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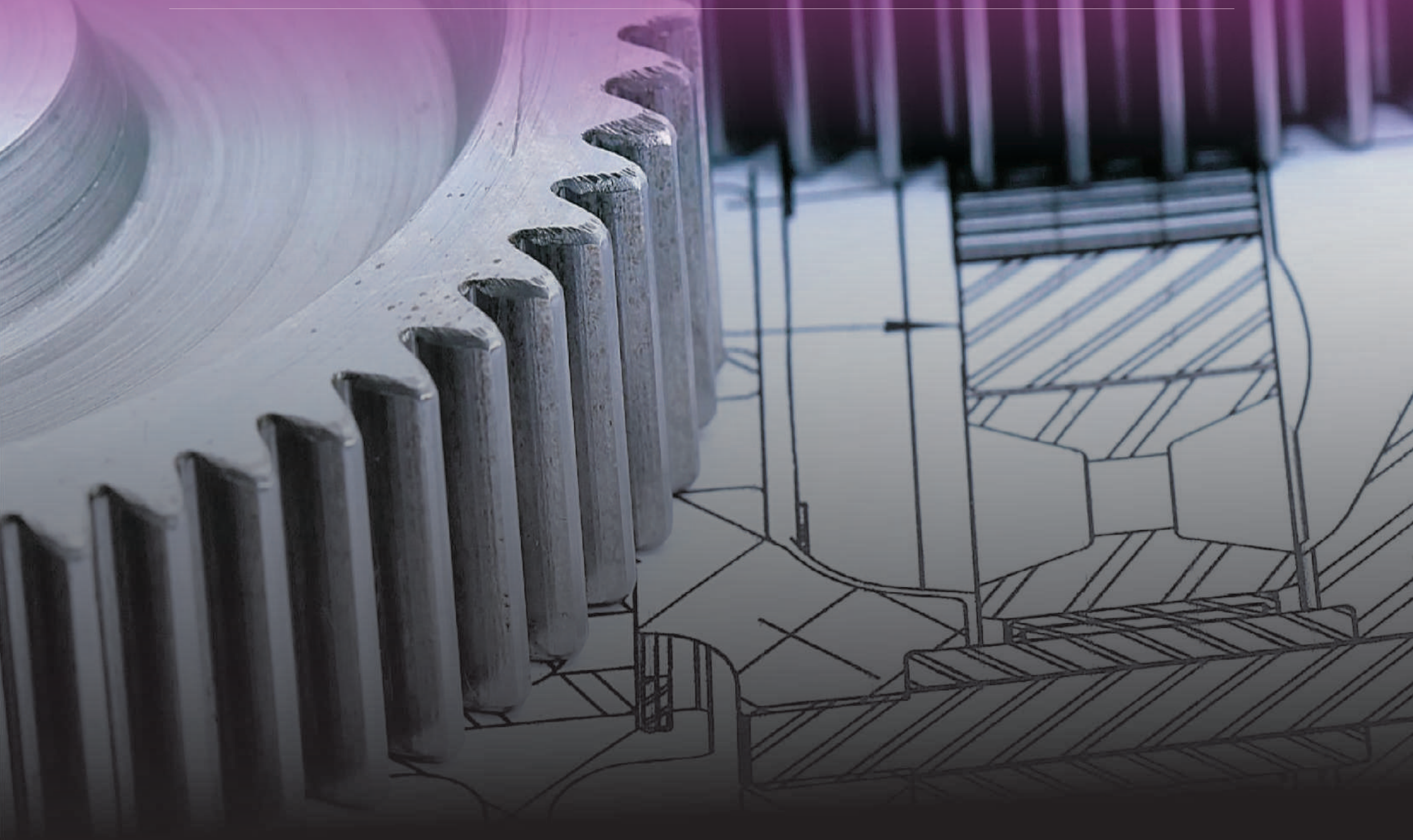

NIGERIA JOURNAL OF ENGINEERING AND APPLIED SCIENCES (NJEAS)

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CONTENTS

Palynofacies Analysis of Ida 5 -well, Niger Delta Basin, Nigeria

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Abstract

Palynofacies analyses of the strata penetrated by Ida-5 well were carried out with the aim of establishing palynostratigraphic zones, biochronology and paleoenvironment of deposition of the stratigraphic sequence of the well. Fifty ditch cutting samples within the interval of 2207 – 3569 m were analyzed. The acid method of sample preparation for palynofacies analyses was followed. The analyses yielded low to abundant pollen and spores, small to large sized palynomacerals 1 and 2, with few palynomacerals 3 and 4. The lithology showed alternation of shale and sandstone units as well as sandy shale. The studied intervals were dated middle Miocene to late Miocene based on the recovered age diagnostic species such as *Multiareolites formosus, Verrutricolporites rotundiporus, Crassoretitriletes vanraadshoveni* and *Racemonocolpites hians.* The lithology, indicates that the entire studied interval belongs to the Agbada Formation. Using the International Stratigraphic Guide for establishment of biozones, three interval range zones were established. These are: *Multiareolites formosus–Monoporites annulatus*, *Verrutricolporites rotundiporus–Crassoretitriletes vanraadshoveni* and *Striatricolporites catatumbus–Racemonocolpites hians* Zones. Paleoenvironmental interpretation based on the lithology and palynofacies association revealed that the stratigraphic interval was in the coastal-deltaic environments.

Keywords: Palynofacies, Biochronlogy, Paleoenvironment, Ida-5 well, Niger Delta Basin

Introduction

The term palynofacies was first introduced by Combaz (1964) to describe the total microscopic image of the organic components in sedimentary rock samples. Subsequently, the term became popular and detailed studies have been made and published. The different names given included: organic matter (Gehmann, 1962; Lorente, 1990), palynodebris (Boulter & Riddick, 1986; Van der Zwan, 1990; Boulter, 1994), and kerogen or palynomacerals (Tyson, 1995; Araujo *et al*., 1998; Whitaker, 1985; Oyede, 1992; Thomas *et al.*, 2015). Palynofacies was defined by Tyson (1995) as a body of sediment containing a distinctive assemblage of palynological organic matter thought to reflect a specific set of environmental conditions or to be associated with a characteristic range of hydrocarbon-generating potential. Batten and Stead (2005) defined palynofacies (palynological facies) generally to mean organic matter that is recovered from a rock or unconsolidated sediment by the standard palynological processing technique of digesting a sample in HCl and/or HF. Schulze solution (a mixture of 1 g of potassium chlorate ($KClO_3$) and 10-15 ml of HNO_3) is used for oxidation of coals (Ediger, 1986). Sedimentary deposits that contain organic matter have an associated palynofacies, it could be a few charcoal particles or miospores (small spores and pollen grains) and phytoclasts (fragments of plants). Palynofacies analysis has several applications in geology, for example in chronostratigraphy, biostratigraphy, paleoecology, and paleoclimatology. The most comprehensive contribution to the knowledge on the palynology of the Niger Delta Basin was made by Germeraad *et al.* (1968). The study was based on the palynomorph assemblages of the Tertiary sediments of three tropical areas: parts of South America, Asia and Africa (Nigeria). The researchers established nine pantropical zones using quantitative base and top occurrence (numeric method) of diagnostic species such as *Echitricolporite spinosus, Crassoretitriletes vanradshoveni, Magnastrites howardi, Verrucatosporites usmensis, Monoporites annulatus* and *Proxapertites operculatus*. Jennifer *et al.* (2012) used gamma ray log signatures and palynological data of ten samples retrieved from well "AX" in the Niger Delta Basin to establish that the samples were deposited in brackish to fresh water environment. Palynology of Bog-1 well, southeastern Niger Delta Basin was carried out by Adebayo *et al.* (2012)**.** The researchers noted that dominant occurrence of the mangrove species, *Zonocostites ramonae* (*Rhizophora*) and *Foveotricolporites crassiexinus* (*Avicennia*), suggests a tidal swamp shoreline inhabited by mangroves.

