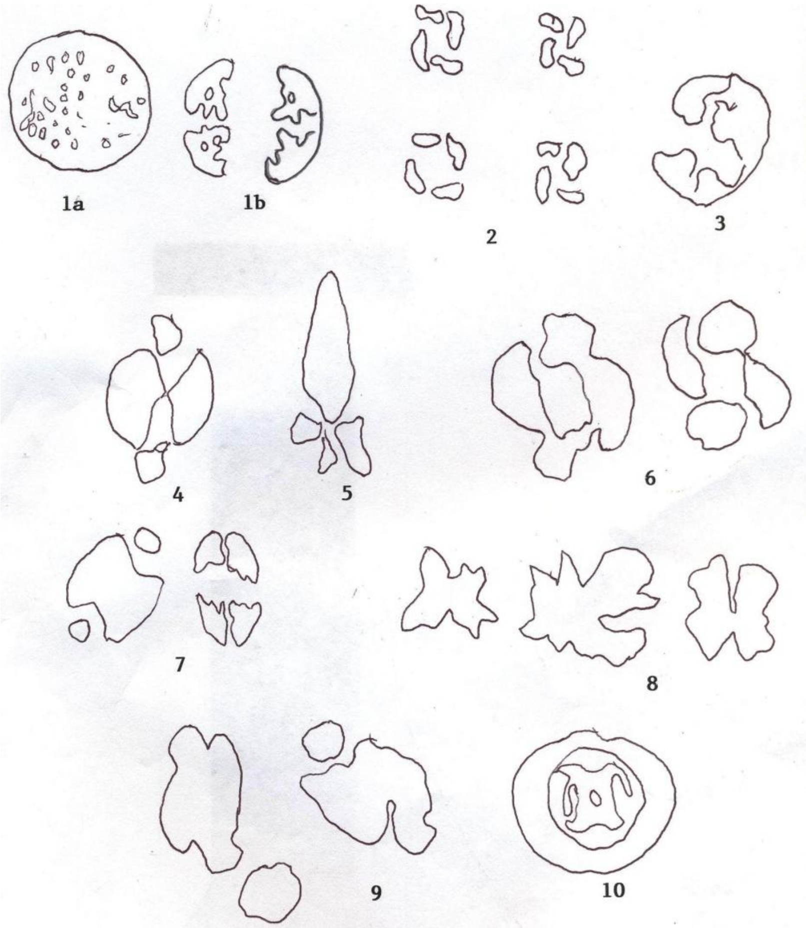

Plate 3. Calcareous nannofossils

Explanation of Plate 1

1. *Globigerinoides sacculiferus* (Brady), X60 (a) Umbilical (b) spiral view
2. *Orbulina universa* (d'Orbigny), X60.
3. *Globigerinoides bolli* (Blow), X50, (a) Umbilical view (b) side view (c)

Spiral view

4. *Globigerina praebulloides* (Blow), X70, (a) spiral view (b) side view (c)

umbilical view

5. *Globigerinoides ruber* (d'Orbigny), X70, (a) dossal view (b) ventral view

6. Globigerinoides immaturus (Le Roy), X100 (a) dorsal view (b) side view

(c) umbilical view

7. Globigerinoides obliquus (Bolli), X60 (a) spiral view (b) side view

(c) Umbilical view

8. Praeorbulina glomerosa (Blow) X100 (A) side view (b) umbilical view

(c) Spiral view

9. Praeorbulina transitoria (Blow) X100 (a) side view (b) spiral view

Explanation of Plate 2:

1. *Poritextularia panamensis* (Cushman) X70
2. *Quinqueloculina microstate* (Natland) X65 (a) dorsal view (b) ventral view
3. *Quinqueloculina lamarckiana* (d'Orbigny) X45 (A) ventral view (b) dorsal view
4. *Quinqueloculina seminulum* (Linne) X100
5. *Lenticulina inornata* (Linne) X50
6. *Heterolepa pseudeoungeriana* (Franzenau) X70
7. *Uvigerina peregrina* (Cushman) X70
8. *Ammonia becarii* (Linne) X60
9. *Uvigerina peregrina* (Cushman) x49, side view
10. *Bolivina interjuncta* (Galloway and MeCulloch) X45, side view
11. *Quinqueloculina lamarckiana* (d'Orbigny) X64 (a) side view (b) opposite side view
12. *Uvgerina sparsicostata* (Cushman and Laiming) X70
13. *Textularia laminata* (Cushman) X70
14. *Bolivina scalprata miocenica*

