British Journal of Applied Science & Technology
19(5): 1-25, 2017; Article no.BJAST.31998
ISSN: 2231-0843, NLM ID: 101664541

SCIENCEDOMAIN *international*
www.sciencedomain.org

Biostratigraphy of Ochigbo–1 Well, Offshore Niger Delta; Evidence from Foraminifera, Spores and Pollen

Olubunmi C. Adeigbe[1*] and Emmanuel A. Ochigbo[1]

[1]Department of Geology, University of Ibadan, Ibadan, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author OCA designed the study, provided the data. Authors OCA and EAO carried out the laboratory works, managed the analyses and the literature searches for the study. Authors EAO and OCA wrote the first draft of the manuscript. The final draft is the sole responsibility of author OCA.

Article Information

DOI: 10.9734/BJAST/2017/31998
Editor(s):
(1) Ahmed Fawzy Yousef, Geology Department, Desert Research Center, Egypt.
Reviewers:
(1) Prince S. Momta, Ciscon Geological Service Department, Nigeria.
(2) Eyankware Moses Oghenenyoreme, Ebonyi State University, Nigeria.
(3) José Martínez Reyes, University of the Ciénega of Michoacán State, México.
Complete Peer review History: http://www.sciencedomain.org/review-history/18316

Original Research Article

Received 2nd February 2017
Accepted 7th March 2017
Published 23rd March 2017

ABSTRACT

This study involved the palynological and micropalaeontological studies of Ochigbo – 1 well, offshore Niger Delta. A total of Sixty-two (62) ditch cutting samples were composited at intervals of 100 ft covering a total depth of 7,235 ft (3,405-10,640 ft). The samples were subjected to standard procedure for palynological and micropalaeontological studies. The recovered palynomorph and the foraminiferal assemblages were rich over the intervals and were generally good to moderate, both diverse and well preserved. The recovered palynomorphs were used in establishing four palynological zones. These are: *Crassoretitriletes vanraadshooveni*/P700 Zone characterized by the quantitative base occurrence of *Crassoretitriletes vanraadshooveni* and co-occurrence of *Belskipollis elegans, Crassoretitriletes vanraadshooveni, Echiperiporites estalae,* and *Verrutricolporites rotundiporus;* dated Middle Miocene; *Magnastriatites howardii*/P600 Zone characterized by quantitative base occurrence of *Peregrinipollis nigericus* and co-occurrence of *Praedapollis flexibilis, Magnastriatites howardii* and *Monoporites annulatus*; dated Early Miocene –

**Corresponding author: E-mail: olukris2009@gmail.com;*

Late Oligocene; *Retibrevitricolporite obodoensis/protudens*/P500 Zone characterized by the co-occurrence of *Arecipites exilimuratus, Retibrevitricolporite obodoensis/protudens, Verrucatosporites usmensis and Gemmamonoporites sp* dated Late – Early Oligocene and *Racemonocolpites hians/*P400 Zone characterized by the base occurrence of *Racemonocolpites hians.* The recovered foraminferal assemblages revealed the well to have penetrated through the N16-N15 (*Uvigerina subperegrina*) Zone (Late – Middle Miocene), N15-N14 (*Spirosigmolina oligocaenica*) Zone; dated Middle Miocene; N13-N11(*Uvigerina sparsicostata*) Zone; dated Middle Miocene; N5-N4 (*Megastomella africana*) Zone: dated Early Miocene; N2 (*Spiroplectammina wrightii*) Zone; dated Late Oligocene;P18-P15 (*Hopkinsinna bononiensis*) Zone; dated Early Oligocene; P14-P12 (*Uvigerina hourqi*) Zone; dated Late Eocene; P12 (*Uvigerina havanensis*) Zone; dated Late – Middle Eocene; P5-P6/P7 (*Lenticullina pseudomamillegarus*) Zone; dated Early Eocene – Late Palaeocene and ?M18 (*Bolivina afra*) Zone; dated Maastrichtian – Late Campanian.
The palaeoclimatic investigation from the recovered palynomorph and foraminifera assemblages revealed dominantly wet climatic environment which ranges from brackish to deep marine environments subjected to trangressive – regressive alternating environment covering Inner Neritic to Upper Bathyal settings.

Keywords: Foraminifera; palynomorph; stratigraphy; Niger Delta; micropalaeontology; palynology.

1. INTRODUCTION

One of the earliest foraminiferal studies in the Niger Delta region was carried out by [1]. He identified species such as *Miliolina, Tuncatilina, Textularia, Bolivina, Globigerina, Lenticulina* and *Buliminina.* He also proposed a shallow water environment for them. The most comprehensive palynological research work was carried out by [2] on some Tertiary sediment from the world's tropical areas. It is largely a comparative study of palynomorphs of Tertiary sediment from tropical South America, Asia and West Africa. Maximum abundance as well as diversity of foraminifera and mangrove palynomorphs coupled with maximum diversity of coastal plant pollen grains enhances the recognition of maximum flooding surfaces and their condensed section, such

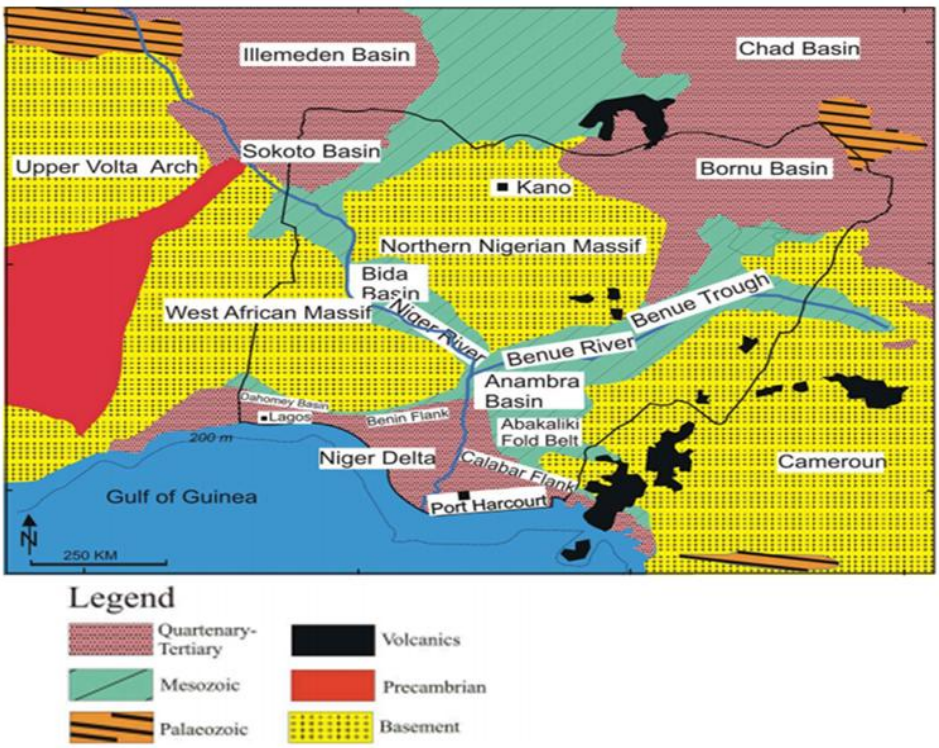

Fig. 1. Simplified geological map of Nigeria showing the location of the Niger Delta Basin and some other basins in Nigeria [3]

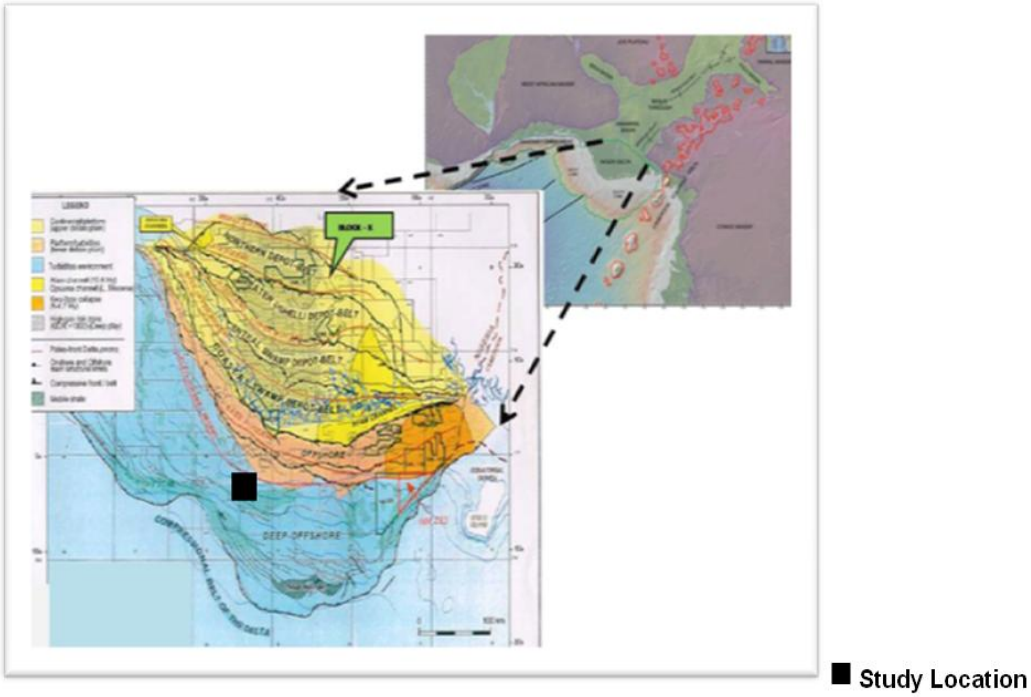

Fig. 2. Niger Delta Depobelt showing the study location (Inset is regional setting of Niger Delta Basin [4])

analysis facilitates better understanding of different facies relationship within sequences [4] in the Niger Delta. The use of integrated data involving the use of palynological and foraminiferal study is applied for this study so as to provide high resolution information on the biostratigraphy and palaeoenvironments.

The Niger Delta, a epicontinental marginal sag basin and petroliferous province is located in the southernmost part of Nigeria. It comprises regressive wedge of clastic sediments which reaches maximum thickness of about 12 km and represents the most significant hydrocarbon province in the West African continental margin. With proven reserve of thirty billion barrels of oil and two hundred and sixty trillion cubic feet of natural gas, ranks the Niger Delta as one of the world's major hydrocarbon provinces [6,7] (Figs. 1 and 2).

2. MATERIALS AND METHODS

2.1 Material

Sixty-two ditch samples from Ochigbo-1 well, offshore Niger Delta were collected from Directorate of Petroleum Resources (DPR) were used for this study. Because of the proprietary nature of the well, the location and the actual name of the well were not given. The samples were composited at intervals of 100 ft and the total depth of well is 7235 ft (3405-10,640 Ft).

2.2 Methods

2.2.1 Lithologic description

The lithology was described using the standard sedimentological approach from the ditch cuttings description. The total thickness of the analyzed interval is 7235 ft. The lithologic description involved the physical observation of the sample with a hand lens.

2.2.2 Palynological analysis

This analysis followed standard procedure for the palynological analysis. The samples were weighed to about 10 gm, soaked overnight in Hydrofluoric acid (HF), and stirred intermittently for effective digestion. To completely remove the fluoro-silicate compounds that usually form from the reaction with HF, the content was again treated with warm 10% HCl and finally completely neutralized with distilled water. This was followed by sieving process with 5 µm mesh in order to remove clay particles present, enhance collection of the debris and to achieve clean slide making. The retrieved debris of the

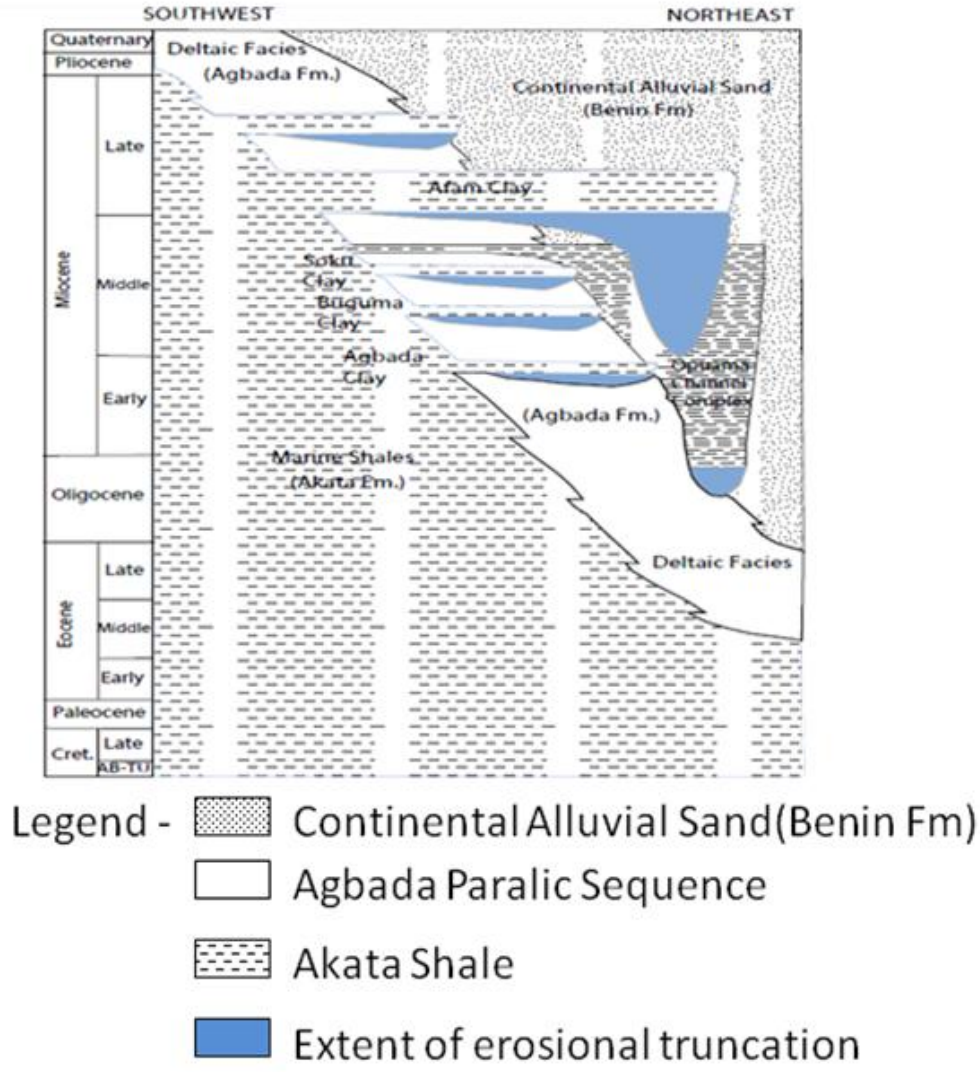

Fig. 3. Stratigraphic column showing three formations of the Niger Delta: Akata, Agbada and Benin Formations [8]

samples was mildly oxidized, followed by heavy mineral liquid separation of the macerals using Zinc bromide (ZnBr2) at 2.1 g/cc. The collected residue was mounted on glass slides with DPX. The preparation method was in accordance with standard methods. Photomicrographs of diagnostic species were taken with Nikon Cool pix P6000 digital camera; abundance of pollen, spores, dinoflagellates, fungal spores, and other stratigraphically significant forms present were determined for each sample.