The aim of this work is to carry out the palynofacies analyses of the ditch cuttings from Ida-5 well in order to establish the palynostratigraphic zonation and paleoenvironment of deposition of the strata penetrated by the well within the interval of 2207 – 3569 m.

Location of Study Area

The studied well (Ida-5) is located within the Ida Field, in the Coastal Swamp Depobelt of the Eastern Niger Delta Basin, Nigeria (Fig. 1). The coordinate that describe the location of Ida-5 is latitude 4.80^o N and longitude 6.76^o E (Fig. 1). Niger Delta Basin lies between latitudes 4^o and 6^o N and longitudes 3^o and 9^o E in the southern part of Nigeria. The successive phases of developments exhibited by the Cenozoic Niger Delta Basin have been referred to as depositional belts or depobelts (Doust and Omatsola, 1990; Reijers *et al.*, 1996). Doust and Omatsola (1990) recognised depobelts in the Niger Delta and are distinguished primarily by their age and most importantly their location. These are: the Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp, and Offshore depobelts (Fig. 1). Each depobelt is filled with paralic sediments and bounded by faults at its proximal and distal limits. The paralic sedimentation in each depobelt resulted from eustatic sea level oscillations active in the basin within the development of the depobelt.

Geology and Stratigraphy of the Niger Delta Basin

Short and Stauble (1967) described the geology and stratigraphy of Niger Delta Basin. The authors recognized three formations in the subsurface: the Akata, Agbada and Benin formations in ascending order (Table 1). The Akata Formation consists of prodelta and open marine dark grey shale with lenses of siltstone and sandstone. Some sand beds considered to be of continental slope channel fill and turbidite are present (Weber and Daukoru, 1975).

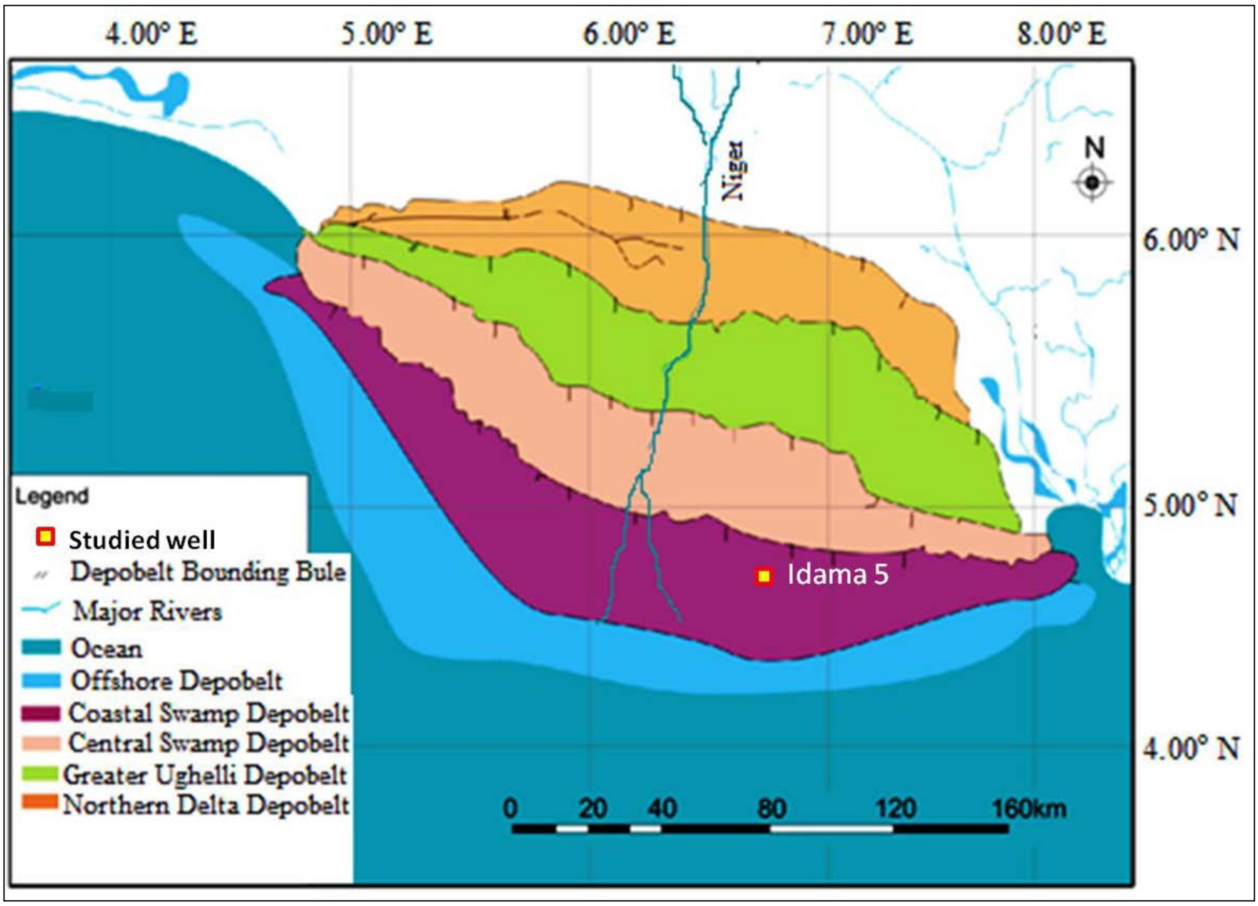

Fig. 1: The location of Ida-5 well in the Niger Delta Basin (Modified after Doust and Omatsola, 1990; Okosun and Chukwuma-Orji, 2016)

Table 1: Formations of the Niger Delta Basin (Modified after Oboh-Ikuenobe *et al*., 2005)

SUBSURFACE FORMATIONS			SURFACE FORMATIONS (OUTCROPS)		
Formation	Youngest Known Age	Oldest Known Age	Formation	Youngest Known Age	Oldest Known Age
Benin	Recent	Oligocene	Benin	Plio/Pleistocene	Oligocene
Agbada	Recent	Eocene	Ogwashi-Asaba Ameki	Miocene Eocene	Eocene Eocene
Akata	Recent	Paleocene	Imo Shale	Late Eocene	Paleocene

