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CHAPTER 6

Palynofacies, sedimentology and palaeoenvironment evidenced by studies on IDA-6 well, Niger Delta, Nigeria

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ABSTRACT: Palynofacies and sedimentological analyses of the strata penetrated by Ida-6 well were undertaken with the aim of determining biozones and the palaeoenvironmental conditions. Fifty ditch cutting samples within the intervals of 2679–4051 m were analysed. The analysis yielded low to abundant recovery of pollen and spores, small to large sizes of palynomaceral 1 (irregularly shaped, orange-brown to dark-brown coloured and opaque plant debris), palynomaceral 2 (irregularly shaped, brown-orange coloured platy plant materials), and few occurrences of palynomaceral 3 (pale to brown coloured, cuticular, and translucent plant materials). The lithology showed alternation of shale and sandstone units with few intercalations of siltstone units. The sandstone units consist of fine to medium grains, occasionally coarse to granule sized. The sand grains are mostly sub-angular to sub-rounded, occasionally rounded, and generally poorly to moderately sorted. The accessory minerals are dominated by ferruginous material, shell fragments and carbonaceous detritus with spotty occurrences of mica flakes. The lithologic, textural, and wire line log data indicated that the entire studied intervals in the well belong to the Agbada Formation. The studied intervals were deposited during middle Miocene to late Miocene based on the recovered age diagnostic marker species such as *Multiareolites formosus, Verrutricolporites rotundiporus, Crassoretitriletes vanraadshoveni* and *Racemonocolpites hians.* Three interval range zones were established using the international stratigraphic guide for the establishment of biozones. The three established palynostratigraphic zones are *Multiareolites formosus–Lavigatosporites* sp., *Racemonocolpites hians–Crassoretitriletes vanraadshoveni* and *Psiltricolporites crassus—Acrostichum aureum* Zones. Coastal-deltaic environments of deposition have been inferred for the studied interval of the well on the bases of the palynofacies association and sedimentological characteristics.

6.1 INTRODUCTION

Palynofacies has been described to mean the total organic matter that is recovered from a rock or unconsolidated sediment by the standard palynological processing technique of digesting samples in HCl and/or HF (Batten and Stead, 2005). In palynofacies analysis, it is not only the palynomorphs (pollen, spores, dinoflagellate cysts, fungal remains, and foraminferal linings) in the palynological slides that are investigated, but the entire organic content of the slides. The organic content includes structured organic matter (phytoclasts and zooclasts) and unstructured organic matter which comprises of amorphous organic matter, gelified matter, solid bitumen, resin, and amber (Batten and Stead, 2005). The nature of the organic contents in the sedimentary rocks reflects the original conditions in the source area as well the depositional environments. The integration of palynofacies and sedimentological analyses significantly contribute to environmental reconstruction and basin evaluation (Oyede, 1992). The understanding of the biochronology and palaeoenvironment are essential in basin evaluation and successful exploration of both organic and inorganic mineral resources. Palynology, sedimentology, and palaeoenvironmental conditions of sedimentary rock deposition within the Niger Delta basin have been published by Ige *et al*. (2011), Ajaegwu *et al.* (2012), Ojo and Adebayo (2012), and Olajide *et al*. (2012). The most comprehensive contribution to the knowledge on the palynology of the Niger Delta 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). They 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*. Evamy *et al*. (1978) established twenty-nine informal palynological zones of the Niger delta using alphanumeric coding method, which seems to form the background information for in-house zonal scheme of Shell Petroleum Development Company. Palynological studies of sediments from North Chioma-3 Well, Niger Delta and its palaeoenvironmental interpretations were carried out by Ige *et al*. (2011). They recognized four pollen zones (I-IV), using pollen diagram method. They further established both wet and warm climate using percentage occurrence of mangrove forest taxa. They interpreted the palaeoenvironment as mangrove swamp environment because of high occurrence of *Rhizophora* sp. palynology of Bog-1 well, south-eastern Niger Delta was studied by Olajide *et al*. (2012). They noted that dominance occurrence of the mangrove species, *Zonocostites ramonae* (*Rhizophora*) and *Foveotricolporites crassiexinus* (*Avicennia*), suggests a tidal swamp shoreline inhabited by mangroves. Ajaegwu *et al.* (2012) discussed the Late Miocene to Early Pliocene palynostratigraphy and palaeoenvironments of Ane-1 well, Eastern Niger Delta, Nigeria. They adopted the alpha-numerical method (Evamy *et al*., 1978; Morley, 1997) to identify eight palynological zones, dated Late Miocene to Early Pliocene. Ojo and Adebayo (2012) carried out palynostratigraphy and palaeoecology of Chev-1 well, south-western Niger Delta basin. They identified nine palynozones and suggested that the studied sediments were deposited during Miocene-Pliocene period in which there was predominance of a high sea level and wet-humid climatic conditions because of the recovered palynomorphs were mainly made up of mangrove swamp floras. Osokpor *et al*. (2015) carried out palynozonation and lithofacies cycles of Paleogene to Neogene age sediments in PML-1 well, Northern Niger Delta Basin. They established two palynozones (*Ephedra claricristata* and *Auricupollenites echinatus* range zones) of Oligocene (Late Rupelian and Chattian stage) and three palynozones (*Verrutricolporites laevigatus*/*Verrutricolporites scabratus* range zone; and *Verrutricolporites rotundiporus* and *Margocolporites* sp. abundance zones) of Early–Late Miocene. The bases for the establishment of the zones are very vague. They neither followed properly the international stratigraphic guidelines nor the alpha-numeric methods of biozonation. Besides, they did not account for some intervals in between the zones. The aim of this work is to carry out the palynofacies and sedimentological studies of the strata penetrated by Ida-6 well in order to establish the palynostratigraphic zonation in line with the international stratigraphic guidelines as well as establish biochronology and palaeoenvironment of deposition of the strata penetrated by the well for the purpose of petroleum exploration.

6.1.1 Location of the studied well

The Niger Delta is located between latitudes 4° and 6°N and longitudes 3° and 9°E in Southern Nigeria. IDA-6 well is situated in the Ida oil field in the Niger delta. It is situated at 4.73°N and 6.96°E in the Coastal Swamp Depobelt of the Eastern Niger Delta (Figure 1).

6.1.2 Geology of the Niger Delta

The geology and stratigraphy of the Tertiary Niger Delta has been described by Short and Stauble (1967). They recognized three formations. In ascending order, these are the Akata, Agbada, and Benin formations (Figure 2). The Akata Formation generally consists of open marine and prodelta 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). Thin sandstone lenses occur near the top, particularly near the contact with the overlying Agbada Formation. An estimated maximum thickness of the Akata Formation is possible only in the northern part of the delta where the formation has been drilled through into the Cretaceous