2.3 Foraminifera Analysis

Standard weights of each sample were disaggregated and were soaked in liquid soap overnight to allow for further disaggregation. The disaggregated samples were then washed under a shower of water over a 63 microns sieve. The washed residue were then dried over a hot plate and sieved into three fractions prior to the picking of the foraminiferal contents. The foraminiferal contents and other microfauna were picked using a picking brush under an Olympus binocular microscope. Foraminiferal and other microfauna were picked, counted, placed in foraminiferas' slides and covered with cover slide for safety and future reference. The slides were properly labeled using both the sample name and interval depths. Micropalaeontological analysis was carried out by identifying the foraminiferal species under light binocular microscope with the help of relevant manuals. The micropalaeontological and statistical data were

plotted using the Stratabug software and photomicrographs of the identified foraminiferal species were made.

Quantitative analysis were made and provided on the charts as follows;

- Total foraminifera abundance per sample expressed in absolute number of individuals
- Total foraminifera diversity expressed in absolute number of species
- Total abundance and diversity of both planktic and benthic foraminifera.

3. RESULTS AND DISCUSSION

3.1 Lithologic Description

From the litholog description carried out, the samples are mainly shale, sandy shale, shaly sand and sand. The shale is fissile, grayish to black while the sand is fine to medium size grains. The shale is intercalated with sandstone and intercalations of whitish sandstone unit.

The observation revealed that the studied well is largely made up of a sequence of fine-grained shale alternating with fine to medium grained sandy shale in the lower part while the upper part is shaly sand, whitish in colour (Fig. 4) [5]. The observed sequence conformed to the Agbada Formation of the Niger Delta basin [9].

3.2 Palynostratigraphy

Palynological zonation of the well is based on the palynofloral assemblages of significant species [10] as well as their stratigraphic distribution with reference to the zonation schemes of Evamy et al. [11]. The section of the well analyzed

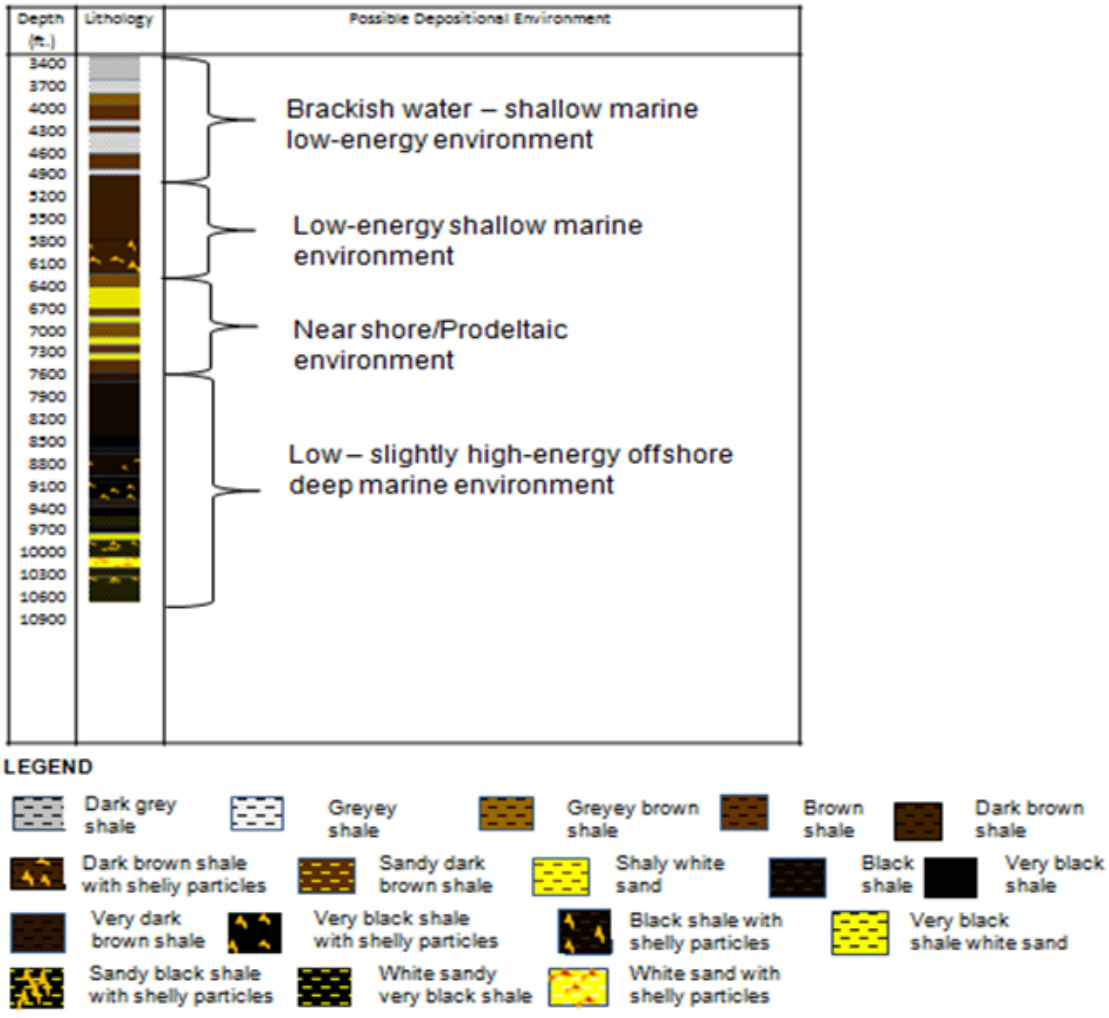

Fig. 4. Lithostratigraphy of Ochigbo – 1 well

has been broadly assigned to the *Crassoretritriletes Vanraadshooveni* /P700 Zone, *Magnastriates Howardii* / P600 Zone, *Retribrevitricolporites Obedensis/Protundens* / P500 Zone and *Racemonocolpites Hians* / P400 Zone. The zones are further subdivided into the P740, P720, P680- P670, P650, P630, P620-P580, P560, P540, P520 and P420 subzones. The well section under study is assigned Late Eocene to Middle Miocene based on the evidence of the palynological study (Fig. 5 and Table 1). Descriptions of the identified palynological zones are provided below (Fig. 11);

3.2.1 *Crassoretitriletes vanraadshooveni*/P700 Zone

Subzone: P740 (3,460 –5,080 ft) Assigned
Age: Middle Miocene
Definition: The subzonal top is probably shallower than the first sample analysed at 3,460 ft and the base is defined by the rich occurrence of *Belskipollis elegans* at 5,080 ft.
Characteristic Features: The occurrence of *Belskipollis elegans* occurs in higher quantities and also regular within the subzone while *Echiperiporites estalae* exhibits higher percentage than underlying subzone and *Verrutricolporites rotundiporus* shows top regular, quantitative and/or top rich occurrence and is found throughout the subzone.

Subzone: P720 (5,080 – 5,320 ft), Assigned
Age: Middle Miocene
Definition: Top marked by the quantitative base rich occurrence of *Belskipollis elegans* at 5,080 ft while its base is defined by the base occurrence of *Crassoretitriletes vanraadshooveni* at 5,320 ft.
Characteristic Feature: *Belskipollis elegans* occurs in low frequencies.

3.2.2 *Magnastriatites howardii*/P600

Subzone: P680 - P670 (5,320– 5,800 ft)
Assigned Age: Early - Middle Miocene.
Definition: The top of the composited subzone is defined by the base occurrence of *Crassoretitriletes vanraadshooveni* at 5,320 ft and its base marked by the quantitative base occurrence of *Magnastriatites howardi* at 5,800 ft.
Characteristic Features: *Magnastriatites howardi* occurs in high percentages while *Racemonocolpites hians* shows an increase compared with the overlying subzone and *Monoporites annulatus* has a base rich occurrence in this subzone.

Subzone: P650 (5,800 –5,920 ft),
Assigned Age: Middle Miocene.
Definition: The Top is defined by the quantitative base occurrence of *Magnastriatites howardi* at 5,800 ft while its base is defined by increase occurrence of *Praedapollis flexibilis* at 5,920 ft.
Characteristic Features: The presence of *Verrucatosporites usmensis* and *Arecipites crassimuratus* exhibit low percentages in this subzone while *Spirosyncolpites brauni* has a quantitative top within this interval.

Subzone: P630 (5,920 –6,280 ft),
Assigned Age: Early Miocene.
Definition: The top is defined by increase *Praedapollis flexibilis* at 5,920 ft and the base is marked by top occurrence of *Praedapollis africanus* at 6,280 ft.
Characteristic Features: It is characterized by the occurrence of *Verrucatosporites usmensis* and *Arecipites exilimuratus* show a top regular occurrence while *Praedapollis flexibilis* and *Peregrinipollis nigericus* exhibit high frequencies than the overlying subzone P650, also the presence of Zonocostites and *Psilatricolporites crassus* and the absence of *Praedapollis africanus*.

Subzone: P620 – P580 (6,280 –6,780 ft),
Assigned Age: Late Oligocene.
Definition: The top of the composited subzone is marked by the top occurrence of *Praedapollis africanus* at 6,280 ft and the subzonal base is defined by the quantitative base of *Peregrinipollis nigericus* at 6,780 ft.
Characteristic Features: *Retibrevitricolporites obodoensis* occurs as frequent as in the underlying subzone P560 while Praedapollis flexibilis and *Striatricolporites catatumbus* are present in abundant and *Peregrinipollis nigericus* occurs in moderate quantities. The presence of *Praedapollis africanus* in single specimen only at the upper part characterized the subzone boundary.

3.2.3 *Retibrevitricolporite obodoensis/protudens*/P500

Subzone: P560 (6,780 – 6,910 ft),
Assigned Age: Late Oligocene
Definition: The top is defined by the quantitative base *Peregrinipollis nigericus* at 6,780ft while the base is marked by the increase in *Retibrevitricolporites obodoensis/protrudens* at 6,910 ft.

Characteristic Feature: *Cinctiperiporites mulleri and Retimonocolpites asabaensis* have a quantitative top occurrence within the interval.

Subzone: P540 (6,910 – 7,150 ft),
Assigned Age: Early Oligocene
Definition: The top is defined by the increase in *Retibrevitricolporites obodoensis/protrudens* at 6,910 ft while its base is marked by the base continuous occurrence of *Arecipites exilimuratus* at 7,150 ft.
Characteristic Features: *Peregrinipollis nigericus and Arecipites crassimuratus* have a base occurrence at or near the base of subzone.

Subzone: P520 (7,150 – 8,100 ft),
Assigned Age: Early Oligocene
Definition: Top of the subzone is defined by the base continuous occurrence of *Arecipites exilimuratus* at 7,150 ft while its base is marked by base occurrence of *Racemonocolpites hians* at 8,100 ft.
Characteristic Features: *Verrucatosporites usmensis* define the very rich top occurrence while the percentage of *Gemmamonoporites sp* is high as compared with the overlying and underlying subzones. The *Praedapollis flexibilis* is present in high quantity throughout and has a base rich occurrence while *Retimonocolpites hians* shows a quantitative base in this subzone.

3.2.4 *Racemonocolpites hians*/P400 Zone

Subzone: P480 & Older (8,100 – 10,640 ft),
Assigned Age: Late Eocene
Definition: The top of the subzone is defined by the base occurrence of *Racemonocolpites hians* at 8,100 ft while its base is tentatively placed at 10,640 ft.
Characteristic Feature: The paucity of palynomorphs especially pollens and spores within this interval limits the well to late Eocene. Some of the Dinoflagellates have a very long age range; therefore it would be difficult to further establish subzones because they are not markers. Examples are *Senegalinium bioavatum*, *Lingulodinium machaerophorum*, *Dapsilidinium stelacum*, *Lejeunecysta sp*, and others.