Explanation of Plate 3

1. *Pontosphaera multipora* (Roth) X1000
2. *Reticulofenestra pseudoumbilicus* (Gartner) X1000
3. *Coccolithus pelagicus* (Schiller) X1000
4. *Helicosphaera carteri* (Kamptner) X1000
5. *Sphenolithus heteromorphus* (Deflander) X1000
6. *Reticulophenestra pseudoumbilicus* (Gartner) X1000
7. *Pontosphaera multipora* (Roth) X 1000
8. *Sphenolithus moriformis* (Bronnimann and Stradner) X 1000
9. *Helicospheara carteri* (Kamptner) X1000
10. *Coccolithus miopelagicus* (Schiller) X1000

ACKNOWLEDGMENT

The authors wish to express their gratitude to the Nigerian Geological Survey Agency (NGSA) Kaduna, Nigeria for the release of the samples, Resistivity and SP logs used for this research.

REFERENCES

[1] E.A. Fayose, "Stratigraphical paleontology of Afowo-1 well, Southern Nigeria,"*J. Minning and Geology*, vol. 5, pp. 1-97, 1970.

[2] S.W. Petters, "Some Late Tertiary foraminifera from parabe-1 well, Eastern Niger Delta," *J. Revista Espanola de micropaleontologia,* vol. 11, pp.1190-1333, 1979.

[3] B.V. Adeniran, "Quantitative Neogene Planktic foraminiferal biostratigraphy of western Niger Delta, Nigeria*," J. Nigerian Association of Petroleum Exploration*, vol.12, no.1, pp. 54-69, 1997.

[4] E.A. Okosun and A. Liebau, "Foraminiferal Biostratigraphy of Eastern Niger Delta, Nigeria," *J. Nigerian Association of Petroleum Explorationist,* vol.14, no.2, pp. 136 -156, Nov. 1999.

[5] M.B. Ozumba and L.C. Amajor, "Evolutionary Relationships in some Benthic Foraminifera of the Middle to Late Miocene, Niger Delta", *J. Nigeria Association of Petroleum Explorationist,* vol.14, no.2, pp. 157-167, Nov. 1999.

[6] O. Ogunjobi "Calcareous Nannofossils Index for Recognition of Marine Transgressions", *J. Nigeria Association of Petroleum Exploration*, submitted for publication.

[7] S.A. Oyebamiji, **"**Calcareous Nannofossil Biostratigraphy of a well in the Niger Delta, Nigeria," M.Sc. Thesis, Dept. of Geology University College, London, 1997.

[8] S.L. Fadiya, "Foraminifera and Calcareous Nannofossil Biostratigraphy and well log Sequence Stratigraphic Analysis of Opolo-5 and Opolo-9 wells, Niger Delta," M.Sc. Thesis, Dept. of Geology, Obafemi Awolowo, University, Ile-Ife, 1999.

[9] E. Martini, "Standard Tertiary and Quaternary Calcareous Nannoplankton from the Experimental Mahole Drilling," *J. Paleontology,* Vol.37, pp. 845 –855, 1971.

[10] H. Okada and D. Bukry, "Supplementary Modification and Introduction of code numbers to Low Latitude Coccolith Biostratigraphic Zonation", *J, Marine Micropaleontology,* Vol.5, pp. 321-325, 1980.

[11] E.A. Farnacci, A. Distefano, D. Rio and A. Negri, "Middle Miocene Quantitative Calcareous Nannofossil Biostratigraphy in the Mediterranean Region", *J. Micropaleontology,* Vol.42, pp. 38-64, 1996.

[12] E. Farnacci, "Calcareous Nannofossil Biostratigraphy of the California Margin Proceedings of the Ocean Drilling Program", *J. Scientific Results*, Vol.167, pp. 3 -40, 2000.

[13] W.H. Blow, "The Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy", *First Geneva Conf. Planktonics,* pp. 199-422, 1969.

[14] W.H. Blow, "*The Cainozoic Globigerinida*", Leiden, E.J. Brill, 2-1413 (1979).

[15] P. Stracher, "Present Understanding of the Niger Delta Hydrocarbon Habitat" *Geology of Deltas*, M.N. Oti and G. Postma, eds. Balkema, Rotter-dam, pp.1-267, 1995.