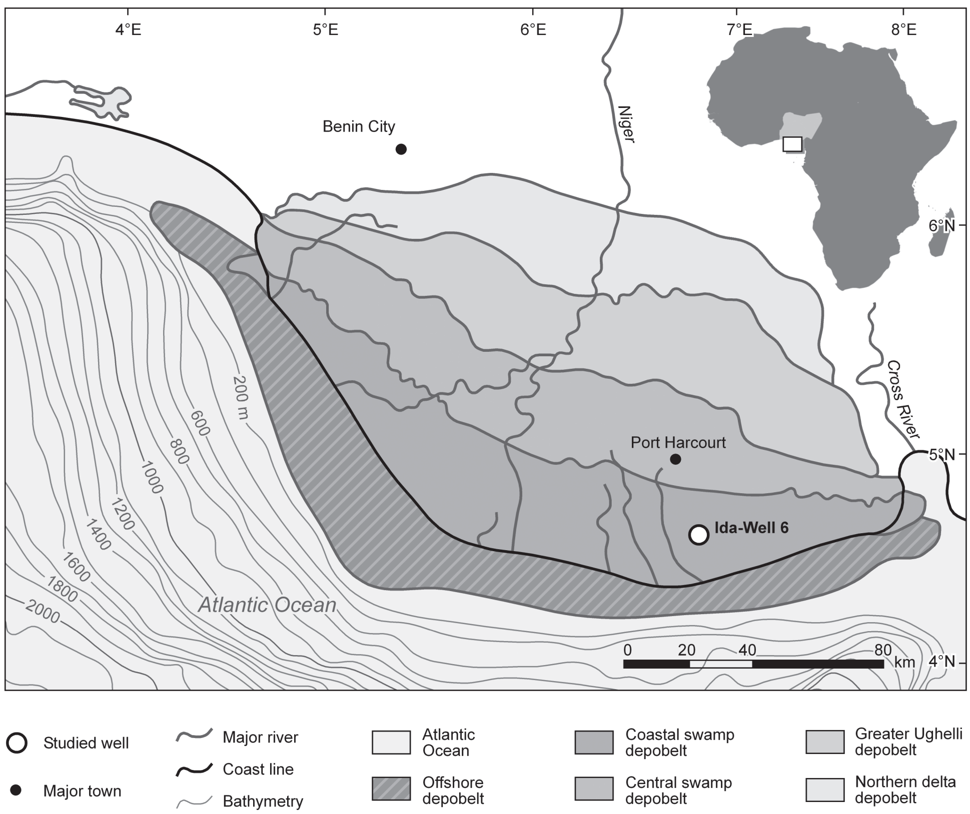


Figure 1. Depobelt map of the Niger Delta and location of the studied well (modified after Okosun and Chukwuma-Orji, 2016).

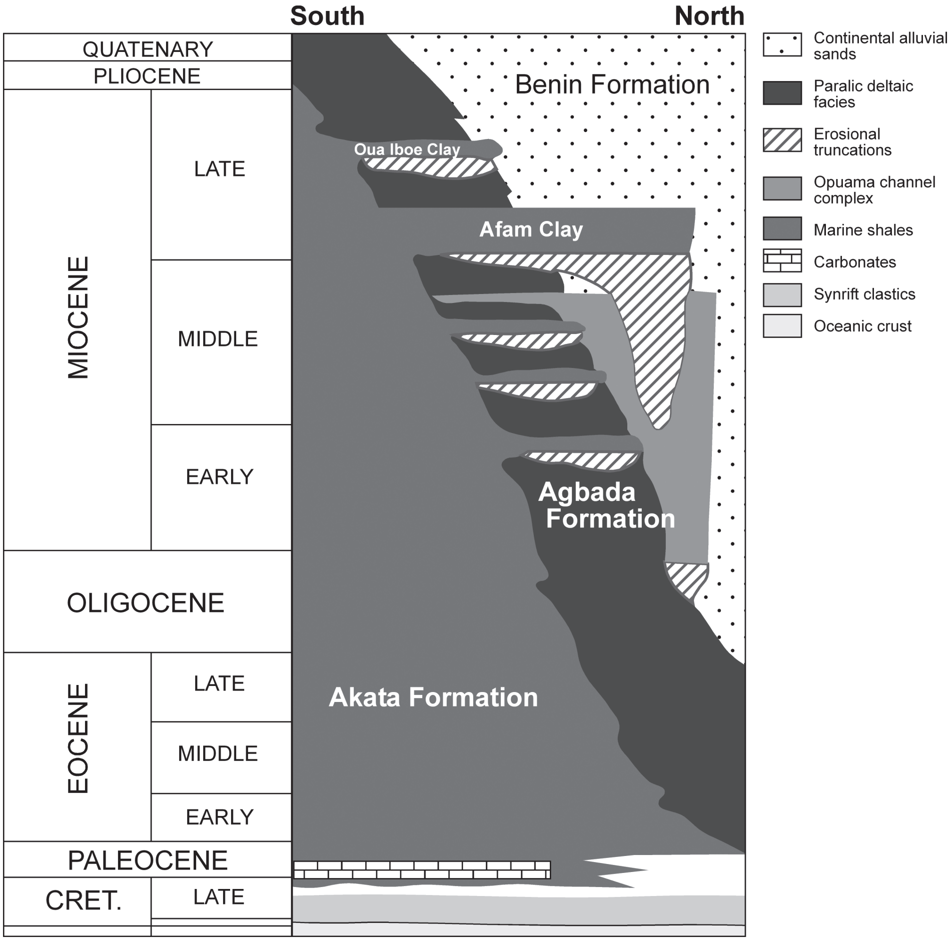


Figure 2. Stratigraphy of the formations of the Niger Delta (Ige, 2010).

(Avbovbo, 1978). A thickness range of 600 m to probably more than 6000 m is suggested by Weber and Daukoru (1975) and Durugbo and Uzodimma (2013). The age of the Akata Formation ranges from the Paleocene in the proximal parts of the delta to recent sediments in the distal offshore. The Agbada Formation consists of cyclic coarsening-upward regressive sequences. The coarsening upward sequences are composed of shales, siltstones, and sandstones which include delta front and lower delta plain deposits (Weber, 1971). The thickness of the Agbada sequences 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 nearshore shelf domain. The Benin Formation comprises 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 2000 m thick in the central onshore part of the delta and thins towards the delta margins (Bustin, 1988). Doust and Omatsola (1990) recognized depobelts in the Niger Delta which 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 (Figure 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 (transgression and regression or rise and fall) active in the basin within the development of the depobelt. During transgression, marine sediments are deposited, while during regression, continentally derived sediments are deposited (Ige, 2010; Bankole, 2010). The cyclicity of paralic sedimentation has been attributed to changes in climate associated with wet and dry climates (Burke and Durotoye, 1970; Bankole, 2010).

6.2 MATERIALS AND METHODS

The ditch cutting samples and wireline logs of Ida-6 well were provided by Chevron Nigeria Plc. Other materials required were made available by Crystal Age Limited, Lagos, Nigeria where sample processing and laboratory analyses were carried out.

For sedimentological analysis, the lithologic description of the stratigraphic intervals studied was based on the study of the log motifs (gamma ray and resistivity logs), physical inspection of the ditch cuttings, and microscopic study of the washed samples. Twenty grams of each sample was crushed and soaked with water and liquid detergent for 24 hours. The soaked samples were briskly washed under a distilled water nozzle tap using a 63 micrometre (μm) sieve mesh. The retained samples on 63 μm sieve were dried over hot plates and bagged for sedimentological studies. The bagged samples were spread on a black anodized aluminium foraminiferal picking tray and viewed using the standard binocular reflected light microscope (Fisher Scientific, No. 62416). The lithologic description was enhanced by the gamma-ray and resistivity logs since high and low values of gamma log and deep induction resistivity log signified shale and sand lithologies, respectively (Olayiwola and Bamford, 2016). The essential parameters studied were: (i) the rock types; (ii) colour and texture such as grain size, sorting and grain shape (roundness); and (iii) accessory mineral and fossil contents. The lithological data were plotted using Stratabug software to generate the vertical lithofacies profiles encountered within the studied intervals.