Table 1. Palynostratigraphy of Ochigbo-1 well [Guided by the work of 11]

Depth (ft)	Chronostratigraphy		Palynological Zone (after Evamy *et al.*, 1978)		Important Palynological Event
	Series	Subseries	Zones	Subzones	
3045				P740	
5080					Base rich Belskipolli *elegons*
5320	Miocene	Middle Miocene	P700	P720	Base occurrence Crassoretotriletes *vanraadshooveni*
5800				P680-P670	Qantitative base Magnastriatites *howardi*
5920		Early to Middle Miocene		P650	Increase Praedapollis *flexibilis*
6280				P630	Top occurrence Praedapollis *africanus*
6780	Oligocene – Miocene	Late Oligocene – Early Miocene	P600	P620-P580	Quantitative base Peregrinipollis *nigericus*
6910	Oligocene	Early Oligocene	P500	P560	Increase Retibrevitricolporite *obodoensis/protudens*
7150				P540	Base continuous Arecipites exilimuratus
8110				P520	Base occurrence Racemonocolpites *hians*
1640	Older & Eocene	Older & Eocene	P400	P480 & Older	TD

3.3 Paleoenvironmental Study and Subdivisions

3.3.1 The upper paralic unit (3,405 – 5,200 feet)

The predominance of mangrove swamp species such as *Zonocostites ramonae, Acrostichum aureum*, *Psilatricolporites crassus Botryococcus brauni and* pteridophytes spores represented largely by species of *Leavigatosporites sp., Verrucatosporites sp.* and *Polypodiaceoisporites sp.* Characterized this interval. Estuarine dinoflagellate cysts such as *Spiniferites ramosus and Tuberculodinium vancampoe,* while the spot occurrence of algae such as *Concentricyst circulus* and *Fungi spore* were also recorded. This assemblage is indicative of an estuarine or brackish-water environment.

3.3.2 The Marine-paralic unit (5,200 – 6,430 feet)

The brackish-water swamp species such as *Acrostichum aureum* and *Botryococcus brauni* and fern spores recorded moderate recoveries. Dinoflagellate cysts increased in abundance and diversity than in the overlying interval. The palynofloral assemblage within this interval suggests deposition in environments fluctuating between marine and nearshore.

3.3.3 The lower paralic unit (6,430 – 7,510 feet)

The proportion of brackish-water swamp species such as *Acrostichum aureum* and *Botryococcus brauni* and fern spores are higher than overlying interval (5,200-6,430). Dinoflagellate cysts become increased in abundance and diversity. The palynofloral assemblage within this interval suggests deposition in environments fluctuating between marine and nearshore.

3.3.4 The marine unit (7,510 – 10,640 feet)

The interval between 7,510 and 10,640ft is totally dominated by marine dinoflagellate cysts such as *Tuberculodinium vancampoe*, *Lejeunecysta sp,Dapsilidinium stelacum Senegalinium bioavatum, Polysphaeridium subtile, Homotrybulium tenuispinosus, Lingulodinium machaerophorum* among others. The occurance of microforaminiferal wall linings and spot occurrence of brackish water species such as *Acrostichum aureum*, *Botryococcus brauni* and pteridophytes spores indicate a deep deposition marine environment.

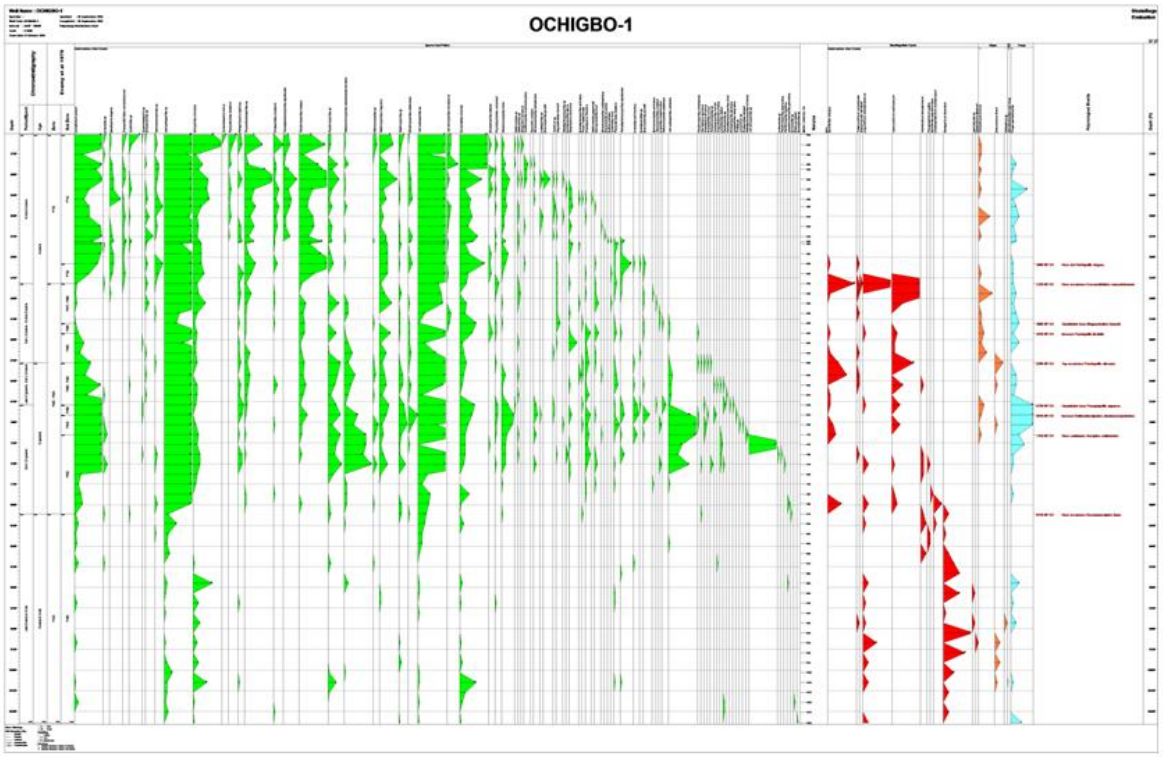

Fig. 5. Distribution and abundance chart of important palynomorphs in Ochigbo – 1 well

3.4 Palaeoclimatic Study and Subdivisions

Palynology is now a strong tool used in determining paleoclimatic conditions. The climate of an area is reflected by its vegetation type [12]. The effect of this variation on floral communities depends on whether such a climate change favours or prejudices against the plant community or individual plant in question [13]. These changes in plant community or variation in their composition or abundance of an assemblage or individual species are usually a direct consequence of variation in climate and / or environment of deposition [13]. The method adopted here is widely practiced and advocated by [12,13,14]. [14] articulated the use of palynomorph abundance and diversity in evaluating sea level changes, palaeoenvironment and palaeoclimatic conditions for Cretaceous sediments in Anambra Basin, Nigeria and its utilization for Recent sediments. For this work, three palynomorph variables represented by *Acrostichum aureum* and *Zonocostites ramonae* for mangrove species depicting wet climate against *Monoporite annulatus* representing Savanna species and dry climate are compared on the bases of their abundance (Fig. 6).

3.4.1 *Monoporites annulatus*

Monoporites annulatus is also the morphogeneric name given to all the pollen species of Poaceae [15,16], they are known to be very homogenous [17] and widely distributed, which makes it easier for recognition. Increase in *M. annulatus* abundance is often used as indicator of large degree of landscape openness [18,19], and increased aridity [20,21].

3.4.2 *Acrostichum aureum*

The genus, *Acrostichumsporitesis* morphologically similar to the spores of *Acrostichum aureum* which has been identified as a principal fern presently growing within mangrove vegetation [22,23,24,25] hence, its adaptation in coastal areas associated with mangrove vegetation, areas inundated with saline waters, open salt marshes, coastal swamps and areas along estuarine rivers [26,25] thus, its use as indicator of wet climatic condtion [16].

3.4.3 *Zonocostites ramonae*

The pollen *Zonocostites ramonae* botanically belongs to the *Rhizophoraceae* [27] therefore increase in the abundance of *Zonocostites ramonae* has been used as an indicator for mangrove vegetation and hence wet climatic condition [28]. As a result of the above, the study well was broken down to four intervals as done above and the paleoclimatic condition of well is done the abundance of *Zonocostites ramonae* (Z. *ramonae*) against *Monoporites annulatus* (*M. annulatus*) and that of *Acrostichum aureum* (*A. aureum*) against *Monoporites annulatus* in each case (Figs. 6, 7, 8, 9 and 10).

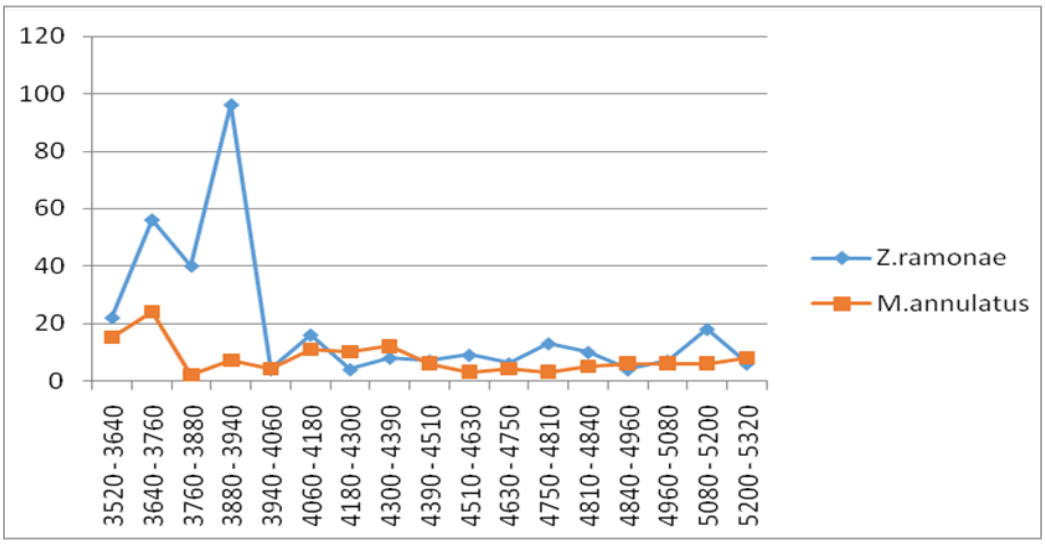

Fig. 6a. Plot of *Zonocostites ramonae* (Z. *ramonae*) against *Monoporites annulatus* (*M. annulatus*) (3,520 ft – 5,320 ft)

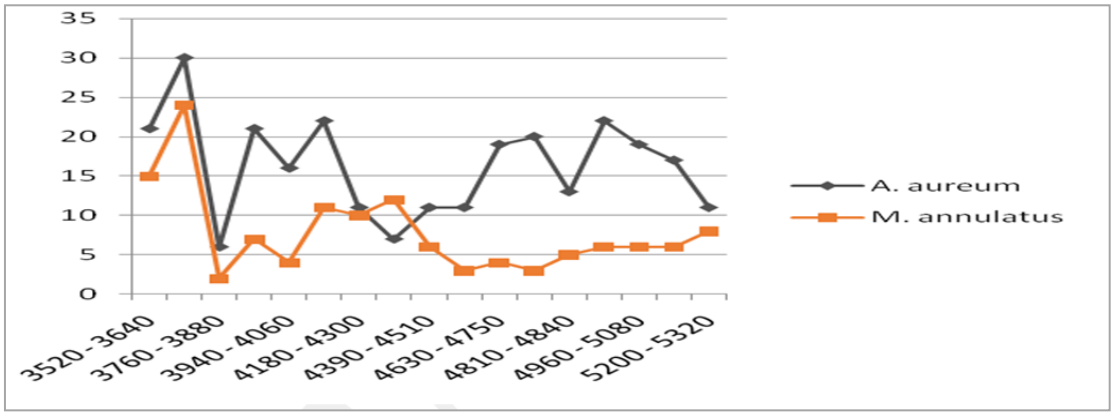

Fig. 6b. Plot of *Acrostichum aureum* (*A. aureum*) against *Monoporites annulatus* (*M. annulatus*) (3,520 ft – 5,320 ft)

From Figs. 6a and 6b, the dominance in abundance of *Zonocostites ramonae* and *Acrostichum aureum* over the relative abundance of *Monoporites annulatus* established wet climatic conditions for interval 3,520 ft to 5,320 ft. while the sediments were belived to have been deposited in a mangrove setting.

From Figs. 6a and 6b, *Zonocostites ramonae* and *Acrostichum aureum* show alternating and relative abundance over one another and thus the the interval revealed and alternating wet and dry climatic condition between 5,320 ft to 6,550 ft.