An estimated maximum thickness of the Akata Formation is in the range of 600 m to probably greater than 6000 m in the northern part of the delta where the formation has been drilled through into the Cretaceous (Weber and Daukoru, 1975; Avbovbo, 1978; Durugbo and Uzodimma, 2013). The age of the Akata Formation ranges from Paleocene in the proximal parts of the delta to Recent in the distal offshore. The Agbada Formation consists of cyclic coarsening-upward regressive sequences composed of shales, siltstones, and sandstones units of delta front and lower delta plain deposits (Weber, 1971). The Agbada Formation has been described as paralic (cyclic) lithofacies sequence of marine and fluvial deposits consisting of alternation of sand/sandstone shale/mudstone units (Bankole *et al*., 2014). The thickness of the Agbada Formation is highly variable (from 300 m up to about 4500 m). The oldest deposits of the Agbada Formation are of Eocene age in the north and are presently being deposited in the near shore shelf domain. The Benin Formation consists of a succession of massive, poorly indurated sandstones, thin shales, coals, and gravels of continental to upper delta plain origin. The Benin Formation first occurs in Oligocene times in the northern delta sector (Reijers *et al*., 1996). The Benin Formation is up to 2,000 m thick in the central onshore part of the delta and thins towards the delta margins (Bustin, 1988). The Benin, Agbada and Akata lithostratigraphic units classifed as formations, frequently referred to as 'facies'has been proposed to elevated to group level (Reijers, 2011). The lithofacies equivalent of these subsurface formations on the surface are: the Imo, Ameki, Ogwashi-Asaba and Benin formations (Table 1). The Imo Formation is composed of grey sandy shale, siltstone and sandstone with lenses of coal, bituminous sand and limestone in some places. The Sandstone member of the Imo Formation consists of the Ebenebe, Umuna and Igbakwu sandstone members (Okeke and Umeji, 2016). The Ameki Formation is predominantly alternating shale, sandy shale, clayey sandstone, and fine-grained fossiliferous sandstone with thin limestone bands (Arua, 1986; Oboh-Ikuenobe *et al*., 2005). The age of the formation has been considered to be Eocene (Reyment, 1965; Adegoke, 1969). It overlies the Imo Formation unconformably (Nwajide, 1980). The Ogwashi-Asaba Formation conformably overlies the Ameki Formation. The Ogwashi-Asaba Formation is composed of alternating cross bedded sandstones, carbonaceous black shales, lignite seams and coal. Reyment (1965) suggested that Ogwashi-Asaba Formation is of Oligocene to Miocene age. However, palynological study by Jan du Cheˆne *et al*. (1978) revealed Middle Eocene age for the basal part. The Ameki Formation and the Ogwashi-Asaba Formation are correlative with the subsurface Agbada Formation. Exposures of Ogwashi Formation are only along stream channels and quarries (Okeke and Umeji, 2016).

Methodology

Lithologic description

The lithologic description of the studied section was based on the study of the log motifs (Gamma Ray and Resistivity logs), physical inspection of the samples with the aid of magnifying hand lens and chart for textural analysis of clastic sediments. Fissile, platy and flagy samples indicate shale while samples with fine to coarse grain sizes indicate sandstone units. The lithologic description was enhanced by the Gamma Ray and Deep Induction Resistivity Logs since high and low values of Gamma Ray Log and Deep Induction Resistivity Log signify shale and sandstone lithologies, respectively (Adegoke, 2002; Olayiwola and Bamford, 2016).

The Gamma Ray Log patterns (fining and coarsening upward signatures) description by Sneider *et al*. (1978) and Beka and Oti (1995) were adopted in this research. Bell shaped log signature on Gamma Ray Logs indicate increasing clay contents up section or fining upward trends or an upward increase in gamma ray value. Bell shaped log signature is a typical feature of fluvial channel. Funnel-shaped log signatures indicate a coarsening upward trend and decreasing clay contents up section. Funnel-shaped pattern shows deltaic progradation and bar deposits. Cylindrical (blocky or boxcar) log motif delineate thick uniformly graded coarse grained sandstone unit that could be probably deposits of braided channel, tidal channel or subaqueous slump deposits. These are typical of beach sands, barrier bar sands and stream bars which are characteristic of deltaic environment. Serrated log patterns suggest intercalation of thin shales in a sandstone body, typically of fluvial, marine and tidal processes. Symmetrical log motifs indicate gradual decrease and increase in gamma ray value. This log pattern results from progradation and then retrogradation of clastic sediments.

Sample preparation for palynomorphs and palynomacerals recovery

The standard acid palynological preparation method was followed. Fifty ditch cutting samples from the well were analyzed. Fifteen grams of each sample was treated with 10% HCl under a fume cupboard for the complete removal of carbonates present in the samples. This was followed by complete washing with distilled water before the next procedure. Then 40% HF was added to the sample and kept for 24 hours to ensure a complete dissolution of the silicates present in the samples. Thereafter, the HF was diluted with water and carefully decanted, then followed by complete washing with distilled water in order to remove fluoro-silicate compounds usually formed from the reaction with HF. The whole wet solution was then sieved and separated using Brason Sonifier 250. Brason Sonifier is an electric device used with the aid of 5 micron sieve to filter away the remaining inorganic matter (silicates, clay, and mud) and heavy minerals to recover organic matters. The sieved residue was given controlled oxidation using concentrated nitric acid (HNO_3). This treatment selectively removes amorphous organic matters that often co-exist with the palynomorphs, and also to lighten the dark-hued palynomorphs. The residues for preparation of palynological slides were then stained with safranin-O in order to improve the study of dinoflagellete cysts. The same procedure for sample preparation for palynomorphs recovery was followed for the palynomacerals, except that the oxidation process with HNO_3 was omitted in order not to bleach the palynomacerals (palynodebris).

Preparation of Slides

The recovered organic matters were uniformly spread on arranged cover slips of 22/32 mm and allowed to dry for mounting. The cover slips were then inverted and glued onto clean glass slides by using Loctite (Impruv) as the mounting medium and were dried under natural sunlight for 5 minutes.

Microscopic Study

Both palynology and palynomacerals (kerogen) slides were examined under the Olympus Binocular light transmitted microscope. Identification of palynomorphs and palynomacerals were done with aid of palynological albums and the published works of previous researchers such as (Germeeraad *et al*., 1968; Ige, 2009; Bankole, 2010; Ige *et al*., 2011; Ajaegwu *et al*., 2012; Durugbo and Aroyewun, 2012). The slides were subjected to quantitative analysis of palynomorphs and palynomacerals (types 1, 2, 3, and 4) as well as structure less organic matter (SOM).

Results and Discussion

The lithology of the studied section (2207 – 3569 m) consists of alternating shale/mudstone and sandstone units with few intercalations of sandy shale units (Fig. 2). The shale/mudstones are moderately hard to hard, platy to flaggy in appearance and grey to brownish grey in colour. The sandstones are predominantly whitish to very light gray coloured, texturally fine to coarse grained, angular to subangular to rounded, and poorly to well sorted). The integration of Gamma Ray Log motif and textural/lithologic attributes enabled the recognition of one broad paralic (cyclic) lithofacies succession. The paralic lithofacies succession designated as the Agbada Formation was subdivided further into an upper and lower Agbada paralic units based on the shale to sand ratio (Durugbo and Uzodimma, 2013). The lower paralic lithofacies unit has thicker shale units, thin sand units and average shale to sand ratio of 80:20% compared to those found within the overlying upper paralic succession.