The standard acid palynological preparation method was followed. Fifty ditch cutting samples from Ida-6 well were subjected to analysis. Fifteen grams of each sample were treated with 10% HCl under a fume cupboard for the complete removal of carbonates. This was followed by neutralization with distilled water before the next procedure. Then 40% HF was added to the sample which was placed on a shaker for 24 hours to speed up the reaction and to ensure a complete dissolution of the silicates and for the particles to settle down. Thereafter, the HF was carefully decanted, followed by neutralisation with distilled water in order to remove fluoro-silicate compounds usually formed from the reaction with HF. Sieving and separation were performed 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). The level of oxidation required by each sample was closely monitored under a microscope. 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 palyno debris. The recovered organic matters were uniformly spotted on arranged cover slips of 22/32 mm and were then allowed to dry for mounting.

The mounting medium used for permanent mounting of cover slip onto glass slide was Loctite (Impruv) and was dried with natural sunlight for five minutes. The slides were then stained with safaranin-O in order to enhance the study of dinoflagellete cysts.

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

6.3 RESULTS AND DISCUSSION

6.3.1 Lithologic description and sedimentological analyses

The lithology consists of alternating shale/mudstone and sandstone units with sandy shale and siltstone units (Figure 3). The shale/mudstones are mostly grey to brownish grey in colour, moderately hard to hard, platy to flaggy in appearance. The sandstones are white to very light gray, coarse to fine grained, angular to subangular to rounded, and poorly to well sorted in texture. The accessories include shell fragments, ferruginous materials, mica flakes, and carbonaceous detritus (Figure 3).

Sedimentological deductions were based on the integration of wire line log motifs, textural/lithologic attributes and the distribution of the accessory materials. These had permitted the assignment of the entire studied sections of Ida-6 well to the Agbada Formation. These criteria also enabled the recognition of one broad lithofacies sequence—The Paralic Lithofacies sequence within the sections (Figure 3). The Paralic Lithofacies Sequences were subdivided further into an Upper and Lower Paralic unit. The Upper Paralic unit consists dominantly of fine to medium grained, occasionally coarse to very coarse grained/granule sized, moderately to well sorted, subangular to subrounded sand grains with reddish brown to grey, platy to flaggy, moderately soft to moderately hard shales. The Lower Paralic unit consists of very fine to medium grained, occasionally coarse grained, well sorted and subangular sand grains with brownish grey, platy to flaggy, moderately soft to moderately hard shales.

6.3.1.1 Palynofacies

The charts in Figures 4 and 5 show the different palynomorph taxa and types of palynomacerals encountered at the different depths interval. Analysis of the slides of Ida-6 well yielded low to moderate palynomorph species. The diversity is also low to moderate. The palynomorphs recovered are pollens, spores and one indeterminate dinoflagellate cyst (Figure 4). The palynomacerals analysis yielded abundant records of palynomacerals 1 and 2, few occurrences of palynomacerals 3. There are no records of palynomacerals 4 and structure-less organic matter (SOM) (Figure 5). Microphotographs of some of the recovered palynomacerals and palynomorphs are presented on plates 1 and 2 respectively.

Palynomaceral 1 (PM 1)

The observed PM 1 are plant debris that appeared orange-brown to dark-brown in colour, opaque, irregular in shape, structure-less and varies in preservation (Plate 1). Batten and Stead (2005), and Oyede (1992) described PM 1 as particulate organic matter (Alginite) that is orange-brown to dark-brown in colour, dense in appearance,

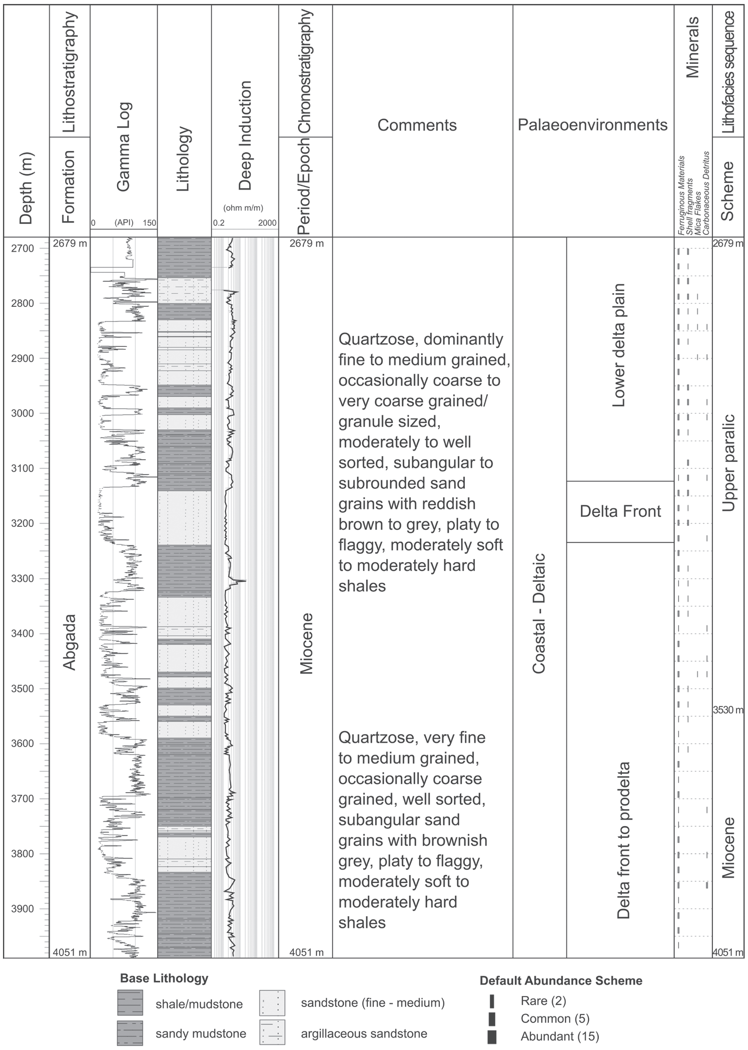
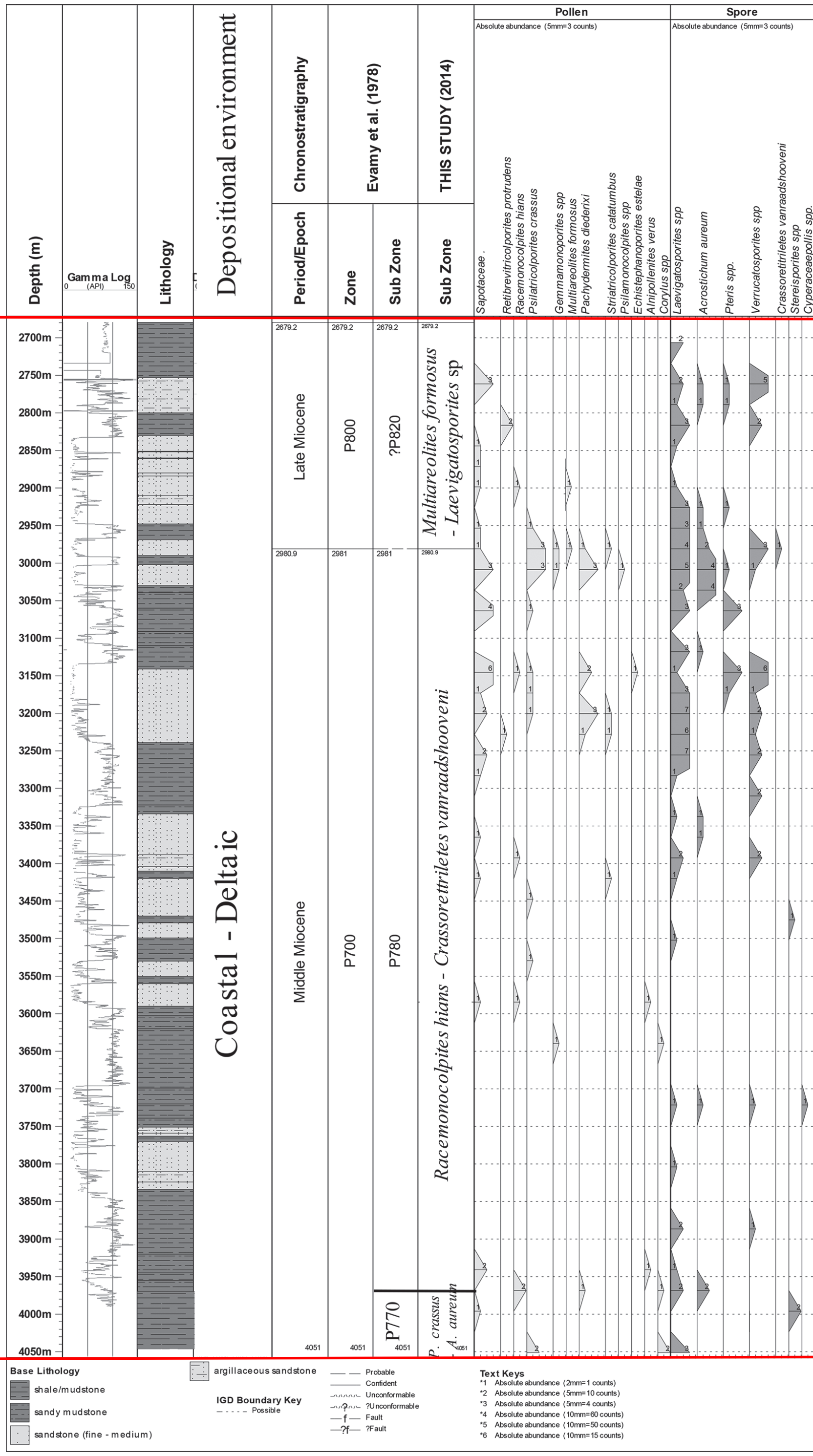