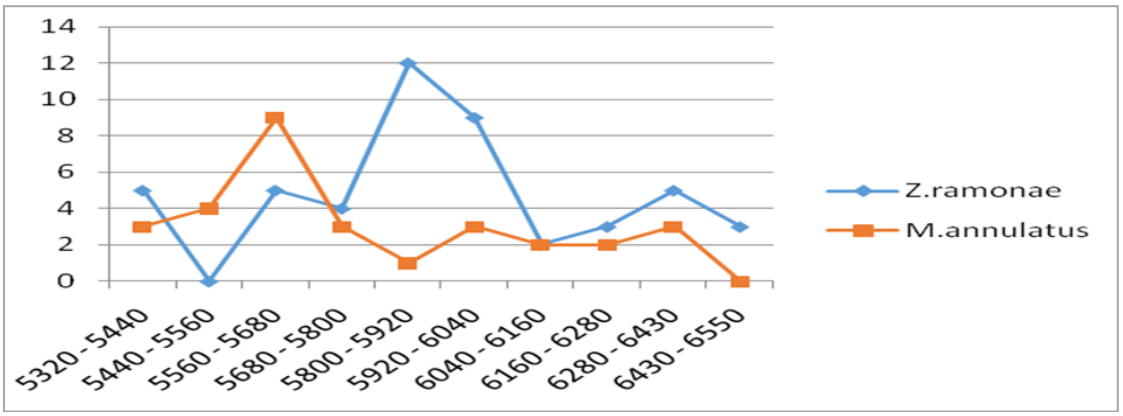

Fig. 7a. Plot of *Zonocostites ramonae* (*Z. ramonae*) against *Monoporites annulatus* (*M. annulatus*) (5,320 ft – 6,550 ft)

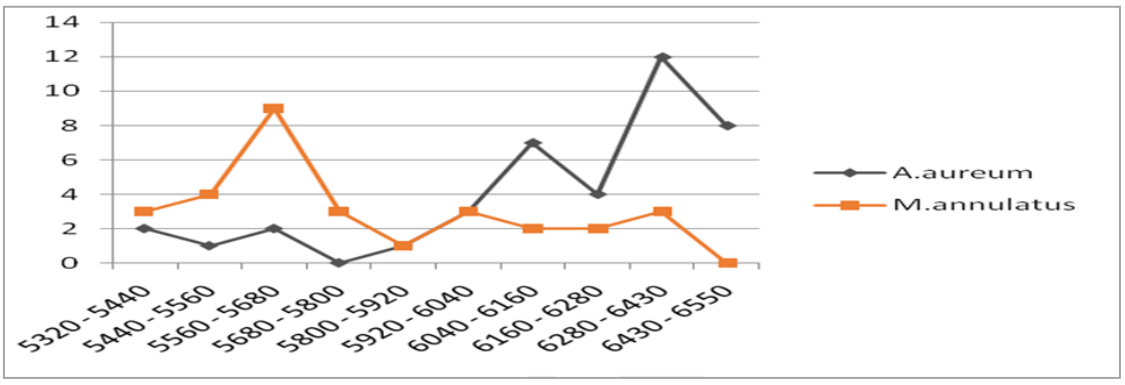

Fig. 7b. Plot of *Acrostichum aureum* (*A. aureum*) against *Monoporites annulatus* (*M. annulatus*) (5,320 ft – 6,550 ft)

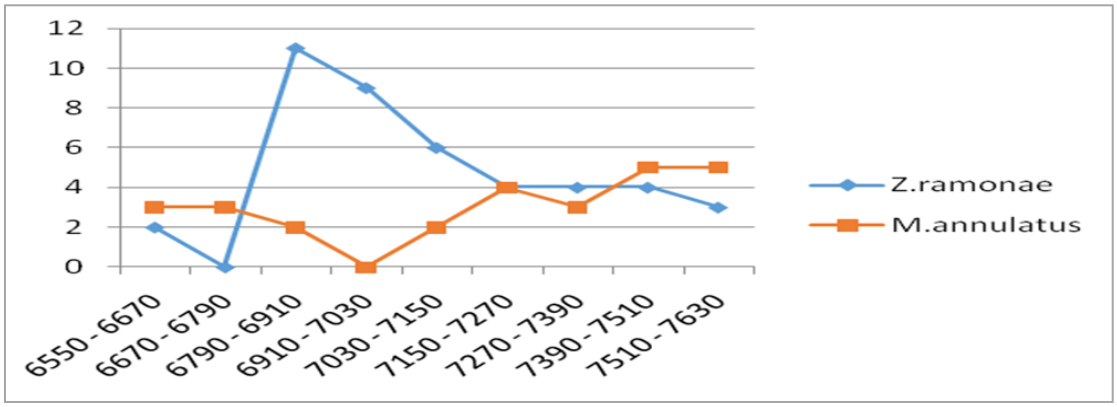

Fig. 8a. Plot of *Zonocostites ramonae* (Z. *ramonae*) against *Monoporites annulatus* (*M. annulatus*) (6,550 ft – 7,630 ft)

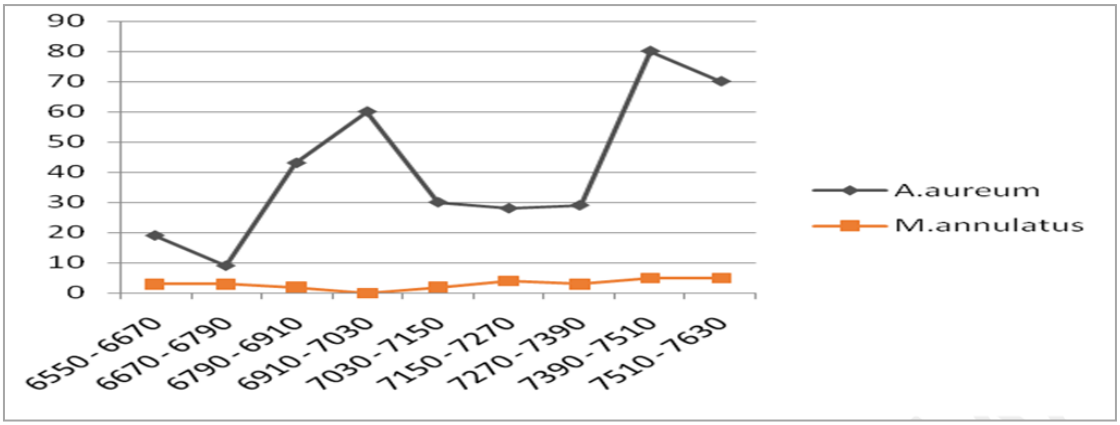

Fig. 8b. Plot of *Acrostichum aureum* (*A. aureum*) against *Monoporites annulatus* (*M. annulatus*) (6,550 ft – 7,630 ft)

In Figs. 9a and 9b, the abundance of *Monoporites annulatus* rose relatively higher than those of *Zonocostites ramonae* and *Acrostichum aureum* within the interval 9,610 ft to 10,640 ft favouring a prevailing dry climatic condition.

The summary of the paleoclimatic and paleoenvironmental condition is shown below (Fig. 10).

The Figs. 8a and 8b also followed similar trend of wet climatic condition.

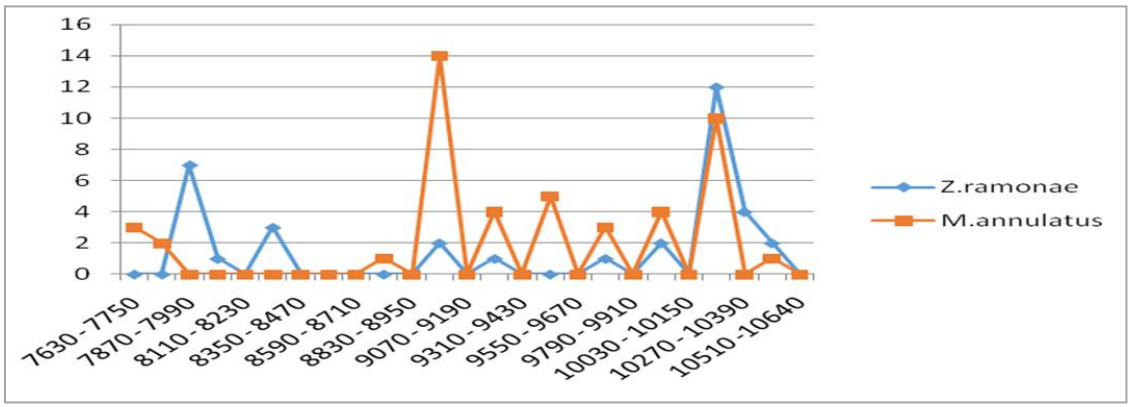

Fig. 9a. Plot of *Zonocostites ramonae* (*Z. ramonae*) against *Monoporites annulatus* (*M. annulatus*) (7,630-10,640)

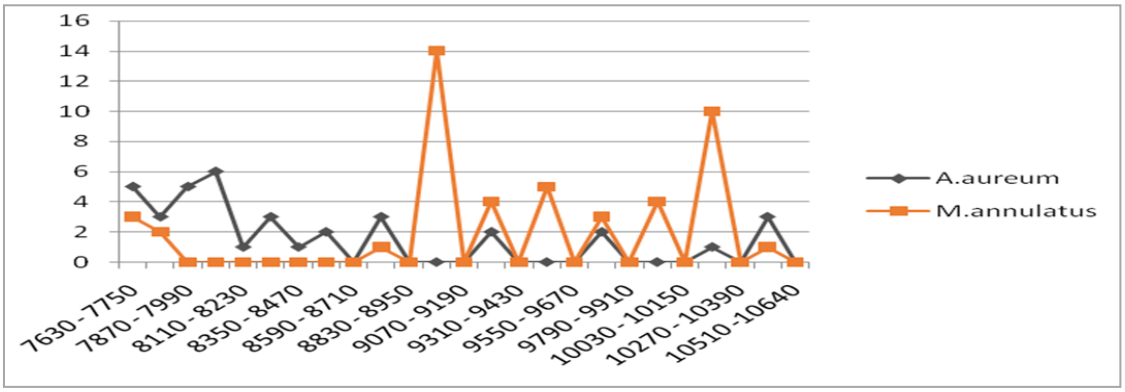

Fig. 9b. Plot of *Acrostichum aureum* (*A. aureum*) against *Monoporites annulatus* (*M. annulatus*) (7,630-10,640)

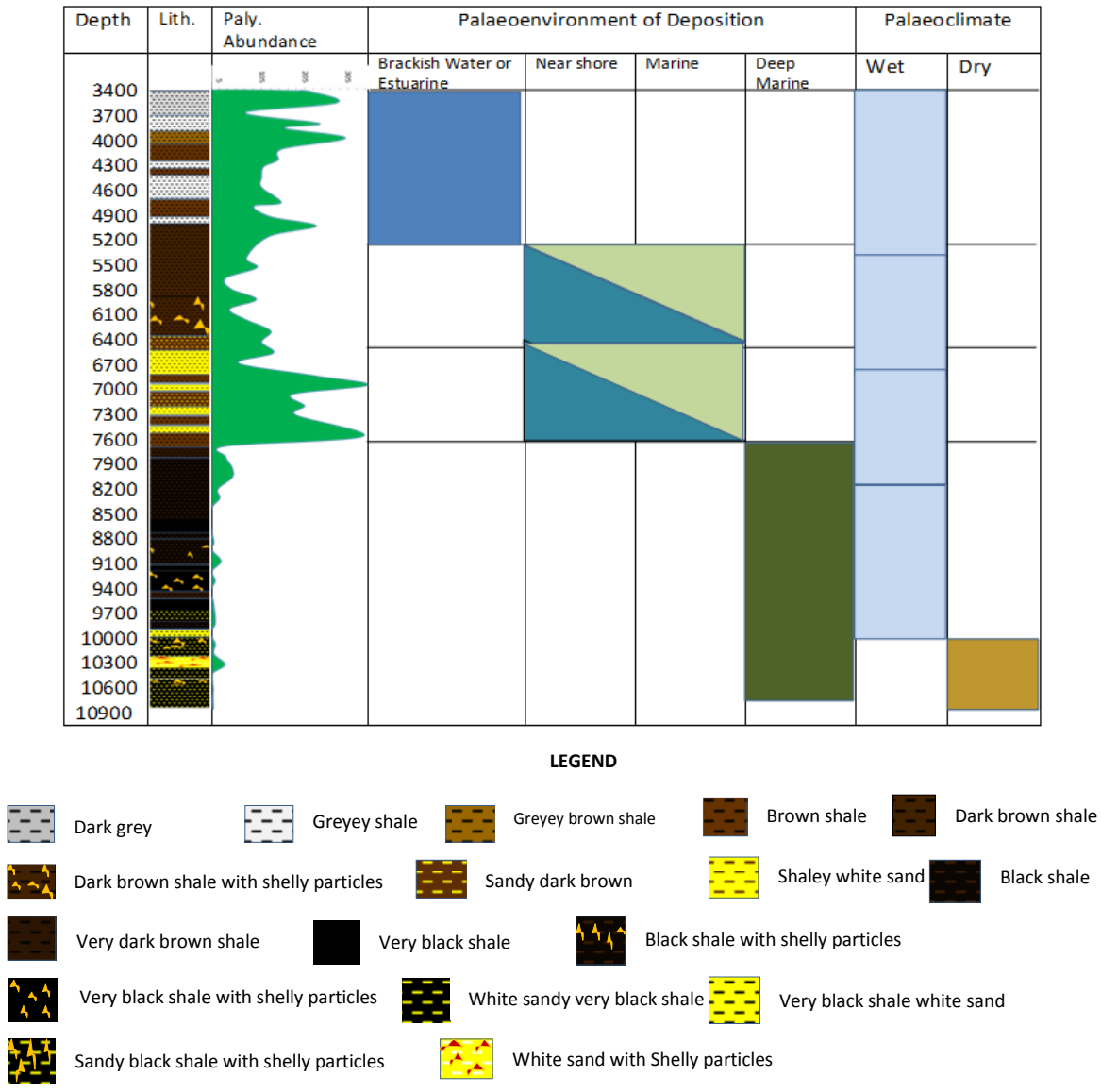

Fig. 10. Palynomorph abundance palaeodepositional environment and palaeoclimatic settings