[16] M.B. Ozumba, "Late Miocene-Pliocene Biostratgraphy Offshore Niger Delta," *J. Nigerian Association of Petroleum Explorationist,* Vol.10, pp. 40-48, 1995.

[17] A.R.Jr. Loeblich and H. Tappan, "Sarcodina Chiefly Thecamoebians and

Foraminiferida",*Treatise on Invertebrate Paleontology, part C, Protista, Vols. 1 and 2,* R.C. Moore, ed., U.S.A., Geological Society of American and University of Kansas Press, pp. C1 –C900, 1964.

[18] J.W. Murray, "*Ecology and Paleoecology of Benthic Foraminifera*", New York, John Willey and Sons Inc. pp.5-397, 1991.

[19] S.W. Petters, "Nigerian Paleocene Benthonic Foraminiferal Biostratigraphy, Paleoecology and Paleobiologeography", *J. Marine micropaleontology*, vol. 4, pp. 85-99, 1979.

[20] S.W. Petters, "Central West African Cretaceous-Tertiary Benthic Foraminifera and Stratigraphy", *J. Paleontographical*, vol.179, pp. 1-104, 1982.

[21] J.A. Postuma, "*Manual of Planktonic Foraminifera*", London, Elsevier Publishing company Amsterdam, pp.1-150, 1971.

[22] B. Haq, J. Hardenbol and P.R. Vail, "The Chronology of Fluctuating Sea Level since the Triassic", *J. Science*, vol.235, pp. 1156-1167, 1987.

[23] J. Backman, "Miocene-Pliocene nannofossils and sedimentation rates in Hatton-Rockall Basin, NE Atlantic Ocean", *J. Stockholm contribution in Geology*, vol. 36, pp. 1-91, 1980.

[24] K. Perch-Nielsen, "Cenozoic Calcareous Nannofossil," *Plankton Stratigraphy,* H.M. Bolli, J.B. Saunders and K. Perch-Nielsen, eds. Cambridge Earth Sciences Series, Cambridge University press, pp. 100-554, 1985.

[25] W. H. Blow, "Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy," *Proc. First International Conf. Planktonic Microfossils*, pp.199 – 422, 1969.

[26] W.H. Blow, "The Cainozoic Globigerinida," Leiden, E.J. Brill, pp.1400-1413, 1979.

[27] H.M. Bolli and J. B. Saunders, "Oligocene to Holocene Low Latitude Planktic Foraminifera", *Plankton Stratigraphy*, H.M. Bolli, J.B. Saunders and K. Perch-Nielsen, eds. Cambridge Earth Sciences Series, Cambridge University Press, pp. 165-262, 1985.

[28] A. Boersma, "Foraminifera," *Introduction to Marine Micropaleontology*, B. U. Haq and A. Boersma, eds. Elsevier North Holland Inc. pp.50- 69, 1978.

[29] O.L. Bandy and R. E. Arnal, "Concept in Foraminiferal Biostratigraphy," *J. American Association of Petroleum Geologists Bulletin*, vol. 44, no.12, pp. 1921 – 1932, 1960.

[30] O.L. Bandy and R. E. Arnal, "Distribution of Recent Foraminifera off the West Coast of Central America," *J. American*

Association of Petroleum Geologists Bulletin, vol. 41, no. 9, pp. 2037 – 2052, 1957.

[31] J.C. Van Wagoner, R.M.Jr. Mitchum, H.W. Posamentier and P.R. Vail, “Key Definitions of Sequence Stratigraphy,” *Atlas of Seismic Stratigraphy, part 2,* A. W. Bally, ed. American Association of Petroleum Geologists studies in Geology, Tulsa Oklahoma 74101, U.S.A. pp. 10-14, 1987.

[32] J.C. Van Wagoner, H.W. Posamentier, R.M.Jr. Mitchum, P.R. Vail, J.F. Sarg, T.S. Loutit, and J. Hardenbol, “An Overview of Sequence Stratigraphy and Definitions,” *Sea level changes, an integrated approach*, C. K. Wilgus, B.
S. Hastings, H.M. Posamentier, J.C. Van Wagoner, C.A. Ross, and C. G.
Kendall, eds. Society of Economic Paleontologist and Mineralogist special publications, vol.42, pp. 39 – 45, 1988.

[33] B.U. Haq and W.A. Beggren, “Late Neogene Calacreous Nannoplankton Biochronology of the Rio Grande Rise (Southern Atlantic),” *J. Paleontology*, vol. 52, pp.1167 – 1194, 1978.