Figure 3. Lithological and sedimentological chart of Ida-6 well, Well code: IDAMA-6-S, Interval: 2679–4051 m.

irregular in shape, structure-less, 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. PM 1 includes small, medium and large sizes of flora debris, humic gel-like substances, and resinous cortex irregularly shaped materials (Batten and Stead, 2005; Oyede, 1992; Thomas *et al.*, 2015).

Palynomaceral 2 (PM 2)

The PM 2 are irregular in shape, brown-orange in colour, and platy-structured plant materials (Plate 1). PM 2 (Exinites) had been described to be 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



Depth (m)
Gamma Log
(API)
Lithology
Depositional environment
Chronostratigraphy
Period/Epoch
Evamy et al. (1978)
Zone
Sub Zone
THIS STUDY (2014)
Sub Zone
Pollen
Absolute abundance (5mm=3 counts)
Spore
Absolute abundance (5mm=3 counts)
Sapotaceae .
Retibrevitricolporites protrudens
Racemonocolpites hians
Psilatricolporites crassus
Gemmamonoporites spp
Multiareolites formosus
Pachydermites diederixi
Striatricolporites catatumbus
Psilamonocolpites spp
Echistephanoporites estelae
Alnipollenites verus
Corylus spp
Laevigatosporites spp
Acrostichum aureum
Pteris spp.
Verrucatosporites spp
Crassoretitriletes vanraadshooveni
Stereisporites spp
Cyperaceaepollis spp.
Coastal - Deltaic
Late Miocene
Middle Miocene
P800
P700
?P820
P780
P770
Multiareolites formosus - Laevigatosporites sp
Racemonocolpites hians - Crassoretitriletes vanraadshooveni
P. crassus - A. aureum
Base Lithology
shale/mudstone
sandy mudstone
sandstone (fine - medium)
argillaceous sandstone
IGD Boundary Key
Possible
Probable
Confident
Unconformable
?Unconformable
Fault
?Fault
Text Keys
*1 Absolute abundance (2mm=1 counts)
*2 Absolute abundance (5mm=10 counts)
*3 Absolute abundance (5mm=4 counts)
*4 Absolute abundance (10mm=60 counts)
*5 Absolute abundance (10mm=50 counts)
*6 Absolute abundance (10mm=15 counts)

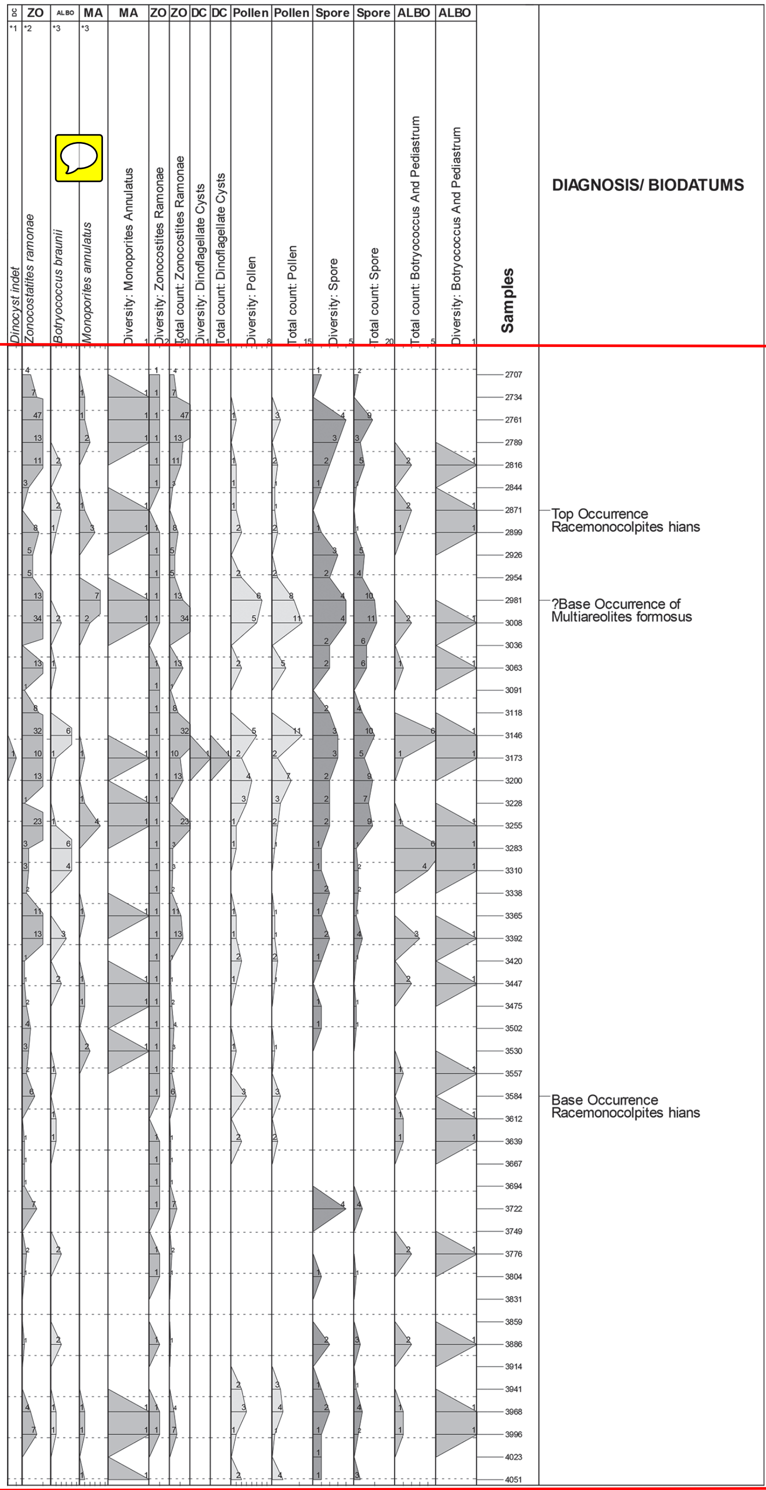


Figure 4. Palynomorph distribution chart of Ida-6 well; Well code: IDAMA-6-P, Interval: 2878–4051 m.