The result of palynofacies analysis is presented in palynomorphs and palynomacerals distribution charts (Fig. 3). The chart shows the different palynomorph taxa and types of palynomacerals encountered at the different studied depth intervals (Fig. 3). The diversity is moderate. Pollen and spores are dominant with a single dinoflagellate species. The spores recorded include *Laevigatosporites* sp., *Verrucatosprites* sp., *Pteris* sp., *Crassoretitriletes vanraadshoveni, Acrostichum aureum* and *Magnastriatites howardi.* The pollen taxa recovered include: *Zonocostites ramonae, Monoporites annulatus, Racemonocolpites hians, Retistephanocolpites gracilis, Striatricolpites catatumbus, Retibrevitricolporites protrudens, Pachydermites diederixi, Arecipites* sp., *Psilatricoloporites crasssus, Retitricolporites irregularis, Fenestrites spinosus, Peregrinipollis nigericus, Gemamonocolpites* sp., *Multiareolites formosus, Verrutricolporites rotundiporus, Nummulipollis neogericus, Canthium* sp., *Coryius* sp., *Psilatricolporites* sp., *Elaeis guineensis, Ctenolophonidites costatus, Bombaccacidites* sp., *Alnipollinites verus, Podocarpidites* sp. and *Retitricolporites* sp. The algal cysts recovered are *Pediastrum* sp, and *Botryococcus braunii. Polysphaeridium zoharyi* a dinoflagellate cysts is recovered only at 2454 m (sandy shale) (Fig. 3). Some of these forms are illustrated in the photomicrographs (Plate 1). The palynomacerals analysis yielded abundant records of palynomercerals 1 and 2, few occurrences of palynomacerals 3 and 4 and no record of structureless organic matter (Fig. 3; Plate 2).