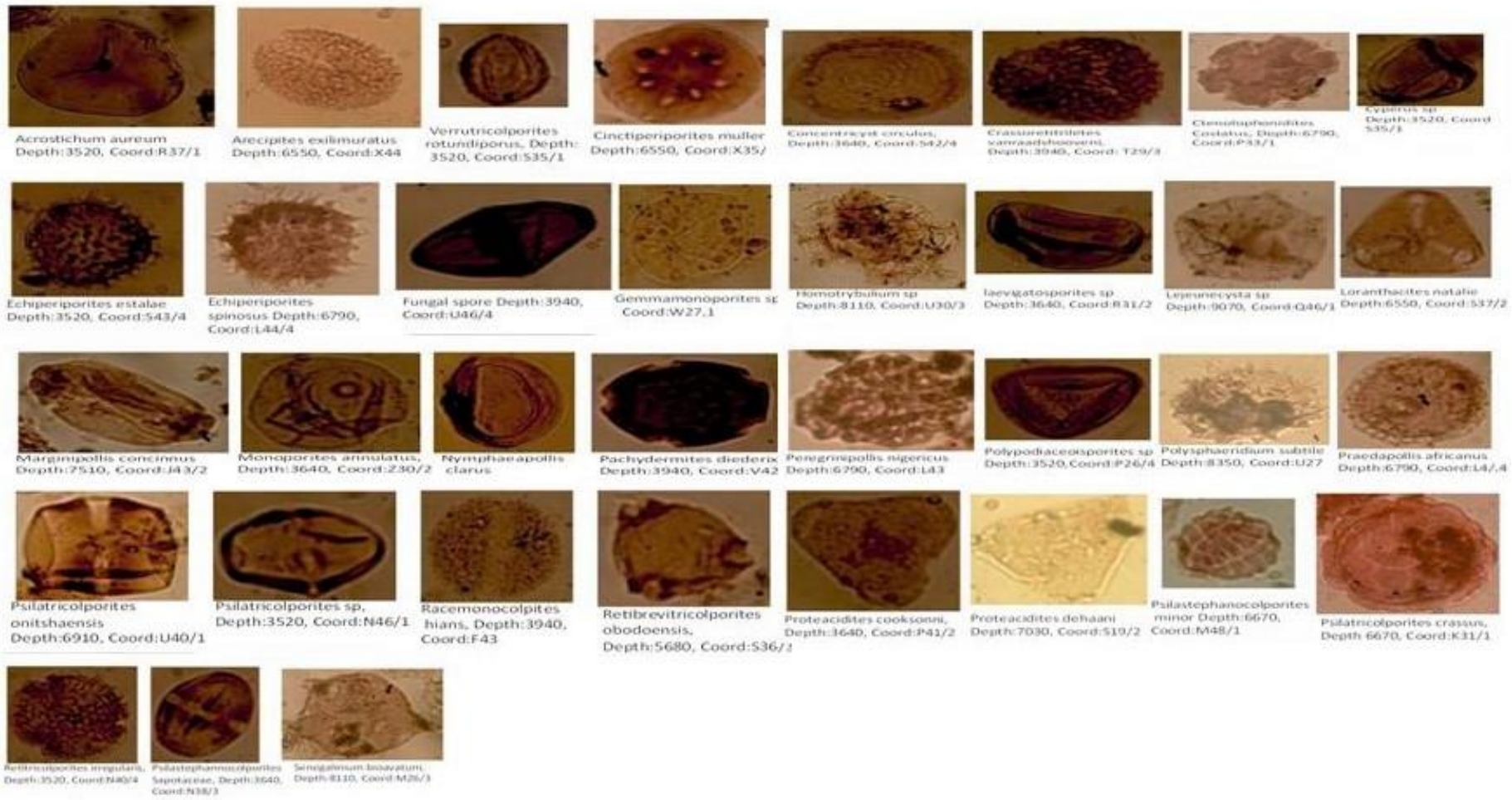

Fig. 11. Some selected Palynomorps photomicrographs recovered from Ochigbo-1 well

3.5 Foraminifera Biostratigraphy

The foraminiferal zonation of the Ochigbo-1well was guided by the works of [29,30,31]. The numerical ages (Ma) were based on the works of [14,32]. Condensed Sections/Maximum Flooding Surfaces were correlated with the Global Cycle Chart of [33].

Planktic foraminiferal species are generally sparse, thus zonation on the basis of planktic species could not be well established but were inferred using the endemic benthic foraminiferal marker species whose stratigraphic distributions have been well established in the Niger Delta and have been calibrated with the planktic foraminifera. The sparse record of planktic species could be due to the paralic nature of the sediments of the Agbada Formation in the Niger Delta.

One hundred and eighty one (181) foraminiferal species were identified. Of these, 170 species (93.92%) are calcareous, while the remaining 11 species (6.08%) are arenaceous. Of the calcareous forms, benthics accounted for 118 species (69.41%) while the remaining 52 species (30.59%) are planktics (Fig. 12).

The results of the analysis indicate that the study interval (3,405 – 10,640 ft) of the Ochigbo-1 well was deposited during Late Miocene? to Late Campanian/Maastrichtian epoch, straddling the N16 to M18 planktic zones of [29,30,31] (Fig. 13, Table 2).

Index species among the recovered foraminiferal assemblages were used to date and zone the intervals as given below.

Interval: 3,405 – 3,760 ft
Planktic zone: N16 – N15 (*Uvigerina subperegrina*) Zone
Age: late? – Middle Miocene
Definition: The top of this zonal interval is placed at 3,405 ft (Top of well) while the base is marked at 3,760 ft by the FDO of *Spirosigmoilina oligocaenica*.
Features: The zone /interval are characterized by the co-occurrences of the following foraminiferal species viz: *Brizalina mandoroveensis, Amphistegina lessonii, Uvigerina subperegrina, Spirosigmoilina oligocaenica, Hanzawaia stratonii, Florilus ex. gr. costiferum,* and *Lenticulina inornata.*This foraminiferal association suggest a middle Miocene age. The FDO of *Spirosigmoilina oligocaenica* at 3,760 ft also confirmed a middle Miocene age. This zone N16 and N15 planktic zone of [29,30] further correlates with *Florilus costiferum/ Globorotalia acostaensis* and *Uvigerina subpergrina/ Globorotalia menardii* zone in the Niger Delta.

Interval: 3,760 – 4,810 ft
Planktic zone: N15 – N14 (*Spirosigmolina oligocaenica*) Zone
Age: middle Miocene
Definition: The top of this zonal interval is marked by the FDO of *Spirosigmoilina oligocaenica* at 3,760 ft.
The base is marked at 4,810 ft by the FDO of *Globigerinoides subquadratus.*
Features: First Downhole Occurrence of *Globigerinoides subquadratus* at 4,810 ft confirms the middle Miocene age of this interval. This zonal interval is characterized by the co-occurrences of *Amphistegina lessonii, Globigerinoides subquadratus, Orbulina universa, Lenticulina inornata, Uvigerina subperegrina, Spirosigmoilina oligocaenica, Brizalina mandoroveensis, Cibicorbis inflata,* and *Poritextularia panamensis.* This zone N15 and N14 planktic zone of correlates with *Spirosigmoilina oligocaenica/ Globorotalia mayeri* and *Globorotalia robusta-lobata* zone in the Niger Delta [29,30].

Interval: 4,810 – 5,560 ft
Planktic zone: N13 – N11 (*Uvigerina sparsicostata*) Zone
Age: Middle Miocene
Definition: The top of this zonal interval is marked by the FDO *Globigerinoides subquadratus* at 4,810 ft while the base is placed at 5,560ft., the terminal depth.
Features: It is characterized by the First Downhole Occurrence of *Globigerinoides subquadratus* at 4,810 ft, FDO *Brizalina interjuncta and Uvigerina sparsicostata* at 4,960 ft. The interval is also characterized by the co-occurrences of *Orbulina universa, Globigerinoides subquadratus, Brizalina interjuncta, Uvigerina sparsicostata, Amphistegina lessonii, Brizalina mandoroveensis,* and *Lenticulina inornata.* This assemblage further confirmed the middle Miocene age while the observed acme of *Amphistegina lessonii* recorded at interval 4,960 – 5200ft suggest a middle Miocene age. The zone N13 – N11 planktic zone of [29,30] correlates with *Uvigerina sparsicostata/ Globorotalia robusta-lobata* and *Globorotalia fohsi* zone in the Niger Delta.

Interval: 5,560 – 5,920 ft
Planktic zone: N13 – N11 (*Uvigerina sparsicostata*) Zone
Age: Middle Miocene
Definition: The top of this zonal interval is placed at 5,560 ft (Top of analyzed interval) and the base is marked at 5,920 ft by the FDO *Globigerinoides primordius*.
Features: The interval is characterized by the co-occurrences of the following foraminiferal aseemblage: *Amphistegina lessonii, Lenticulina inornata, Uvigerina sparsicostata, Heterostegina sp.,* and Valvulineria *sp.* The zone N13 and N11 planktic zone of [29,30] correlates with *Uvigerina sparsicostata/Globorotalia robusta-lobata* and *Globorotalia fohsi* zone in the Niger Delta.

Interval: 5,920 – 6,430 ft
Planktic zone: N5 – N4 (*Megastomella africana*) Zone
Age: Early Miocene
Definition: The top of this zonal interval is marked by the FDO *Globigerinoides primordius* at 5,920 ft and the base is also marked at 6,430 ft by the LDO *Globigerinoides primordius.*
Features: The FDO *Globigerinoides primordius* at 5,920 ft and LDO of *Globigerinoides primordius* at 6,430 ft suggests an early Miocene age at this depth. The acmes of *Uvigerina sparsicostata* and *Eponides eshira/Lenticulina grandis* at 5,920 – 6,430 ft and 6,040 – 6,430 ft respectively also led credence to the interval. This might possibly be a regional event. The interval was also characterized by the co-occurrences of *Eponides eshira, Lenticulina grandis, Uvigerina sparsicostata, Brizalina mandoroveensis, Uvigerina auberiana, Fursenkoina scalaris, Hanzawaia concentrica, Brizalina interjuncta, Altistoma tenuis, Brizalina imperatris, Buliminella subfusiformis,* and *Nonion centrosulcatum.* These foraminifera associations are typical of early Miocene age. Planktic foraminifera assemblage that characterized this zonal interval include; *Globigerinoides primordius, Globorotalia mayeri, Globorotalia continuosa, Globorotalia obesa, Globoquadrina dehiscens, Globoquadrina altispira* and *Globigerinoides subquadratus.* This also gives credence to the assigned early Miocene age. The N5 and N4 planktic zone of [29,30] correlates with *Fursenkoina punctata* and *Megastomella africa/Globigerinoides primordius* and *Catapsydrax dissimilis* zone in the Niger Delta.

Interval: 6,430 – 6,910 ft
Planktic zone: N2 (*Spiroplectammina wrightii*) Zone
Age: Late Oligocene
Definition: The top of this zonal interval is marked by the LDO *Globigerinoides primordius* at 6,430 ft and the base is marked at 6,910 ft by the LDO *Pseudohastigerina sp*
Features: The top of the interval correspond to the LDO *Globigerinoides primordius* at 6,430 ft and the base correspond to LDO of *Spiroplectammina wrightii* and *Pseudohastigerina sp* at 6,910 ft and the bioevents suggests Oligocene age. The interval is also characterized by the co-occurrences of *Hanzawaia concentrica, Eponides eshira, Lenticulina grandis, Bolivina dertonensis, Poritextularia panamensis, Spiroplectammina wrightii, Nonion centrosulcatum, Uvigerina sparsicostata, and Brizalina interjuncta.* This assemblage also confirms a late Oligocene age. The zone N2 planktic zone of [29,30] correlates with *Bolivina interjuncta/Globorotalia opima* and *Spiroplectammina wrightii/Globorotalia opima* zone in the Niger Delta.

Interval: 6,910 – 7,270 ft
Planktic zone: P18 – P15 (*Hopkinsinna bononiensis*) Zone
Age: Early Oligocene
Definition: The top of this interval is marked by the LDO *Pseudohastigerina sp.*at 6,910 ft. The base is marked at 7,270 ft by the FDO *Uvigerina hourqi.*
Features: The LDO of *Spiroplectammina wrightii* at 6,910 ft suggests an early Oligocene age while FDO of *Uvigerina hourqi* at 7,270 ft. The interval is 1 also characterized by the co-occurrences of *Hopkinsinna bononiensis, Eponides eshira, Lenticulina grandis, Brizalina imperatrix, Buliminella subfusiformis, and Hanzawaia concentrica,* this assemblage conforms to the early Oligocene age. The planktic zone P18-P15 of [29,30] correlates with *Hopkinsinna bononiensis/Globigerina ampliapertura, Uvigerina gallowayi/Cassigerinella chipollensis, Nonion oyae/Globorotalia cerroazullensis* and *Bolivina ihuoensis/Globorotalia cerroazullensis* zones in the Niger Delta.

Interval: 7,270 – 7,510 ft
Planktic zone: P14 – P12 (*Uvigerina hourqi*) Zone
Age: Late Eocene
Definition: The top of this zonal interval is marked by the FDO *Uvigerina hourqi* at 7,270 ft and the base is marked at 7,510 ft by the FDO *Uvigerina gallowayi.*
Features: The interval is marked by FDO *Uvigerina hourqi* at 7,270 ft and the base is FDO

of *Uvigerina gallowayi* at 7,510 ft which suggests late Eocene age. The acme of *Uvigerina hourqi* recorded at 7,270 ft to 7,630 ft is a regional event in the Niger Delta and it also corroborated the late Eocene age. The interval also characterized by the co-occurrences of*, Hopkinsinna bononiensis, Altistoma scalaris, Eponides eshira, Lenticulina grandis, Brizalina imperatrix, Buliminella subfusiformis,* and *Hanzawaia concentrica,* which also confirms late Eocene age. The zone P14 - P12 planktic zone of [29,30] correlates with *Uvigerina hourqi/Turborotalia rohri, Eponides africana/ Turborotalia rohri* and *Hopkinsina danvillensis/Truncorotaloides pomeroli* zones in the Niger Delta.

Interval: 7,510 – 7,870 ft
Planktic zone: P12 (*Uvigerina havanensis*) Zone
Age: late – Middle Eocene
Definition: The top of this zonal interval is marked by the FDO *Uvigerina gallowayi* at 7,510 ft.
The base is marked at 7,870 ft by the occurrences of *Globigerina triculinoides.*
Features: marked by FDO *Uvigerina gallowayi* at 7,510 ft and characterized by the co-occurrences of*, Uvigerina hourqi, Hopkinsinna bononiensis, Eponides eshira, Lenticulina grandis, Hanzawaia concentrica, Uvigerina sparsicostata, Brizalina imperatrix and Buliminella subfusiformis,* This assemblage confirms late/middle Eocene age. The zone P12 planktic zone of [29,30] correlates with *Altistoma tenuis*/*Uvigerina havanensis/ Chiloguembelina cubensis* zones in the Niger Delta.