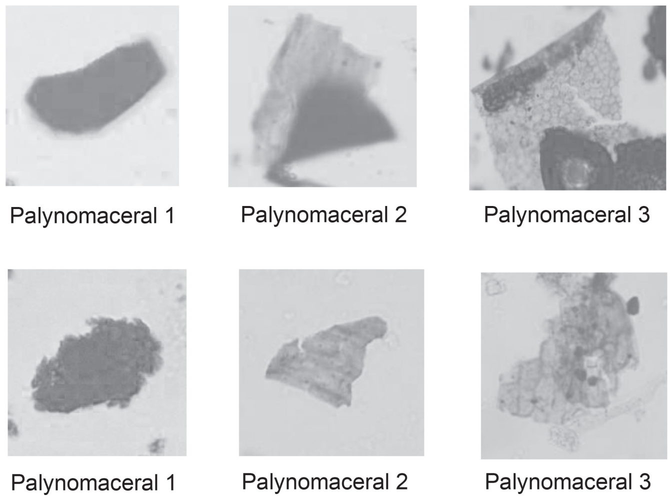


Plate 1. Palynomacerals recovered from the studied well (×400).

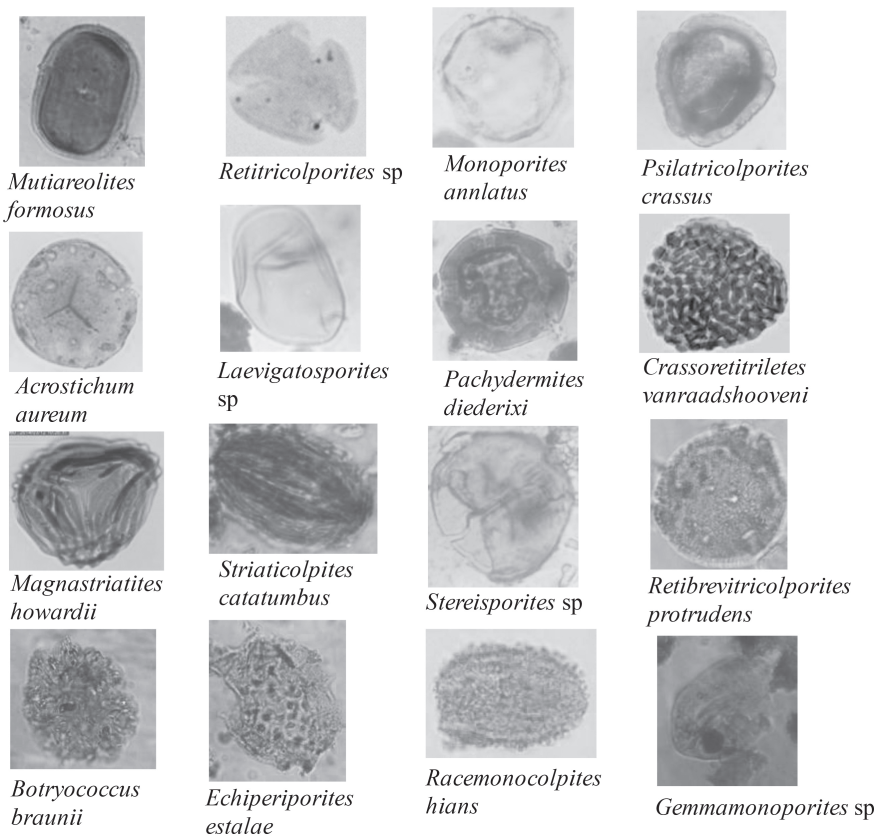


Plate 2. Palynomorphs recovered from the studied well (×400).

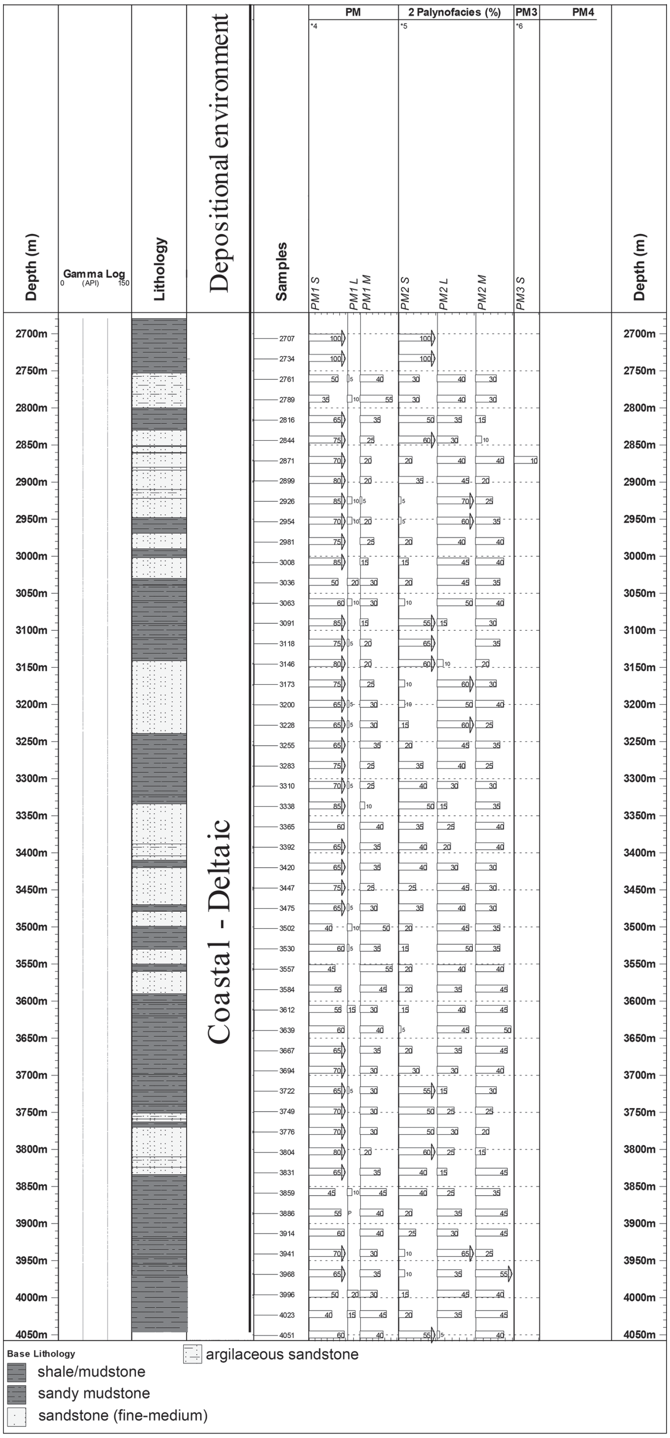


Figure 5. Palynomaceral distribution chart of Ida-6 well, Well code: IDAMA-6-P, Interval: 2679–4051 m.

humic gels and resinous substances. PM 2 is more buoyant than PM 1 because of its thinner lath-shaped character (Batten and Stead, 2005; Oyede, 1992; and Thomas *et al.*, 2015).