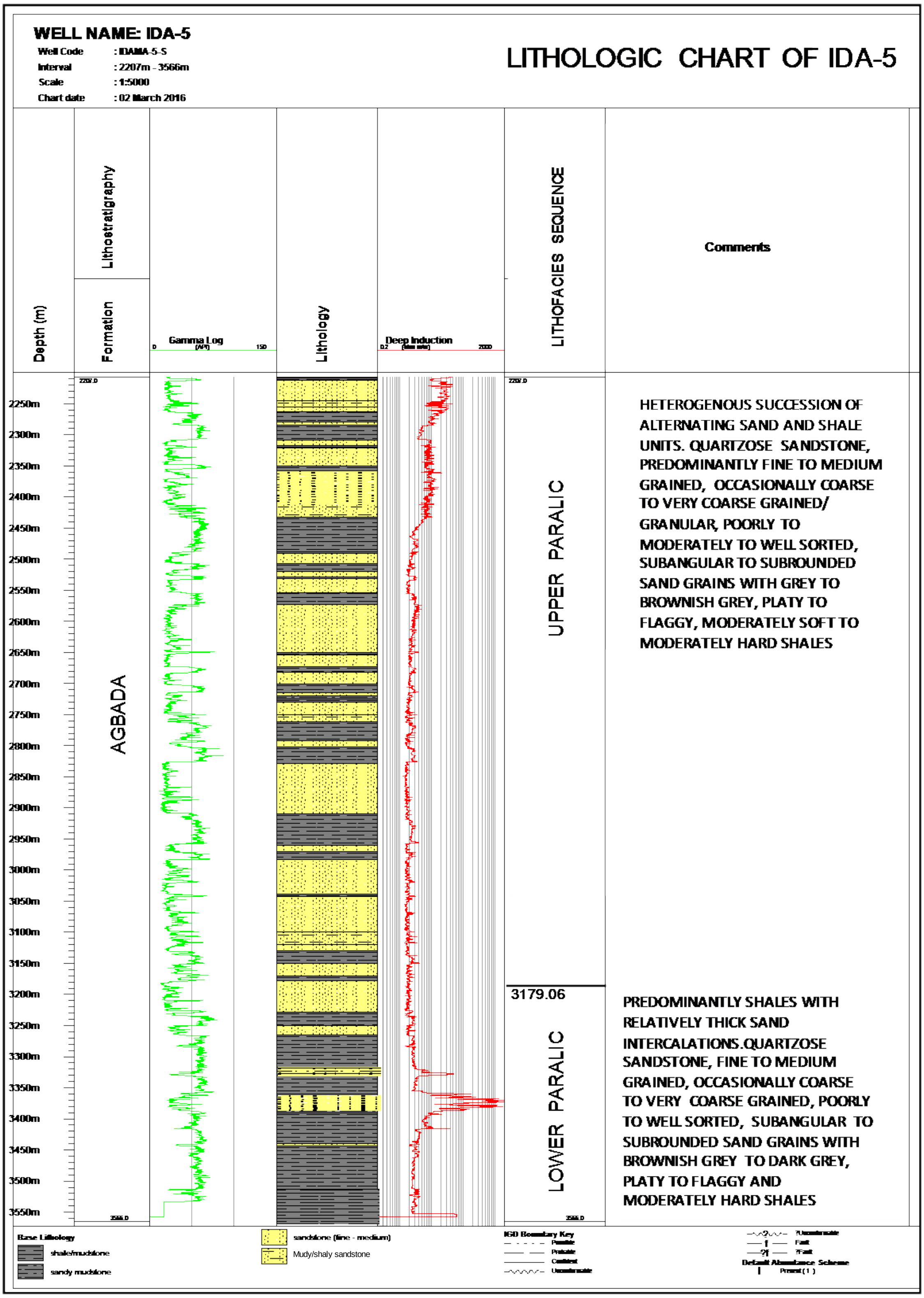

Fig. 2: Lithologic chart of Ida-5 well

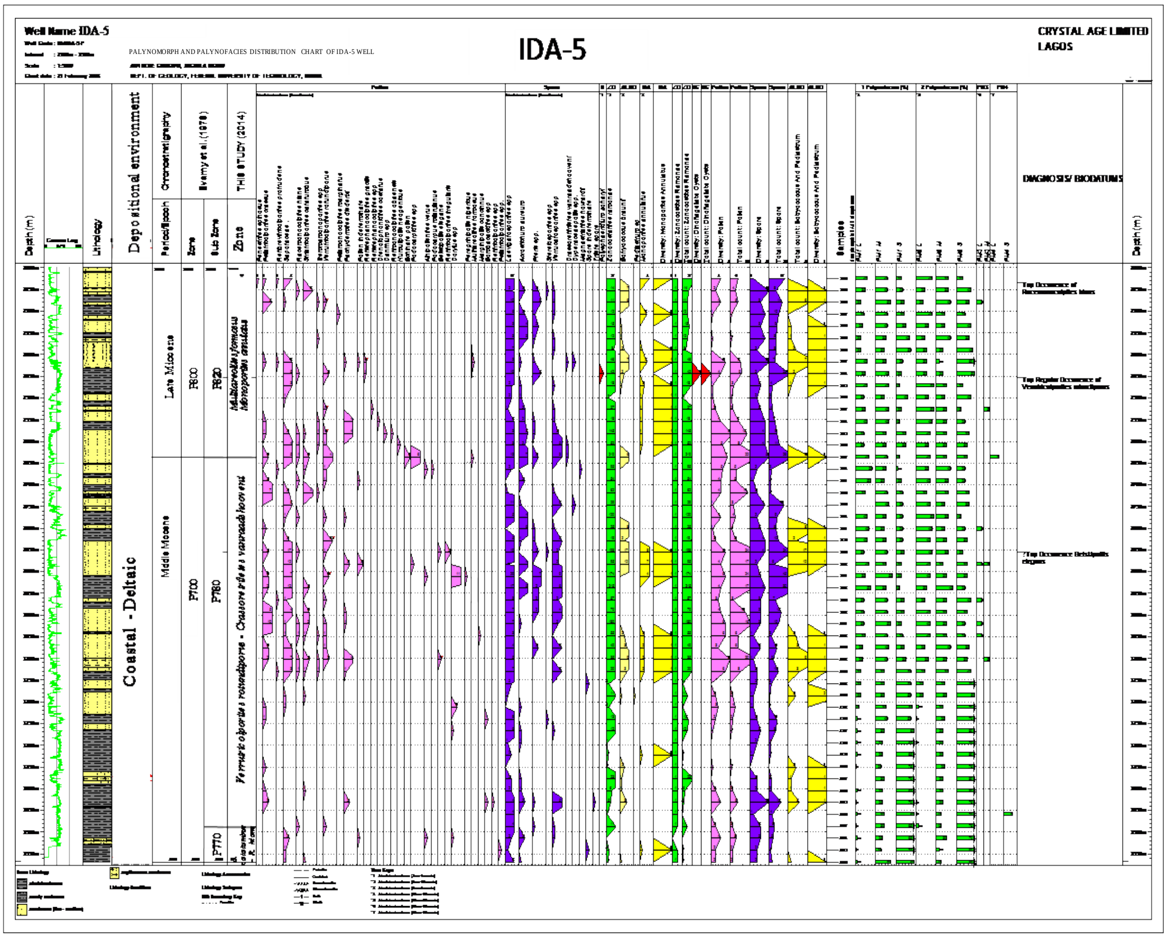

Fig. 3: Palynomorphs and palynomacerals chart of Ida-5 well

Palynomaceral 1 (PM1)

In this study, the observed palynomaceral 1 appeared orange-brown to dark-brown in colour, opaque, irregular in shape, structureless and varies in preservation (Plate 2). Oyede (1992) stated that Palynomaceral 1 is a particulate organic matter (Alginite) that is orange-brown to dark-brown in colour, dense in appearance, irregular in shape, structureless and varies in preservation. It is heterogeneous and of higher plant in origin and some are products of exudation processes such as the gelification of plant debris in the sediments. Palynomaceral 1 includes small, medium and large sizes of flora debris, humic gel-like substances and resinous cortex irregularly shaped materials (Oyede, 1992 and Thomas *et al.*, 2015).

Palynomaceral 2 (PM 2)

The PM 2 observed in this study is irregular in shape, brown-orange in colour, and platy in structure (Plate 2). According to Oyede, 1992, palynomaceral 2 (Exinites) is usually brown–orange colour, structured but irregular in shape. It encompasses platy like structured plant materials (leaves, stems or small rootlet debris), algae debris and a few amounts of humic gels and resinous substances. It is more buoyant than palynomaceral 1 because of its thinner lath-shaped character.

Palynomaceral 3 (PM 3)

The PM 3 observed in this study, generally is translucent and contained stomata, pale to brown in colour and is irregular in shape (Plate 2). Oyede, 1992 stated that PM 3

(Vitrinite) is pale, relatively thin and irregularly shaped and occasionally contains stomata. Also, it includes structured plant material, mainly of cuticular origin and degraded aqueous plant material. It is more buoyant than palynomaceral 2 (Thomas *et al.*, 2015).

Palynomaceral 4 (PM 4)

Some of the observed PM 4 in this study varies from black to dark brown in colour, with blade or needle like shapes (Plate 2). Oyede (1992) described PM 4 (Inertnite) as being black to charcoal black in colour. Also, it is equidimensional, blade or needle shaped material. It is uniformly opaque and structureless, but may occasionally show cellular structure. The components of this palynomaceral are of different origins and they include compressed humic gels, charcoal and geothermally fusinized material. Blade-shaped palynomaceral 4 is extremely buoyant and resistant to degradation. Thus, they are often transported over long distances (Oyede, 1992 and Thomas *et al.*, 2015). Concentration of PM-4 characterizes high energy environment.

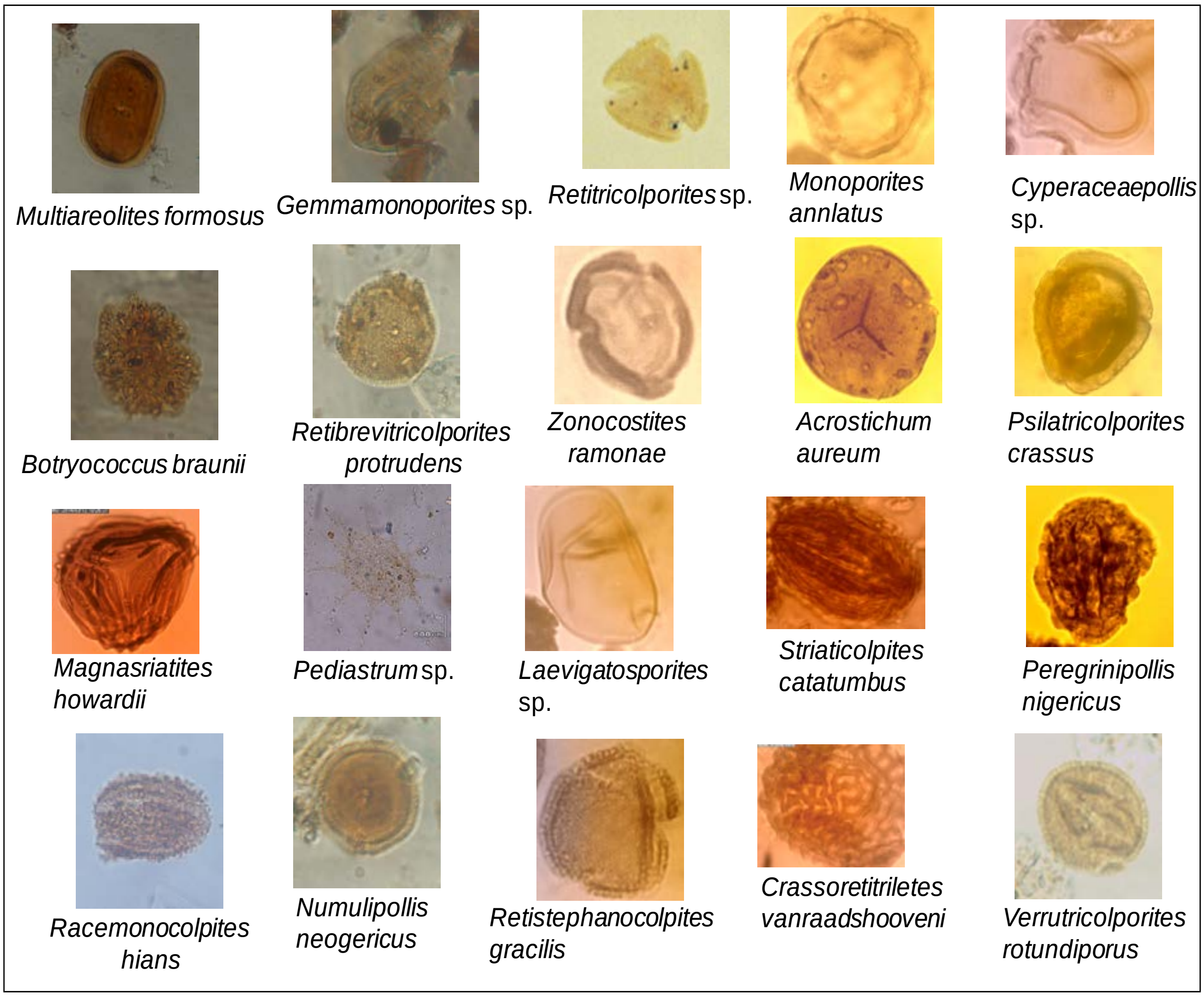

Plate 1: Microphotographs of some recovered palynomorphs (x400).