Interval: 7,870 – 7,990 ft
Planktic zone: P5-P6/P7 (*Lenticullina pseudomamillegarus*) Zone
Age: early Eocene – Late Paleocene
Definition: The top of this zonal interval is marked by the occurrence of *Globigerina triculinoides* at 7,870 ft and the base is placed at 7,990 ft.
Features: The occurrences of *Globigerina triculinoides* and *Morozovella quetra* at 7,870 ft. Suggest a late Paleocene age. The interval is characterized by the co-occurrences of *Uvigerina hourqi, Hopkinsinna bononiensis, Eponides eshira, Lenticulina grandis, Hanzawaia concentrica, Uvigerina sparsicostata, Cassigerinella chipollensis and Brazilina ihuoensis,* This assemblage confirms a late Paleocene age. The occurrences of *Globigerina triculinoides and Morozovella quetra* at the last sample analyzed (7,870 – 7,990 ft) confirmed late Paleocene age of this interval. The planktic zone P5-P6/P7 of [29,30] correlates with *Eponides pseudoelavatus/Morozovella subbotinae* and *Lenticulina pseudomamillegarus/ Morozovella velascoensis* zone in the Niger Delta.

However, it should be noted that the admixtures of zonal markers and missing of some zones e.g N8 to N3 and P19, P11 to P8 in the course of the study suggest possible erosional activities, faulting/unconformity.

Interval: 8,590 – 10,640 ft
Planktic zone: M18 – (*Bolivina afra*)? Zone
Age: Maastrichtian - Late Campanian
Definition: The top of this zonal interval is marked by the FDO *Bolivina afra* at 8,590 ft and the base is placed at 10, 640 ft, the Terminal Depth of the analyzed well.
Features: The interval is characterized by FDO *Bolivina afra Hedbergella holmdellensis* (Maastrichtian age) at 8,590 ft. Also, FDO *Praebulimina genus (P.fang, P. prolixa, laddi)* at 8,710 ft and *Globotruncana aegyptiaca* (Maastrichtian age) at 9,550 ft. The interval 8710 ft to 9550 ft is characterized by acme of foraminiferal species dominated by the species of *Bolivina afra* and genus *Praebulimina (P. fang, P. prolixa, P. laddi, P. longa*) which could be a regional transgressive event. Also the interval also characterized by the co-occurrences of*, Praebulimina fang, Praebulimina lata, Praebulimina laddi, Praebulimina prolixa, Praebulimina longa, Gavelinella guineana, Gavelinella intermedia, Orthokaestenia clavata,* and *Lenticulina stephensoni.* The planktic assemblage is characterized by *Hedbegella monmouthensis, Hedbergella holmdellensis, Hedbergella planispira, Heterohelis reussi, Heterohelix globulosa,* and *Globotruncana aegyptiaca* suggesting late Campanian to Maastrichtian age. The planktic zone M18? of [29,30] correlates with *Bolivina afra/Praebulimina* and *Hedbergella holmdellensis* zone in the late Campanian to Maastrichtian age in the Niger Delta (Fig. 13).

However, the admixtures of zonal markers and absence of P4 to P1 zones within this interval may probably be due to erosional activities, faulting/unconformity.

The presence of foraminiferal assemblages such as *Amphistegina lessonii, Heterostegina sp., Poritextularia panamensis, Quinqueloculina microcostata, Valvulineria sp., Quinqueloculina sp, Lenticulina inornata, Planulina sp, Spiroplectammina wrightii,* and

Haplophragmoides were used in establishing this depositional environment. It is recorded over the following intervals; 3,880 – 3,940 ft, 5,200 – 5,920 ft and 6,790 – 6,910 ft of Ochigbo-1 well (Fig. 14).

3.6 Middle Neritic

This paleoenvironmental setting is characterized by relatively high abundance and diversity of foraminiferal species. The abundance of Planktic foraminiferal species suggest open marine setting. Typical assemblages recorded are *Globigerinoides subquadratus, Globigerinoides immaturus, Globigerinoides primordius, Globorotalia mayeri, Globorotalia obesa, Globoquadrina dehiscens* and *Globoquadrina altispira Uvigerina sparsicostata, Uvigerina auberiana, Brizalina mandoroveensis, Altistoma tenuis, Lenticulina grandis, Brizalina interjuncta, Buliminella subfusiformis, Brizalina imperatrix,Uvigerina hourqi, Eponides eshira, Uvigerina gallowayi, Uvigerina subperegrina, Heterolepa crebbsi, Heterolepa pseudoungeriana, Spirosigmoilina oligocaenica, Lenticulina inornata, Amphistegina lessonii, Lenticulina pseudomamilligerus, Eponides pseudoelevatus, Hanzawaia concentrica, Haplophragmoides excavata, Eponides africana Hopkinsinna danvillensis, Marginulina costata, and Lagena costata.* Middle Neritic environment thrived over the following intervals: 3,405 – 3,880 ft, 3,940 – 4,390 ft, 4,840 – 5,200 ft, 6,430 – 6,790 ft, 7,030 - 7, 390 ft, 7,630 – 7,990 ft, 7,990 - 8,470 ft and 10,150 – 10,640 ft (Fig. 14).

3.7 Palaeoenvironmental Studies

Paleoenvironmental deductions of this study were based primarily on benthic foraminiferal assemblages and abundance and diversity of species. Presence or absence of planktic foraminifera also helped in deciphering open ocean environments. The following environments were deduced from the studied well and were outlined below; Inner neritic, middle neritic, outer neritic and Upper Bathyal.

3.8 Inner Neritic

The presence of foraminiferal assemblages such as *Amphistegina lessonii, Heterostegina sp., Poritextularia panamensis, Quinqueloculina microcostata, Valvulineria sp., Quinqueloculina sp, Lenticulina inornata, Planulina sp, Spiroplectammina wrightii,* and *Haplophragmoides* were used in establishing this depositional environment. It is recorded over the following intervals; 3,880 – 3,940 ft, 5,200 – 5,920 ft and 6,790 – 6,910 ft of Ochigbo-1 well (Fig. 14).

3.9 Middle Neritic

This paleoenvironmental setting is characterized by relatively high abundance and diversity of foraminiferal species. The abundance of Planktic foraminiferal species suggest open marine setting. Typical assemblages recorded are *Globigerinoides subquadratus, Globigerinoides immaturus, Globigerinoides primordius, Globorotalia mayeri, Globorotalia obesa, Globoquadrina dehiscens* and *Globoquadrina altispira Uvigerina sparsicostata, Uvigerina auberiana, Brizalina mandoroveensis, Altistoma tenuis, Lenticulina grandis, Brizalina interjuncta, Buliminella subfusiformis, Brizalina imperatrix,Uvigerina hourqi, Eponides eshira, Uvigerina gallowayi, Uvigerina subperegrina, Heterolepa crebbsi, Heterolepa pseudoungeriana, Spirosigmoilina oligocaenica, Lenticulina inornata, Amphistegina lessonii, Lenticulina pseudomamilligerus, Eponides pseudoelevatus, Hanzawaia concentrica, Haplophragmoides excavata, Eponides africana Hopkinsinna danvillensis, Marginulina costata, and Lagena costata.* Middle Neritic environment thrived over the following intervals: 3,405 – 3,880 ft, 3,940 – 4,390 ft, 4,840 – 5,200 ft, 6,430 – 6,790 ft, 7,030 - 7,390 ft, 7,630 – 7,990 ft, 7,990 - 8,470 ft and 10,150 – 10,640 ft (Fig. 14).

3.10 Outer Neritic

Most of the foraminiferal species recorded in the Middle Neritic also characterized the Outer Neritic environment. This environment is further characterized by high abundance and diversity of foraminiferal species dominated by the genus - *Uvigerina, (Uvigerina sparsicostata, Uvigerina hourqi,) and Eponides eshira and Lenticulina grandis.* This environment is recorded in 5,920 - 6,430 ft, and 7,390 – 7,630 ft (Fig. 14).

3.11 Outer Neritic and Upper Bathyal

Outer Nertic and Upper Bathyal depositional environments are characterized by high abundance and diversity of foraminifera such as *Hedbergella, Heterohelix, Globotruncana, Globigerinelloides Bolivina afra, Praebulimina fang, Praebulimina lata, Praebulimina laddi, Praebulimina prolixa, Praebulimina longa, Orthokarstenia clavata, Gavelinella guineana, Gavelinella intermedia, Neobulimina albertensis,* and *Lenticulina stephensoni,* suggesting a relatively deeper environment. This

paleoenvironment and the above foraminiferal associations are recorded over the interval: 8,470 – 10,150 ft of the analyzed interval (Fig. 14).

Table 2. Foraminiferal Biostratigraphic summary of Ochigbo-1 well (Guided by the works of 29, 30 and 31)

Depth (ft)	Age	Plantic Zone	Benthic Zone	Important Bioevents
3405	? Late Miocene – Middle Miocene	?N16 – N15	? Florilus costiferum – Uvigerina subperegrina	FDO Spirosigmoilina oligocaenica (12.26Ma)
3760				
4810	Middle Miocene	N15 – N14	Spirosigmoilina oligocaenica	FDO Globigerinoides subquadratus (13.12Ma)
4960		N11 – N13	Uvigerina sparsicostata	FDO Brizalinainterjuncta FDO Uvigerina sparsicostata (13.12Ma)
5920				FDO Globigerinoides primordius
6430	Early Miocene	N4 – N5	Fursenkoina punctata – Megastomella africana	LDO Globigerinoides primordius
6910	Late Oligocene	N2	Bolivina interjuncta – Spiroplectammina wrightii	LDO Bolivina dertonensis
7270				LDO Spiroplectammina wrightii
	Early Oligocene	P15 – P18	Hopkinsinna Bononensis – Bolivina ihuoensis	LDO Pseudohastigerina sp FDO Uvigerina hourqi (13.0Ma)
7510	Late Eocene	P12 – P14	Uvigerina houri – Hopkinsinna dannillensis	ACME of Uvigerina hourqi FDO Uvigerina gallowayi (43.2Ma)
7870	Middle Eocene – Late Eocene	P12	Altistoma tenius – Uvigerina havanensis	Occurrence of Globigerina Triculinoides and Morozovella quetra
7990	Early Eocene – Late Paleocene	P5/P6 – P7	Eponides pseudoelevatus – Lenticulina pseudomamillegarus	FDO Lenticula pseudo mamillegerus (55.9Ma)
8590				FDO Bolivina afra (64.6Ma)
8710	Late Campanian – Maastrichtian	M?	Bolivina afra – praebulimina	FDO Hedbergella holmdellensis FDO Praebulimina genus (P. fang, P. proxiixa, P. laddi etc) ACME of Bolivina afra & Praebulimina genus
9550				LDO Globotruncana aegyptiaca
10640				

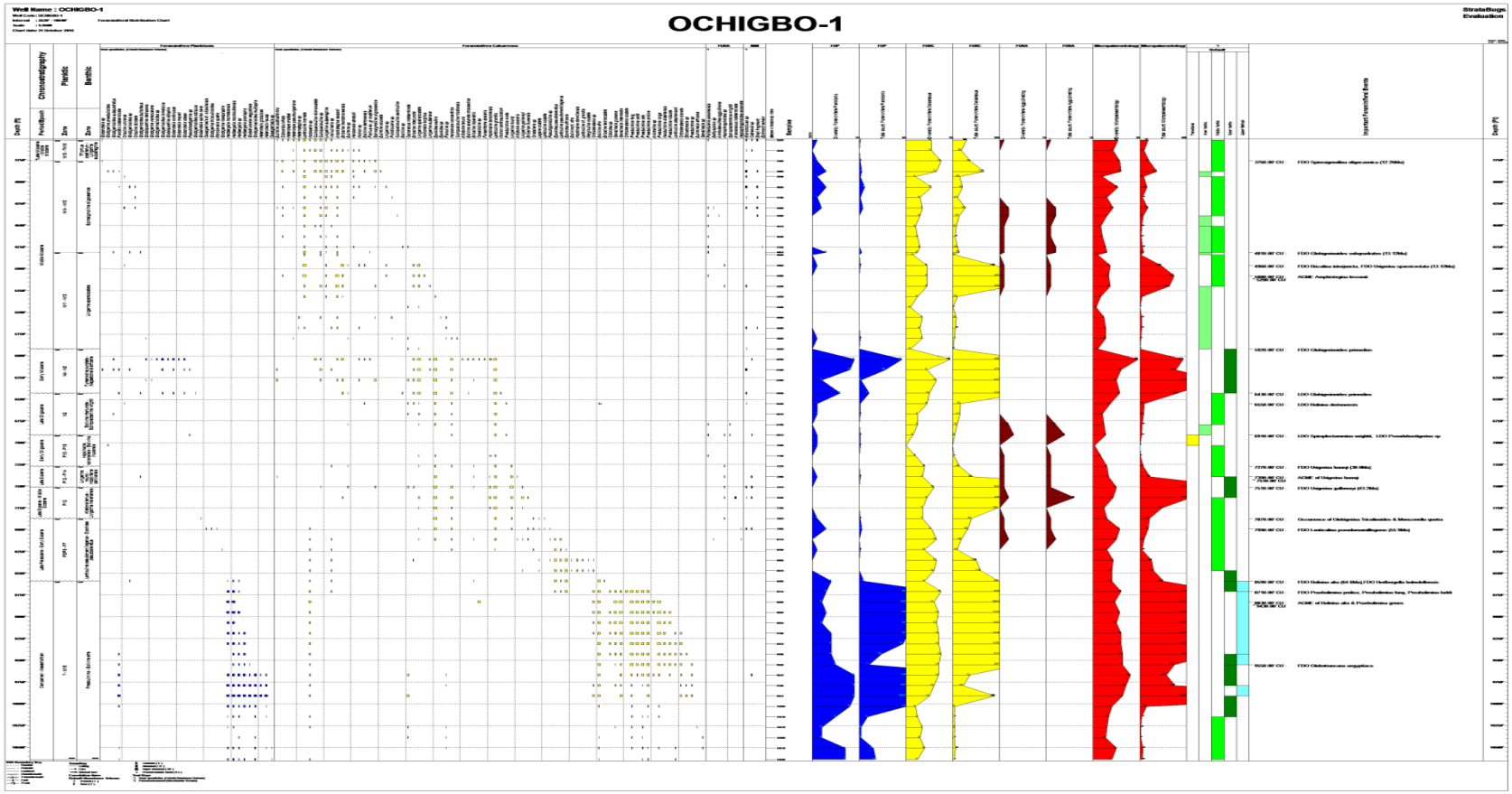

Fig. 12. Micropalaeontological distribution and abundance chart for Ochigbo – 1 well