Palynomaceral 3 (PM 3)

PM 3 showed plant materials that are pale to brown in colour, irregular in shape, translucent and contain stomata (Plate 1). Batten and Stead (2005), Oyede (1992) and Thomas *et al.* (2015) 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 PM 2 (Thomas *et al.*, 2015).

6.3.1.2 Palynostratigraphic zonations and biochronology of Ida-6 well

The biozones established are characterised by *Multiareolites formosus—Lavigatosporites* sp., *Racemonocolpites hians—Crassoretitriletes vanraadshoveni*, and *Psiltricolporites crassus—Acrostichum aureum* zones.

Multiareolites formosus–Lavigatosporites sp. *Zone (Interval Zone)*

Stratigraphic interval: 2707–2981 m

Definition: The interval between the FDO of *Lavigatosporites* sp. and the LDO of *Multiareolites formosus* defines the zone. The top of the zone is at 2707 m while the base is at 2981 m. LDO of *Crassoretitriletes vanraadshoveni* also marks the base of the zone.

Characteristics: The zone shows the presence of *Verrucatosporites* sp., *Pteris* sp., *Psiltricolporites crassus,* and *Racemonocolpites hians*. The zone is also characterised by moderate to rich occurrence of *Zonocostites ramonae* and *Laevigatosporites* sp.

Age: The zone is dated to the Late Miocene because of the association of *Crassoretitriletes vanraadshoveni, Multiareolites formosus,* and *Botryococcus brannii,* which are indicative of the Late Miocene (Morley, 1997)

Racemonocolpites hians–Crassoretitriletes vanraadshoveni Zone (Interval Zone)

Stratigraphic interval: 2981–3968 m

Definition: The top of the zone is marked by the LDO of *Crassoretitriletes vanraadshoveni* at 2981 m; while the base is marked the LDO of *Racemonocolpites hians* at 3968 m. FDO of *Pachydermites diederix, Striatricolporites catatumbus* and *Gemmamonoporites* sp. also characterise the top.

Characteristics: The zone is characterised by the association of the following taxa: *Racemonocolpites hians, Retibrevitricolporites protrudens, Pachydermites diederix, Striatricolporites catatumbus, Psilatricolporites crassus, Gemmamonoporites* sp., and Sapotaceae. The zone has moderate to rich occurrences of *Verucatosporites* sp., *Zonocoastites ramoneae, Laevigatosporites* sp., *Botryococcus brauni*, and a dinocysts indeterminate.

Age: The zone is dated to the Middle Miocene because of the association of the above mentioned taxa such as *Racemonocolpites hians, Retibrevitricolporites protrudens,* and *Pachydermites diederix,* which are indicative of the Middle Miocene (Morley, 1997).

Psilatricolporites crassus–Acrostichum aureum Zone (Interval Zone)

Stratigraphic interval: 3968–4051 m

Definition: The interval between the FDO of *Psilatricolporites crassus* and *Acrostichum aureum* at 4051 m and 3968 m respectively, defines the zone.

Characteristics: The zone is marked by the association and low occurrence of the following taxa: *Zonocoastites ramonae, Laevigatosporites* sp., *Botryococcus brauni, Coryius* sp. and *Acrostichum aureum*.

Age: The zone is dated to the Middle Miocene.

6.3.1.3 Palaeoenvironmental conditions of deposition

The Palaeoenvironment during the deposition involves the periodic changes in the depositional environment over geological time. Evaluation of the palaeoenvironment 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 palaeodepositional environments of the studied wells was made based on the following criteria:

The palynoecological groupings of the recovered palynomorphs and the association of environmentally restricted diagnostic species such as *Zonocostites ramonae, Psilatricoloporites crasssus* (mangrove), *Monoporites annulatus* (montane), *Pachydermites diederixi* (fresh water swamp), *Laevigatosporites* sp., and *Botryococcus braunii* (rainforest) is shown in Table 1. Generally, the palynoecological groupings of the recovered palynomorph taxa indicate that the mangrove taxa have highest representation of the total recovery, followed by freshwater and rainforest swamps taxa in the well. Montane and savanna taxa have the lowest representation (Figure 6). Some authors (Adojoh *et al*., 2015; Olayiwola and Bamford, 2016) 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 characterised by high representation of mangrove, other coastal swamp plants (from beach, brackish, freshwater swamp, rainforest, and palm) miospores, fungal elements, freshwater algae, and marine species (Adojoh *et al*., 2015; Olayiwola and Bamford, 2016) (Figure 7). Similarly, during sea level fall, the coastline is shifted basinward and the shelf area ini-

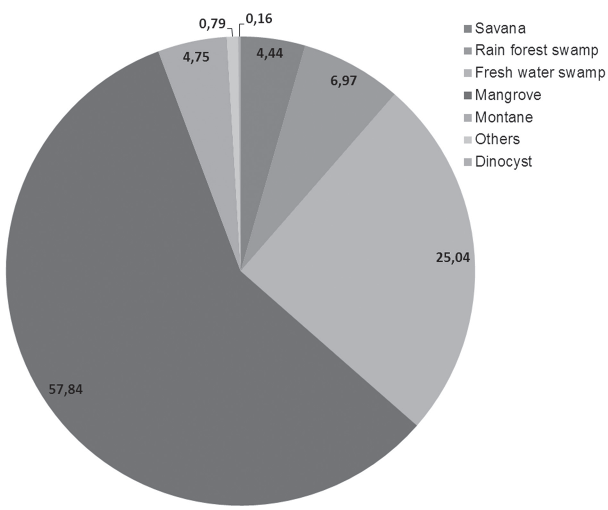


Figure 6. Palynoecological groups (%) of the recovered palynomorph taxa.

tially 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 then become characterised by widespread savanna and montane vegetation belts (Figure 7). This depositional environment is characterised by maxima spectra of savanna and montane pollen (Adojoh *et al*., 2015; Olayiwola and Bamford, 2016; see also Germeraad *et al*., 1968; Jennifer *et al.*, 2012; Olajide *et al.*, 2012).

The type/nature of organic matter (palynomercerals) recovered from the samples point towards terrestrial/coastal and marine depositional environments, which have

Table 1. Palynoecological groupings of palynomorph taxa recovered from IDA-6 well.