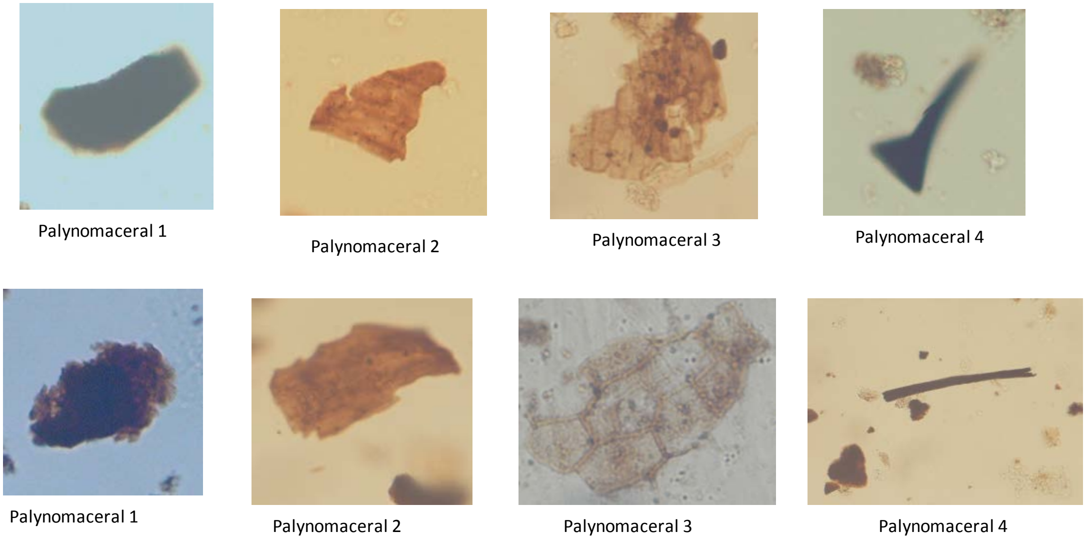

Plate 2: Types of palynomacerals recovered (x 400)

Palynostratigraphic zonations and Relative age dating of Ida-5 well

The zones established were *Multiareolites formosus–Monoporites annulatus*, *Verrutricolporites rotundiporus–Crassoretitriletes vanraadshoveni* and *Striatricolporites catatumbus–Racemonocolpites hians* Zone.

***i. Multiareolites formosus – Monoporites annulatus* Zone (Interval zone)**

Stratigraphic interval: 2225 – 2637 m

Definition: The top of the zone is defined by the first downhole occurrence (FDO) of *Monoporites annulatus* at 2225 m while the base is marked by the last downhole occurrence (LDO) *Multiareolites formosus* at 2637 m.

Characteristics: The assemblages of palynomorphs taxa that characterize this zone include *Crassoretitriletes vanraadshoveni*, *Retistephanocolpites gracilis*, *Gemmamonoporites* sp., *Nummulipollis neogericus* and *Retibrevitricolporites protudens*. Other taxa occurring within the zone are *Psilatricoloporites crasssus*, *Verrucatosprites* sp., *Pteris* sp., *Acrostichum aureum* and *Magnastriatites howardi*.

Age: The zone is dated late Miocene because of the presence of *Retistephanocolpites gracilis*, *Cyperaceaepollis* sp., *Multiareolites formosus* and *Nummulipollis neogericus* which are diagnostic of late Miocene.

Remark: The zone is equivalent to P800 zone and P820 subzone of Evamy *et al*. (1978) and J1 (Upper) of Morley, (1997) (Fig. 4). This is because the age diagnostic species such as *Multiareolites formosus* and *Monoporites annulatus* used in erecting the zone are contained in the zones of the above mentioned authors.

***ii. Verrutricolporites rotundiporus–Crassoretitriletes vanraadshoveni* Zone (Interval zone)**

Stratigraphic interval: 2637 - 3487 m

Definition: The top of the zone is defined by the last downhole occurrence (LDO) of *Crassoretitriletes vanraadshoveni*, at 2637 m while the base is marked by the last downhole occurrence of *Verrutricolporites rotundiporus* at 3487 m.

Characteristics: The zone is characterized by the presence and lowermost documented occurrence of *Racemonocolpites hians*, *Retibrevitricolporites protrudens*, *Pachydermites diederixi*, *Psilatricoloporites crasssus*, *Gemamonocolpites* sp, *Multiareolites formosus*, and *Verrutricolporites rotundiporus* within the zone. The occurrence of *Zonocostites ramonae*, *Laevigatosporites* sp and *Monoporites annulatus* are high within this zone. The single occurrence of *Peregrinipollis nigericus* (late Miocene specie) could have resulted from caving during drilling or sample mix during sampling.

Age: The zone is dated middle Miocene because taxa such as *Verrutricolporites rotundiporus*, *Retibrevitricolporites protrudens*, and *Racemonocolpites hians* are diagnostic of middle Miocene.

Remark: The zone is equivalent to P700 zone and P780 subzone of Evamy *et al*, (1978) and J1 (Lower) of Morley, (1997) (Fig. 4). The age diagnostic species: *Verrutricolporites rotundiporus* and *Crassoretitriletes vanraadshoveni* used in erecting the zone are contained in the zones of the cited authors.