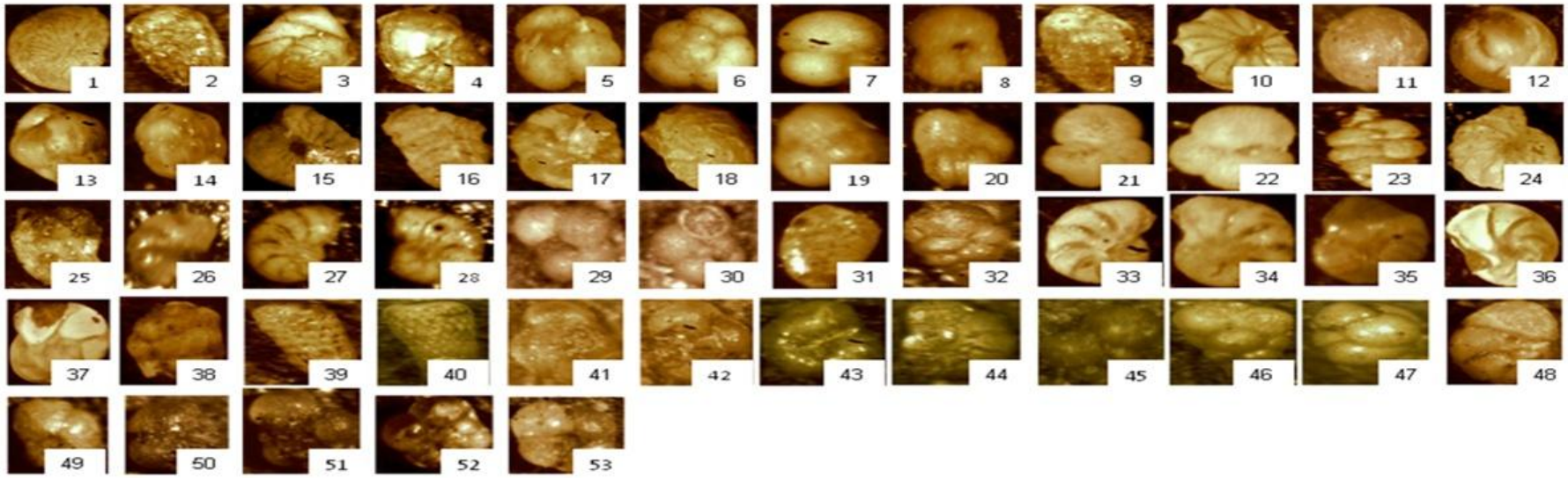

Fig. 13. Selected Foraminifera photomicrographs recovered from Ochigbo-1 well

1. Amphistegina lessonii 2. Brizalina mandoroveensis 3. Eponides eshira (spiral side) 4. Eponides eshira (umbilical side) 5. Globoquadrina altispira (umbilical side) 6. Globoquadrina altispira (spiral side) 7. Globigerinoides pimordius 8. Globigerinoides subquadratus 9. Uvigerina hourqi 10. Lenticulina grandis 11. Orbulina universa 12. Spirosigmoilina oligocaenica 13. Uvigerina gallowayi 14. Uvigerina sparsicostata 15. Amphistegina lessonii 16. Brizalina interjuncta 17. Eponides eshira (umbilical side) 18. Eponides eshira (spiral side) 19. Globorotalia mayeri (spiral side) 20. Globorotalia mayeri (umbilical side) 21. Globorotalia obesa (spiral side) 22. Globorotalia obesa (umbilical side) 23. Hopkinsina bononiensis 24. Lenticulina grandis 25. Heterostegina sp 26. Nonion centrosulcatum 27. Hanzawaia concentrica (spiral side) 28. Globorotalia continuosa (umbilical side) 29. Globorotalia continuosa (spiral side) 30. Spiroplectamina wrightii 31. Bolivina sp 32. Buliminella subfusiformis 33. Cibicorbis inflata (umbilical side) 34. Cibicorbis inflata (spiral side) 35. Florilus costiferum 36. Lenticulina inornata 37. Lenticulina inornata 38. Uvigerina subperegrina 39. Bolivina afra 40. Bolivina afra 41. Globotruncana aegyptiaca (spiral side) 42. Globotruncana aegyptiaca (umbilical side) 43. Gavelinella guneana (umbilical side) 44. Gavelinella guneana (spiral side) 45. Heterohelix reussi 46. Praebulimia fang 47. Praebulimia prolixa 48. Eponides pseudoelevatus (spiral side) 49. Eponides pseudoelevatus (umbilical side) 50. Hedbergella holmdelensis (umbilical side) 51. Hedbergella holmdelensis (spiral side) 52. Hedbergella holmdelensis (spiral side) 53. Hedbergella monmouthensis (spiral side)

The palaeoenvironmental deposition of the Ochigbo – 1 well (Fig. 14) started at Middle Neritic (10,640 ft – 10,150 ft) followed by regression (sea level fall) during Upper Bathyal (10,150 ft – 8,470 ft). This scenario is followed by transgression (Sea level rise) from Upper Bathyal to Middle Neritic (8470 ft–7630 ft). The environment experienced regression again from Middle Neritic to Outer Neritic (7630 ft–7390 ft). Another transgression occurred again from Outer Neritic to Middle Neritic (7390 ft–7030 ft) and went further to Inner Neritic (7030 ft–6790 ft). There was an opposite movement of the transgression from Inner Neritic to Middle Neritic (6790 ft– 5920 ft) then to Outer Neritic (5920 ft–5200 ft). There was a transitional 'leap' from Outer Neritic to Inner Neritic (5200 ft– 4840 ft) causing a land-ward transgressive movement after which there is a regression from Inner Neritic to Middle Neritic (4840 ft – 3940 ft). The final transgression was from Middle Neritic to Inner Neritic (3940-3880) and then finally a regression to Middle Neritic (3880 – 3405 ft).

3.12 Palaeoenvironmental Reconstruction of Ochigbo – 1 Well

The palynological and micropalaeontological forms recovered revealed that the Ochigbo – 1 well penetrated Late Cretaceous (Late Campanian – Maastrichtian) to Middle Miocene. The reconstruction was done from Late Cretaceous to Early Oligocene using ages revealed by the micropalaeontological forms (foraminifera). While the remaining reconstruction (Late Oligocene to middle Miocene) was done using integrated results as revealed from the two aspects of biostratigraphy

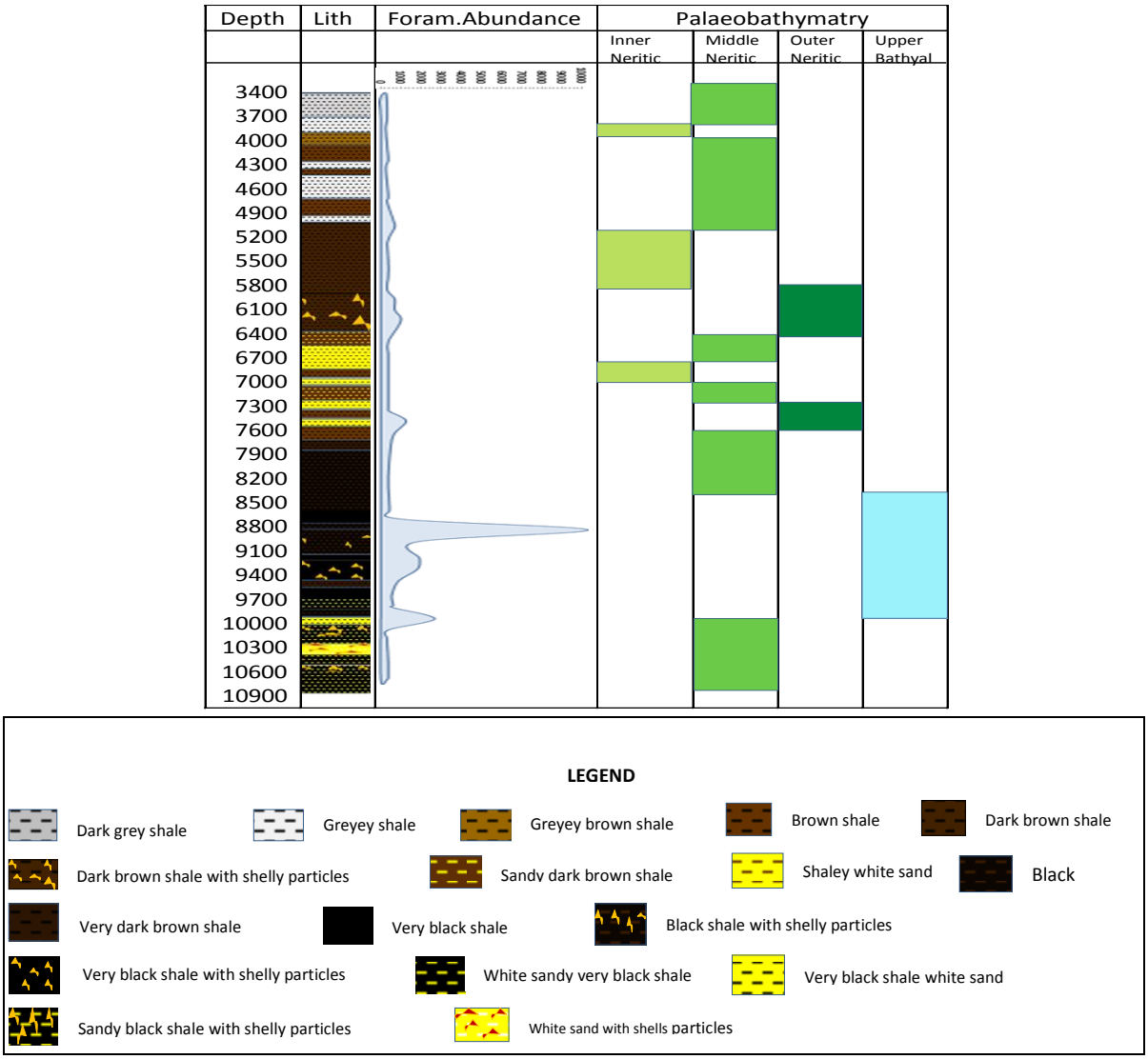

Fig. 14. Foraminiferal abundance and palaeobathymetric depositional environment

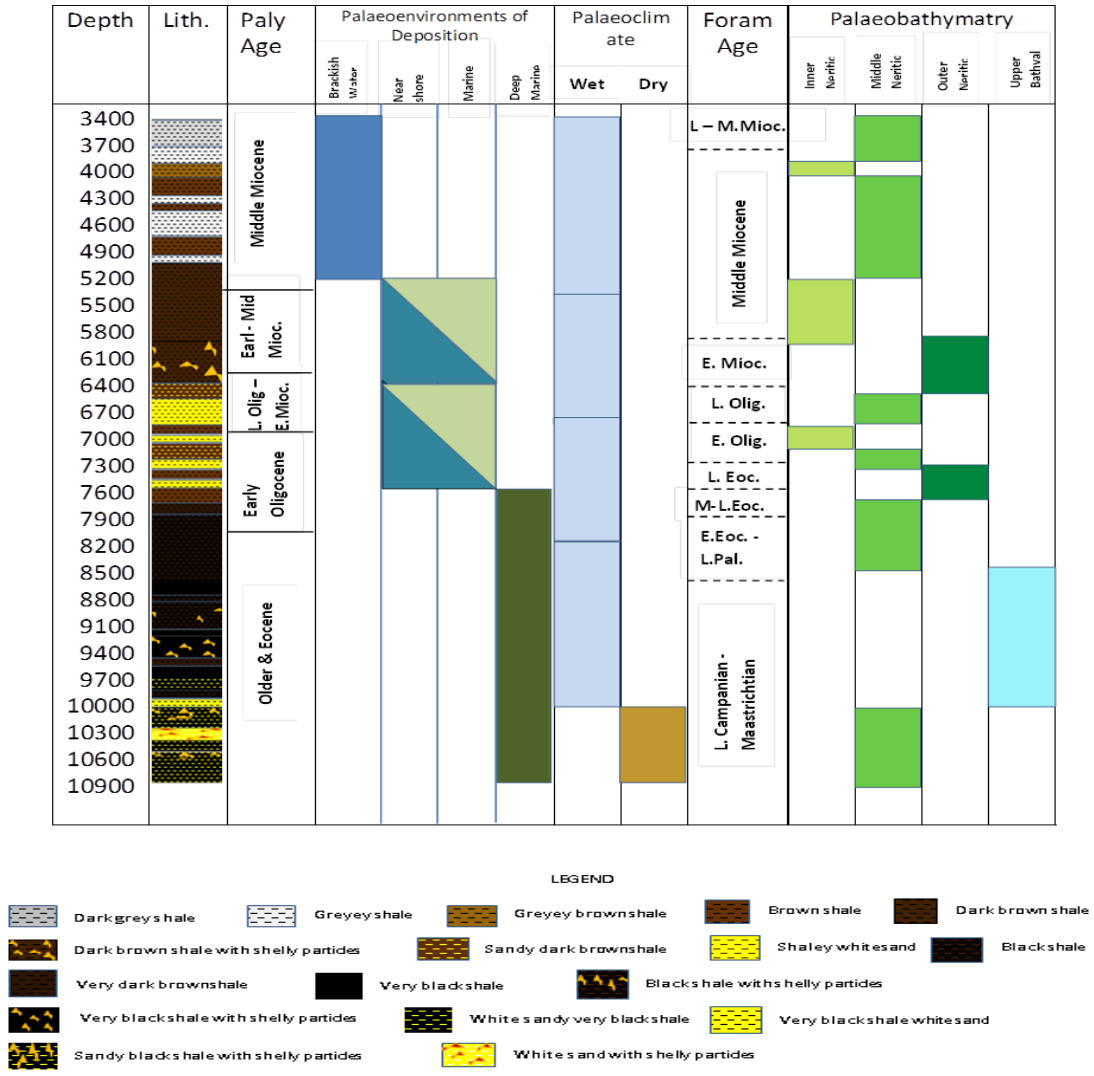

Fig. 15. Palaeoenviromental chart from palynology and micropalaeontology

employed for this work (micropalaeontology and palynology). This was because the palynological forms (pollen and spores) recovered were not able to date the sediments older than Eocene and the Dinoflagellates recovered were long ranged and could not serve as index forms. Thus, underscore the importance of integrated approach in biostratigraphy and palaeoenvironmental reconstruction work in any basin.