		Savanna Taxa							Montane Taxa			RFS Taxa			Freshwater swamp Taxa									Mangrove Taxa				Others			Dinocyst
S/N	Sample depth (meters)/ taxa	*Pteris* sp.	*Cyperaceaepollis spp*	*Coryius spp*	*Stereiosporites* sp.	Fungal spore	*Retibrevitricolporites protrudens*	Total savana taxa	*Monoporites annulatus*	*Ainipollenites verus*	Total Montane taxa	*Pachydermites diederxi*	*Sapotaceae*	Total RainForest Swamp taxa	*Striatricolporites catatumbus*	*Gemmamonoporites* sp.	*Racemonocolpites hians*	*Multiareolites formosus*	*Crassoretitriletes vanraadshooveni*	*Laevigatosporites* sp.	*Botrycoccus braunii*	*Verrucatosporites* sp.	Total Freshwater Swamp taxa	*Zonocostatites ramonae*	*Psilatricolporites crassus*	*Acrostichum aureum*	Total mangrove taxa	*Psilamonocolpites* sp.	*Echistephanoporites estalae*	Total others	dinocyst indeterminate
1	2707							0			0			0						2			2	4			4			0	
2	2734							0	1		1			0									0	7			7			0	
3	2761	1						1	1		1		3	3						2		5	7	47		1	48			0	
4	2789	1				1		2	2		2			0						1			1	13		1	14			0	
5	2816						2	2			0			0						3	2	2	7	11			11			0	
6	2844							0			0		1	1						1			1	3			3			0	
7	2871							0	1		1		1	1							2		2	3			3			0	
8	2899							0	3		3		1	1			1			1	1		3	8			8			0	
9	2926	1						1			0			0						3			3	5		1	6			0	
10	2954							0			0		1	1						3			3	5	1	1	7			0	
11	2981							0	2		2	1	1	2	1	1		1	1	4		3	11	13	3	2	18			0	
12	3008	1						4	2		2	3	3	3		1				5	2	2	10	34	3	4	41	1		1	
13	3036							0			0			0						2			2			4	4			0	
14	3063	3						3			0		4	4						3	1		4	13	1		13			0	
15	3091							0			0			0									0	1			1			0	
16	3118							0			0			0						8			8	32		1	33			0	
17	3146	3				4	2	9			0	2	6	8			1			1	5	5	12	8	1		9		1	1	
18	3173	1				3		4	7		7		1	1						3	1	1	5	10	1		10			0	1
19	3200	4						4	1		1	3	2	5	1					4		2	7	13	1		14			0	
20	3228					4	1	5	4		4	1		1	1					6		1	8	1			1			0	
21	3255							0	3		3		2	2						7	1	2	10	23			23			0	
22	3283							0			0		1	1						1	6		7	3			3			0	
23	3310					1		1			0			0							4	2	6	3			3			0	
24	3338							0			0			0						1			1	2		1	3			0	
25	3365							0	1		1		1	1									0	11		1	12			0	
26	3392							0			0			0			1			2	3	2	8	13			13			0	
27	3420					1		1			0		1	1	1					1			2	1			1			0	
28	3447							0	1		1			0							2		2	1	1		2			0	
29	3475				1			1	1		1			0									0	2			2			0	
30	3502							0			0			0						1			1	4			4			0	
31	3530							0	2		2			0									0	3	1		4			0	
32	3557							0			0			0							1		1	2			2			0	
33	3584							0		1	1		1	1			1						1	6			6			0	
34	3612							0			0			0							1		1				0			0	
35	3639			1				1			0			0		1					1		2	1			1			0	
36	3667							0			0			0									0	1			1			0	
37	3694							0			0			0									0	1			1			0	
38	3722		1					1			0			0						1		1	2	7		1	8			0	
39	3749							0			0			0									0				0			0	
40	3776							0			0			0							1		1	2			2			0	
41	3804							0			0			0						1			1	1			1			0	
42	3831							0			0			0									0				0			0	
43	3859							0			0			0									0				0			0	
44	3886							0			0			0						2	2	1	5	1			1			0	
45	3914							0			0			0									0				0			0	
46	3941							0		1	1		2	2						1			1				0			0	
47	3968			1				1	1		1	1		1			2			2	1		5	4		2	6			0	
48	3996				2			2	1		1		1	1							1		1	7			7			0	
49	4023							0			0			0								1	1				0			0	
50	4051			1				1	1		1			0						3			3		2		2			0	

RFS = Rain forest Swamp

been distinguished to have distinctive and characteristic palynofacies (Oyede, 1992; Thomas *et al*., 2015). The terrestrial/coastal environments are characterised by poorly sorted PM 1 and 2, absence of dinocysts, and common to abundant occurrence of fungal spores; while marine environment is characterised by a good sorting of organic matter predominantly small to medium, common to abundant PM 1 and 2, some needle-shaped to lath-shaped PM 4, and presence of dinocysts and/or foraminifera linings (Oyede, 1992). The wire line log motifs, lithology, and accessory minerals were also considered in the palaeoenvironmental determination.

Based on these criteria, the lower delta plain to delta front and prodelta (subaerial delta to subaqueous delta plains) environments within coastal-deltaic environment of deposition have been inferred for the sediments encountered in the analysed intervals of Ida 6 well (Table 2, Figure 3).

The interval 2679–3135 m in Ida-6 well was delineated to have been deposited in the lower delta plain environment (Figure 3). The interval is characterised by high occurrences of mangrove taxa (*Zonocostites ramonae–Rhizophora*, *Psilatricoloporites crasssus* and *Acrostichum aureum*), followed by freshwater swamp (*Laevigatosporites* sp., and *Botryococcus brannii*) and rainforest swamp taxa (sapotaceae and *Pachydermites diederixi*). This interval has also little representation of savanna (*Retibrevitricolporites protudens, Pteris* sp., and fungal spore) and montane taxa (*Monoporites*

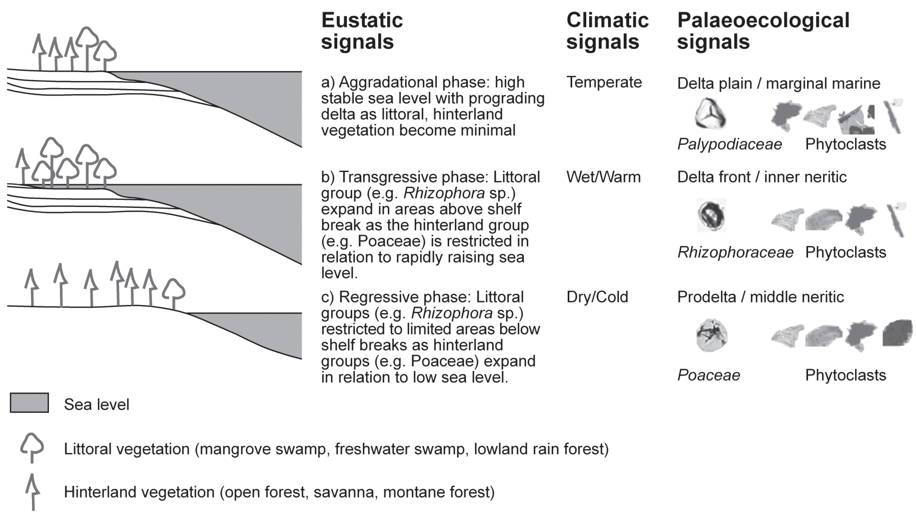


Figure 7. Relationship between palaeoecology, palaeovegetation, eustasy and climate in the tropical setting (modified after Adojoh *et al.*, 2015).

Table 2. Environment of deposition in Ida-6 well.

Ida 6 well interval (m)	Inferred depositional environment
2679–3135	Subaerial delta (lower delta plain)
3135–3240	Subaqueous delta (delta front) plain
3240–4051	Subaqueous delta (delta front to prodelta) plain

annulatus—Poacaea) (Table 1). High representation of coastal miospores (mangrove, fresh water and rainforest taxa) compared to minimal representation of hinterland miospores (savanna and montane taxa) are characteristics of subaerial sediments that were deposited during sea level rise and wetter climate; while the opposite represents sea level fall and drier climate (Morley, 1995; Ige, 2009; Adojoh *et al*., 2015; Olayiwola and Bamford, 2016). The higher occurrences of mangrove, rainforest and fresh water taxa within the interval are indications that the interval was deposited in lower delta plain during sea level rise and wet climate (Figure 7). The prevailing climatic conditions supported the flourishing of the mangrove, rainforest, and fresh water vegetations. This deduction agrees with that of some previous researchers in the Niger Delta (Durugbo *et al*., 2010; Ige *et al*., 2011; Ola and Adewale, 2014; Bankole *et al*., 2014). They utilised high percentage occurrences of mangrove taxa (Rhizophora), fresh water and rainforest taxa to delineate wet climatic zones, which were also an indication of rise in sea level. The abundant records of poorly sorted palynomacerals 1 and 2 (Figure 5) indicate coastal deltaic environment of deposition with influx of fresh water from moderate quantities of *Botryococcus braunii* and *Laevigatosporites* sp. recorded within the interval (Oyede, 1992). The recorded PM 1 and 2 consist of large, medium and small sizes.