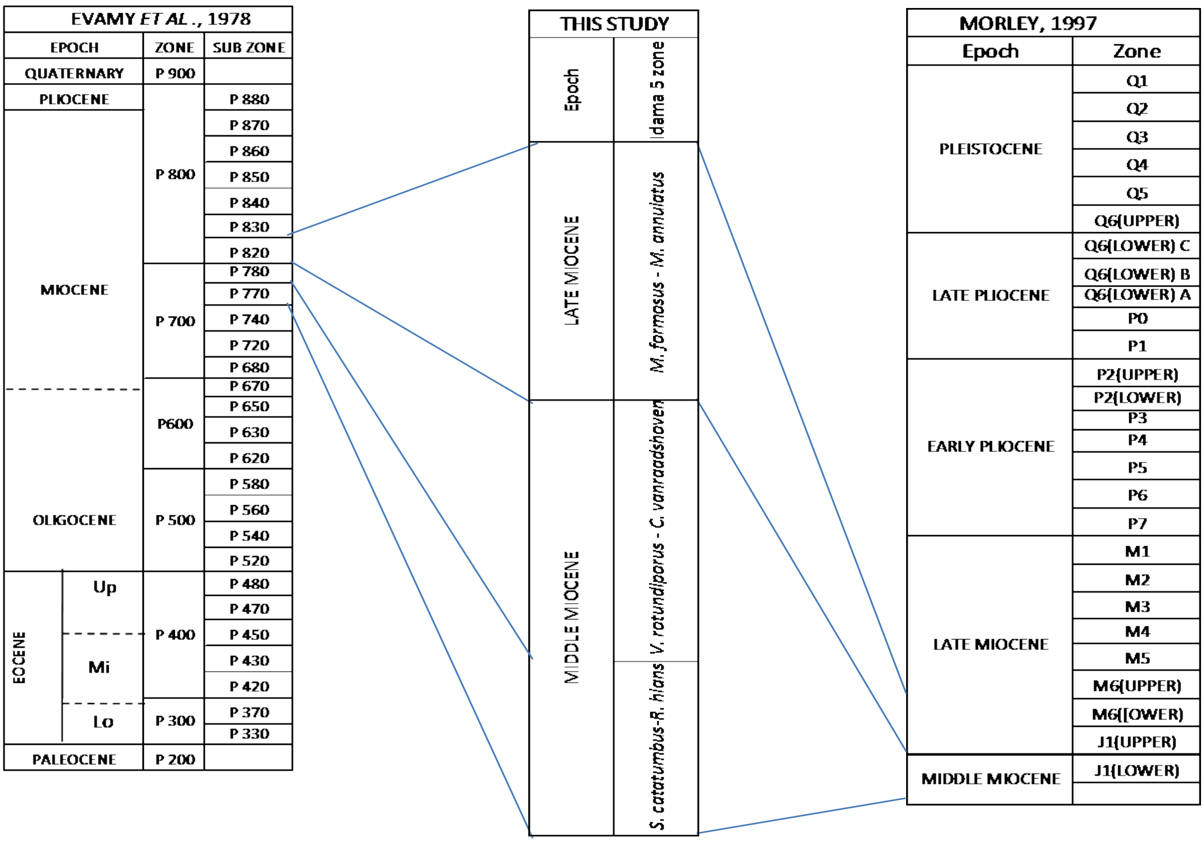

Fig. 4: Correlation of the established palynostratigraphic zones with the works of Evamy *et al*. (1978) and Morley (1997)

***Iii Striatricolporites catatumbus– Racemonocolpites hians* Zone (Interval zone)**

Stratigraphic interval: 3569 - 3487 m

Definition: The zone is defined as the interval between the lowermost documented occurrence of *Racemonocolpites hians* and *Striatricolporites catatumbus* within the studied interval. The top and the base of the zone is defined by the last downhole occurrence (LDO) of *Racemonocolpites hians* at the depth of 3487 m and *Striatricolporites catatumbus* at the depth of 3569 m (the last sample analyzed). Also marking the top (3487 m) of the zone is the LOD of *Pteris* sp.

Characteristics: The zone is characterized by the few occurrences of sapotaceae, *Ainipollenites verus, Coryius* sp., *Lavigatosporites* sp., *Acrostichum aurem, Monoporites annulatus* and *Zonocostites ramonae.*

Age: The zone is dated middle Miocene. The stratigraphic position of the zone and the presence of the above mentioned taxa that defined and characterized the zone aided in the age assignment, although *Pteris* sp. have long geologic age range of Paleogene to Neogene. *Striatocolporites catatumbus* has age range of Early-Middle Miocene (Germeraad *et al*., 1968).

Remark: The zone is equivalent to P700 zone and P770 subzone of Evamy *et al*, (1978). The diagnostic species of this zone: *Striatricolporites catatumbus* and *Racemonocolpites hians* were used by Evamy *et al*. (1978).

Paleoenvironment of Deposition

This involves the periodic changes in the depositional environment over geologic time. Evaluation of paleoenvironment of deposition is essential because different depositional environments give rise to reservoirs with different qualities and characteristics such as porosity, permeability, heterogeneity and architecture. Inference of the paleodepositional environments of the studied well was made based on the following criteria:

i. The lithology and wire line log motifs of the studied section (Fig. 2);

ii. The nature of organic matter (palynomercerals) present in the sediment. The terrestrial/coastal and marine depositional environments have been distinguished to have distinctive and characteristic palynofacies (Oyede, 1992 and Thomas *et al*., 2015). The terrestrial/coastal environments are characterized by poorly sorted palynomacerals 1 and 2, absence of dinocysts and common to abundant occurrence of fungal spores while marine environment is characterized by a good sorting of organic matter predominantly small to medium, common to abundant palynomacerals 1 and 2, some needle-shaped to lath-shaped palynomaceral 4 and presence of dinocysts and or foraminifera linings (Oyede, 1992); and

iii. Association of environmentally restricted diagnostic species such as *Zonocostites ramonae, Monoporites annulatus, Pachydermites diederixi, Psilatricoloporites crasssus, Laevigatosporites* sp. and *Botryococcus braunii.*

Some previous authors agree that landward shifting of coastlines during sea level rise result in deposition of marine sediments in the subaerial delta plain. This period is also associated with shifting of the mangrove and other coastal swamp plant belts due to their preference for saline water. Therefore, the subaerial delta plain depositional environment is characterized by high representation of mangrove, other coastal swamp plants (from beach, brackish, freshwater swamp, rainforest and palm) miospores, fungal elements, freshwater algae and marine origin species (Adojoh *et al*., 2015; Olayiwola and Bamford, 2016).

Similarly, during sea level fell the coastline is shifted basinward and the shelf area initially covered by marine water, become exposed and probably incised due to erosion by fluvial activities. This results in deposition of terrestrial sediments in the subaqueous delta plain which is characterized by widespread savanna and montane vegetation belts. This depositional environment is characterized by maxima spectra of savanna and montane pollen (Adojoh *et al*., 2015; Olayiwola and Bamford, 2016).

Based on the above mentioned criteria, lower delta plain to delta front and prodelta (subaerial delta to subaqueous delta plains) environment within coastal–deltaic environment of deposition have been inferred for the sediments encountered in the analyzed intervals of Ida-5 well (Table 2). The interval: 2207 – 2829 m is delineated to have been deposited in the lower delta plain environment. The lower delta plain is equivalent to fore shore and fluvio-marine environment (Fig. 5). The reasons for this deduction are:

i. The interval is characterized by high representation of mangrove, freshwater swamp and rainforest swamp taxa, freshwater algae, savana and montane taxa and marine species such as *Zonocostites ramonae, Monoporites annulatus, Striatricolpites catatumbus, Retibrevitricolporites protudens, Pachydermites diederixi, Psilatricoloporites crasssus, Verrutricolporites rotundiporus, Botryococcus braunii, Verrutricolpites rotundiporus, Acrostichum aureum, Pachydermites diederixi* and *Laevigatosporites* sp.

ii. The abundant records of palynomacerals 1 and 2 indicate coastal deltaic environment of deposition with influx of fresh water from the moderate quantities of *Botryococcus brannii,* and *Laevigatosporites* sp recorded within the interval in Ida-5 well.

iii. Aggradational, progradational and retrogradational log motifs characterize the sands (intercalated by shales) in the interval suggest deposition as channel/bar complexes in a delta plain to delta front setting. Lithologically, the sands are milky white, very fine to medium-grained, occasionally coarse to very coarse-grained/granule -sized, poorly to well sorted and sub-angular to sub-rounded. The shales are reddish brown to grey, silty, platy and moderately soft to moderately hard. These criteria indicate deposition in lower deltaic plain environments.