The sediments in the Ochigbo – 1 well were found deposited in Middle Neritic (10,640 ft – 10,150 ft) during the Late Cretaceous, after, there seems to be a major unconformity around Early to Middle Palaeocene. There was a record of deposition again in Upper Bathyal (10,150 ft – 8,470 ft), this transition is suggested to be as a result of a regression in Late Palaeocene. There was a transgression back to Middle Neritic (8,470 ft – 7,630 ft) around Late Palaeocene to Early Eeocene. A regression is suggested to have taken place again around Middle Eocene to Late Eocene causing sediments to be deposited in Outer Neritic (7,630 ft – 7,390 ft). Around Late Eocene, a transgression started again to Middle Neritic (7,390 ft – 7,030 ft) from Outer Neritic and went further to Inner Neritic (7,030 ft – 6,790 ft) in Early Oligocene. The deposition of sediments from palynological results, took place in a wet climatic condition in an environment fluctuating between near-shore and marine. At about the ages between the end of Early Oligocene to Late Oligocene an unconformity is suggested to have taken place after which a regression happened allowing the recording of sediments in Middle Neritic (6,790 ft – 5920 ft) in Late Oligocene. The regression went further to Outer Neritic (5,920 ft

– 5,200 ft) from Middle Neritic in Early Miocene, still within a wet climatic condition in an environment fluctuating between near-shore and marine. About the end of Early Miocene there was a transgression from Outer Neritic to Inner Neritic (5,200 ft – 4,840 ft), still a wet climate fluctuating between near-shore and marine. During Middle Miocene, in a wet climate and brackish water environment, there was a regression from Inner Neritic to Middle Neritic (4,840 ft – 3940 ft). Within this time and environmental setting, there was a transgression from Middle Neritic to Inner Neritic (3,740 ft – 3,880) and a regression again to Middle Neritic (3,880 ft – 3,405 ft). Fig. 15 shows the reconstruction chart, depositional environments and bathymetric ranges used in establishing the palaeoenvironmental reconstruction.

This alternating trangressive – regressive movement observed in Ochigbo – 1 well established that the well and the interval of study (3405 ft–10,640 ft) actually fall within the paralic sequence known as Agbada FormationOchigbo-1 well (Figs 14 and 15).

4. CONCLUSIONS

Palynonologial and micropalaeontological analysis of sixty-two (62) samples of Ochigbo – 1 well within interval of 3405 ft and 10640 ft were processed, prepared and analyzed. The lithostratigraphic unit, age, zonation, and environment of deposition of the studied well carried out. This revealed that the well penetrated a major sedimentary formation in the Niger Delta, comprising of shale, sandy shale and shaly sand, probably the paralic sequence of Agbada Formation.

A very rich recovery of palynomorphs, dominated by land-derived species of pollen and spores, abundant and diverse dinoflagellates cysts, brackish water spore and Fungal/spore/hyphae were recorded. The Palynological zonation of the well and their stratigraphic distribution based on the zonation schemes of [12] are broadly assigned to *Crassoretritriletes Vanraadshooveni* /P700 Zone, *Magnastriates Howardii* / P600 Zone, *Retribrevitricolporites Obedensis/Protundens* / P500 Zone and *Racemonocolpites Hians* / P400 Zone which were further subdivided to the following subzones P740, P720, P680 - P670, P650, P630, P620-P580, P560, P540, and P420.

The assigned age is late Eocene to Late Miocene maybe as a result of the paucity of palynomorphs towards the bottom of the studied well. The boundary between Miocene and Oligocene was at 6780 ft with the Quantitative base occurrence of *Peregrinipollis nigericus* and that between Oligocene and Eocene is at 8110 ft with the base occurrence of *Racemonocolpites hians*. The palynoflora identified suggests an environments ranging from estuarine/brackish water to deep marine whereas the palaeoclimatic setting is predominantly a wet climate.

One hundred and eighty one (181) foraminiferal species were identified. These include 170 species (93.92%) calcareous, while the remaining 11 species (6.08%) are arenaceous. Of the calcareous forms, benthics accounted for 118 species (69.41%) while the remaining 52 species (30.59%) are planktics. The results of the analysis indicated that the study interval (3,405 – 10,640 ft) of the Ochigbo-1 well was deposited during the late Miocene? to Late Campanian/Maastrichtian epoch, straddling the N16 to M18 planktic zones of [33,34]. The boundary between Miocene and Oligocene was established at 6430 ft based on the last downhole occurrence (LDO) of *Globigerinoides primordius* and *Bolivina dertonensis* while the boundary between Oligocene and Eocene was placed at 7270 ft, based on first downhole occurrence (FDO) of *Uvigerina hourqi* (38.0Ma). The boundary between Early Eocene – Late Paleocene and Late Campanian – Maastrichtian was at 8590ft based on the FDO *Bolivina afra* (64.6 Ma) and *Hedbergella holmdellensis*. One condensed section in the Ochigbo – 1 well was identified at the intervals between 8,700 ft and 9,310 ft, this also house the Maximum Flooding Surface (MFS) at the depth of 8830 ft, being its highest peak with a count of 9,910 [15,16].

Palaeoenvironmental deductions from Micropaleontology were based primarily on benthic foraminiferal assemblage, abundance and diversity of species. Presence or absence of planktic foraminifera also helped in deciphering open ocean environments. From the identified microfauna, the palaeoenvironments of deposition alternates in a regressive – transgressive pattern cutting across Inner Neritic to Upper Bathyal.

Gathering from the integrated study of palynologyand micropalaeontology, lithology and palaeoenvironmental study, the studied interval (3,405 ft – 10,640 ft) is here by suggested to have penetrated the Agbada Formation of the Niger Delta Basin, Nigeria. The alternation of

shale and sandy shale within the sequence provides the combination of source, reservoir and cap rocks necessary for hydrocarbon generation, accumulation and trapping.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. 1.Parkinson B. The post-cretaceous stratigraphy of southern Nigeria. Quart. Jour. Geol. Soc. London. 1907;63:311-320.
2. 2.Germeraad JH, Hopping CA, Muller J. Palynology of tertiary sediments from tropical areas. Review of Palaeobotany and Palynology. 1968;6:189-348.
3. 3.Boboye OA, Ademola OJ. Late miocene foraminiferal and palynologic events of Oborduka-1 well, deep offshore, Niger Delta, Nigerian. Middle-East Journal of Scientific Research. 2013;13(7).
4. Reijers TJA. Selected chapters on Geology: Sedimentary geology and sequence stratigraphy in Nigeria and three case studies and a field guide. Shell Petroleum Company of Nigeria, Corporate Repographic Services, Warri. 1996;197.
5. Stacher P. Present understanding of the Niger Delta hydrocarbon habitat. In. M. N. Oti and Postma, G. (eds.), Geology of Deltas. A.A. Balkema, Rotterdam. 1995;257-267.
6. Doust H, Omatsola E. Niger Delta: In Edwards, J. D and Santogrossi, P. A. (Eds.) Divergent/passive margin basins. American Association of Petroleum Geologists Memoir. 1990;48:201-239.
7. Avbovbo AA. Tertiary lithostratigraphy of Niger Delta. American Association of Petroleum Geologists Bulletin. 1978;62:295-300.
8. Doust H, Omatsola E. Niger Delta, In J.D. Edwards and P. A. Santogrossi, eds., Divergent/Passive margin basin: AAPG Memoir. 1989;48:201-238.
9. Short AJ, Stauble KL. Outline of the geology of the Niger Delta. Amer. Asso. of Petrol. Geolo. Memoir. 1967;51:761-779.
10. Adegoke OS, Dessauvagie TFJ, Kogbe CA. Planktonic foraminifera in Gulf of Guinea sediments. Microplaleontology. 1971;17:197–213.
11. Evamy BD, Haremboure J, Kamerling P, Knaap WA, Molloy FA, Rowlands PH. Hydrocarbon habitat of tertiary Niger Delta AAPG Bulletin. 1978;62:1-39.
12. Samant B, Phadtare NR Stratigraphic palynoflora of the early eocene Rajpardi lignite, Gujarat and the lower age limit of the Tareswar Formation of south Cambay Basin, India. Palaeontographica Abt. B, Lfg. 1997;245(1-6):1-108.
13. Bankole SI. Palynology and stratigraphy of three deep wells in the Neogene Agbada Formation, Niger Delta, Nigeria. Implications for petroleum exploration and paleoecology. "Fachgebiet Explorationsgeologie, Institut für Angewandte Geowissenschaften, Fakultät VI, der Technischen Universität Berlin,Germany" A phD thesis (unpublished); 2010.
14. Akaegbobi IM, Ola-Buraimo AO, Denedo AE. High resolution palynostratigraphy and paleoclimatic condition of prograding deltaic facies of 3 wells located in forcados yokri field (Upper Early Miocene) Nigeria. J. Biol. Chem. Research. 2016;33(1):188-205.
15. Vail PR, Wornardt W. An integrated approach to exploration and development in the 90s. Well log seismic sequence stratigraphy analysis. Gulf Coast Association of Geol. 1991;40(1):630-650.
16. Morley RJ. Biostratigraphy characterization of systems tracts in tertiary sedimentary basins. Proceedings of the International of Conference Sequence Stratigraphy in SE Asia; 1995.
17. Ola-Buraimo AO, Akaegbobi IM. Palynology, an important tool in evaluating sea level changes, paleoenvironment and paleoclimatic conditions in geologic time; 2013a.
18. Joly C, Barille L, Barreau M, Mancheron A, Visset L. Grain and annulus diameter as criteria for distinguishing pollen grains of cereals from wild grasses. Rev. Palaeobot Palynol. 2007;146:221-233.
19. Schüler L, Behling H. Poaceae pollen grain size as a tool to assess palaeoecological grassland dynamics in South America. Veget Hist Archaeobot. 2011;20:83–96.
20. Salgado-Labouriau ML, Rinaldi M. Measurements of gramineae pollen of the venezuelan mountains. Rev Brasil Biol. 1990;50:115–122.

21. Behre KE. The interpretation of anthropogenic indicators in pollen diagrams. Pollen Spores. 1981;23:225-245.
22. Birks HJB. Indicator values of pollen types from post-6000 B.P. pollen assemblages from southern England. Quaternary Studies in Poland. 1990;10:21-31.
23. Simon BK, Alfonso Y. AusGrass2; 2011. Available:http://ausgrass2.myspecies.info
24. Bankole SI, Schrank E, Osterloff PL. Palynostratigraphy, paleoclimates and paaeodepositional environments of the Miocene aged Agbada formation in the Niger Delta, Nigeria. Journal of African Earth Sciences. 2014;95:41-62.
25. Kar RK. Occurrence of *Acrosticum spores* from the Langpar formation early palaeocene of Meghala, India. Geophytology. 1992;22:33-36.
26. Graham A. Diversification of Gulf/ Caribbean mangrove communities through Cenozoic time. Biotropica. 1995;27(1):20-27.
27. Ramcharan EK, McAndrews JH. Holocene development of coastal wetland at Maracas Bay, Trinidad, West Indies. Journal of Coastal Research. 2006;22(3): 581-586.
28. Massini García JL, Jacobs BF, Pan A, Tabor N, Kappelman J. The occurrence of the fern Acrostichum in oligocene volcanic strata of the Northwestern Ethiopian Plateau. Int. J. Plant Sci. 2006;167(4):909-918.
29. Van der Hammen T, Wymstra TA. A palynology study on the Tertiary and upper cretaceous of British Guiana. Leidse Geologische Mededelingen. 1964;D1(30): 183-241.
30. Blow WH. The cenozoic globigerinida. Brill. Leiden. 1979;1413.
31. Berger WH, Miller KG. Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiostratigraphy. Micropale-ontology. 1988;34:362–380.
32. Poumot C. Palynological evidence for eustatic events in the tropical Neogene. Bull. Centres Rech. Explor. –Prod. Elf-Aquitaine. 1989;13(2):437-453.
33. Gradstein FM, Ogg JG, Smith AG, (eds). A geological time scale 2004. Cambridge University Press; 2005.
34. Hardenbol J, Thierry J, Farley MB, et al. Charts. In: Mesozoic and Cenozoic Sequence Stratigraphy of European Basins (P-C. De Graciansky et al., eds). Spec. Publ. Soc. Sed. Geol. 1998;60.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/18316