Similarly, the interval: 2829 – 2910 m is delineated to have been deposited in delta front (inner neritic) environment of deposition. The criteria for this deduction are:

i. The interval is characterized by increased representation of savanna and montane taxa such as *Monoporite annulatus*, *Coryius* sp. and *Pteris* sp., reduced occurrences of mangrove, freshwater swamp and rainforest swamp taxa compared to the interval above.

ii. The palynomacerals 1 and 2 that occur are more of large and medium sizes than the small size.

iii. The sands and shale intercalations in this interval are characterized by blocky/ aggradational log motifs (slightly serrate cylinder on funnel-shaped log character); suggesting their deposition as channels/channel fills in a delta front setting.

Table 2: Environment of deposition in Ida-5 well.

Idama 5 well interval (m)	Inferred Depositional environment
2207 – 2829	Subaerial delta (lower delta plain)
2829 – 2910	Subaqueous delta (delta front) plain
2910 – 3560	Subaqueous delta (delta front to prodelta) plain

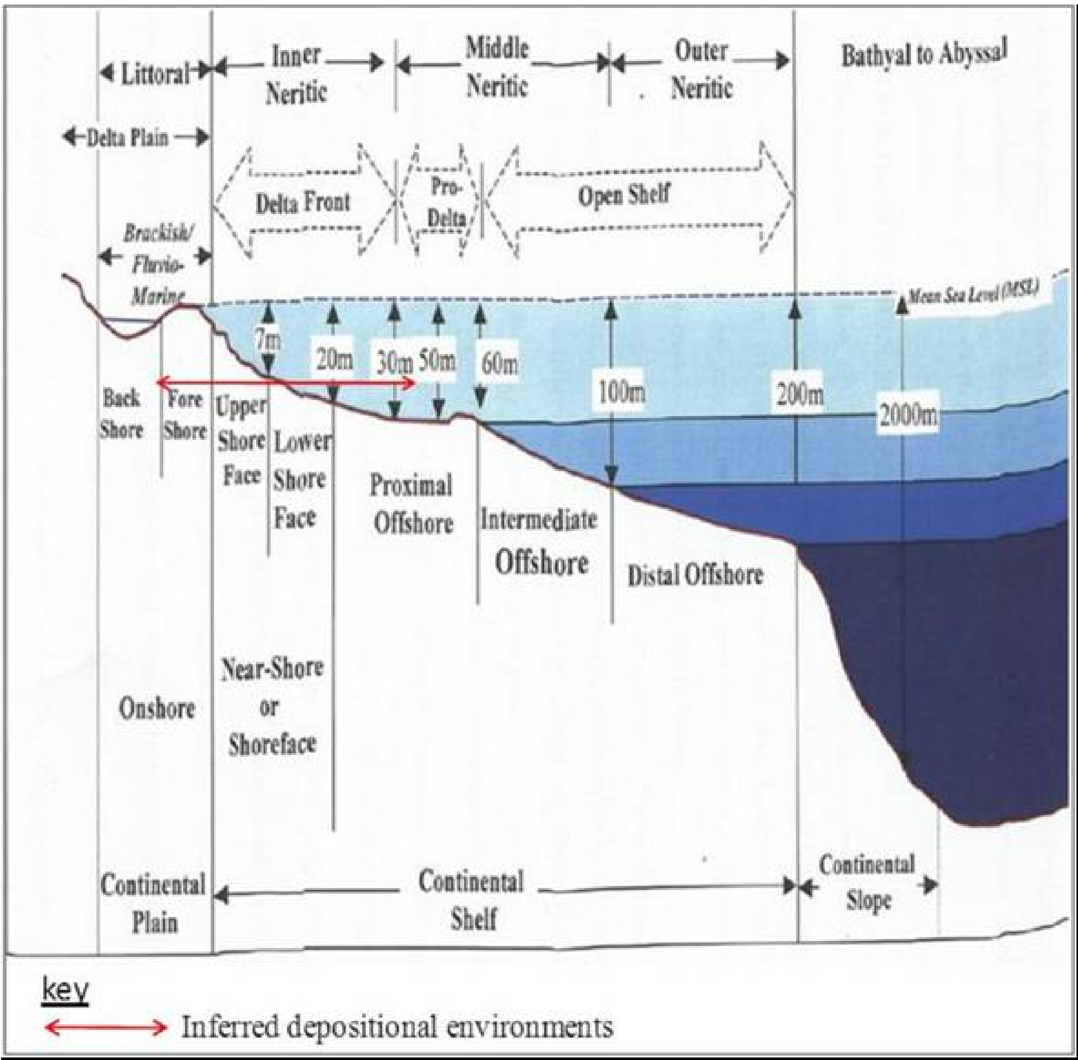

Fig. 5: Depositional environments used in paleoenviromental interpretation (Modified after Ijomah *et al*., 2016).

The lowermost segment of the studied interval: 2910 – 3560 m is also inferred to have been deposited in delta front to prodelta (inner to middle neritic) environment of deposition. The reasons for this inference are:

i. The interval is characterized by moderate to high representation of mangrove, freshwater swamp and rainforest swamp taxa, rare to non presentation of savanna and montane taxa and marine species, suggesting subaqueous delta environment.

ii. They are characterized by moderate to good sorting of palynomacerals 1 and 2, predominantly common to abundant small to medium sizes.

iii. The predominantly shale character of the lower section suggests deposition in low energy, oxic, shallow marine settings. The sand units exhibited multiserrate funnel, cylinder/ subtle bell-shaped Gamma Ray Log interpreted as subaqeous mouth bars and distributary channel deposits indicates prograding shoreline.

Conclusion

Palynofacies analyses were carried out on the strata penetrated by Ida-5 well using the ditch cuttings and Gamma Ray Log provided by Chevron Nigeria Limited. Fifty ditch cutting samples each within the intervals of 2207 – 3569 m were subjected to palynofacies analyses. The standard method of sample preparation for palynofacies analyses was followed. The analysis yielded low to abundant recovery of pollen and spores, small to large sizes of palynomacerals 1 and 2, few occurrences of palynomacerals 3 and 4. The lithology showed alternation of shale and sandstone units with few intercalations of sandy shale units. The grain sizes are essentially fine to medium-grained, occasionally coarse/very coarse-grained. The sands are mostly sub-angular to sub-rounded, occasionally rounded and generally poorly to moderately well sorted. The lithologic, textural and wireline log data indicate that the entire studied intervals in the well belong to the Agbada Formation. The studied intervals were dated middle Miocene to late Miocene base on the recovered age diagnostic marker species such as *Multiareolites formosus, Verrutricolporites rotundiporus, Crassoretitriletes vanraadshoveni* and *Racemonocolpites hians.* Three palynostratigraphic zones each were established in the well using the international stratigraphic guide for establishment of biozones. *Multiareolites formosus–Monoporites annulatus, Verrutricolporites rotundiporus-Crassoretitriletes vanraadshoveni* and *Striatricolporites catatumbus–Racemonocolpites hians* Zones were established in Ida-5 well. The three zones established in the studied well are equivalent to P770, P780 and P820 of Evamy *et al*. (1978). Coastal-deltaic (lower delta plain to prodelta) environments of deposition have been inferred for the well on the bases of the palynofacies association.

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