Aggradational, progradational and retrogradational log motifs characterise the sandstone units (intercalated by shales and silts) in the intervals suggest their deposition as channel/bar complexes in a delta plain–delta front setting (Selley, 1978). Lithologically, the sand grains are white, very fine to medium–grained, occasionally coarse to very coarse-grained/granule-sized, poorly to well sorted, and subangular to subrounded. The shales are reddish brown to grey, platy, and moderately soft to moderately hard. The accessory mineral suites are mostly ferruginous materials, shell fragments, carbonaceous detritus, and mica flakes in decreasing order of abundance. These criteria indicate deposition in lower deltaic plain (inner neritic) environments.

Similarly, the interval 3135–3240 m was delineated to have been deposited in delta front (inner neritic) environment of deposition (see Figure 3).

The criteria for this deduction are: The interval is characterised by increased occurrence of savanna taxa such as *Pteris* sp. and fungal spores, and *Monoporite annulatus* (montane taxa). The reduced occurrences of mangrove, freshwater swamp, and rainforest swamp taxa compared to the above interval indicates dry climate and sea level fall and sediments deposition in delta front environment (Adojoh *et al.,* 2015). Durugbo *et al*. (2010), Ige (2009) and Bankole *et al*. (2014) have utilized this approach of low representation of mangrove taxa (Rhizophora), fresh water and rainforest taxa, and high representation savanna and montane taxa to delineate dry climatic zones.

The PM 1 and 2 that occur are more of large and medium size than small size (Figure 5).

This interval is characterised by blocky/aggradational log motifs (slightly serrate cylinder on funnel–shaped log character), suggesting deposition as channels fills in a delta front setting. Accessory minerals are dominated by ferruginous materials and shell fragments. Carbonaceous detritus showed spotty occurrences and absence of glauconite pellets may suggest a distributary channel-subaqeous mouth bar.

Finally, the interval 3240–4051 m was inferred to have been deposited in delta front to prodelta (inner to middle neritic) environment of deposition (see Figure 3).

The reasons for this inference are: The interval is characterised by moderate occurrence of mangrove taxa (*Zonoccostatites ramonae*, *Psilaticolporites crassus* and *Acrostichum aureum*), freshwater taxa (*Striatricolporites catatumbus*, *Levigatosporites* sp., *Botryococcus brauni*, *Verrucatosporites* sp. and *Gemmamonoporites* sp.), and rainforest taxa (*Pachydermites diederixi* and sapotacea). This is supported by rare to no presence of savanna (*Coryius* sp., *Cyperaceapollis* sp., *Pteris* sp., and fungal spores) and montane taxa (*Monoporites annulatus*) (Table 1). These suggest sediment deposition in subaqueous delta during stable and temperate climatic conditions and a relative decrease in sea level (Figure 7).

The interval is also characterised by moderate to good sorting of palynomacerals 1 and 2, predominantly common to abundant small to medium sizes.

The predominantly shaly/silty character of the lower section; and the presence of ferruginous materials, shell fragments and carbonaceous detritus suggest deposition in low energy, oxic, shallow marine settings (Selley, 1978). The sand units exhibited multiserrate funnel, cylinder/subtle bell-shaped gamma ray log profiles interpreted as subaqueous mouth bars and distributary channel deposits indicate a prograding shoreline.

6.4 CONCLUSION

Palynofacies and sedimentological analyses were carried out on the strata penetrated by Ida-6 well using the ditch cuttings and wire line logs data provided by Chevron Nigeria Plc. The recovery of the palynomorphs was not very rich and hence poorly diversified. However, three palynostratigraphic zones (interval zones) have been established using the international stratigraphic guide for establishment of biozones (Murphy and Salvador, 1999). They are *Multiareolites formosus–Lavigatosporites* sp., *Racemonocolpites hians—Crassoretitriletes vanraadshoveni,* and *Psiltricolporites crassus—Acrostichum aureum* zones. The studied stratigraphic interval was dated to the Middle Miocene to Late Miocene base on the recovered Miocene age diagnostic marker species such as *Multiareolites formosus, Verrutricolporites rotundiporus, Crassoretitriletes vanraadshoveni,* and *Racemonocolpites hians.* The lithology showed alternation of shale and sandstone units with few intercalations of siltstone units. Accessories minerals are dominated by ferruginous material, shell fragments, and carbonaceous detritus with spotty occurrence of mica flakes. The lithologic, textural, and wire line log data indicate that the entire studied interval belong to the Agbada Formation. Coastal-deltaic (lower delta plain to prodelta) environments of deposition have been inferred for the studied interval on the bases of the palynofacies association and sedimentological characteristics. The variations in the relative abundance of the recovered palynomorphs (hinterland versus coastal/lithoral) taxa are characteristics of different palaeoenvironments of prograding paralic succession (Morley, 1995). The higher occurrences of mangrove, rainforest, and fresh water taxa (lithoral/coastal vegetation) with few savanna and montane taxa within the interval (2679–3135 m) are indications that the interval was deposited in lower delta plain during sea level rise and wet climate (Figure 7). The increased savanna and montane taxa within 3135–3240 m of the studied interval and reduced occurrences of mangrove, freshwater swamp, and rainforest swamp taxa compared to the interval above indicate dry climate, sea level fall, and sediment deposition in a delta front environment (Adojoh *et al*., 2015). The moderate occurrence of mangrove, rainforest, and fresh water taxa rare to no presence of savanna and montane taxa within 3240–4051 m suggest sediment deposition in a subaqueous delta (delta front to prodelta) during stable and temperate climatic conditions and a relative decrease in sea level.

REFERENCES

Adojoh, O., Lucas F.A. and Dada, S., 2015, Palynocycles, Palaeoecology and Systems Tracts Concepts: A Case Study from the Miocene Okan-1 Well, Niger Delta Basin, Nigeria. *Applied Ecology and Environmental Sciences*, **3**, pp. 66–74. doi: 10.12691/aees-3-3-1.

Ajaegwu, N.E., Odoh, B.I., Akpunonu, E.O., Obiadi, I.I. and Anakwuba, E.K., 2012, Late Miocene to Early Pliocene Palynostratigraphy and Palaeoenvironments of ANE-1 Well, Eastern Niger Delta. *Nigeria Journal of Mining and Geology,* **48**, pp. 31–43.

Avbovbo, A.A., 1978, Tertiary lithostratigraphy of Niger Delta. *American Association of Petroleum Geologists Bulletin*, **62**, pp. 295–300.

Bankole, S.I., 2010, *Palynology and stratigraphy of three deep wells in the Neogene Agbada Formation, Niger Delta, Nigeria. Implications for petroleum exploration and paleoecology*, PhD thesis, Technische Universität Berlin, pp. 1–190.

Batten, D.J. and Stead, D.T., 2005, Palynofacies analysis and its stratigraphic application. In *Applied stratigraphy*, edited by Koutsoukos, E.A.M., (Dordrecht: Springer), pp. 203–226.

Burke, K. and Durotoye, B., 1970, Late Quaternary climate variation in the southwestern Nigeria, evidence from pediments and pediment deposits. *Bulletin d'Asequa*, **25**, pp. 79–96.

Bustin, R.M., 1988, Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta: Origin of source rocks in a deltaic environment. *American Association of Petroleum Geologists, Bulletin,* **72**, pp. 277–298.

Doust, H. and Omatsola, E., 1990, Niger Delta Divergent/Passive Margin Basins. *American Association of Petroleum Geologists, Memoir*, **48**, pp. 201–238.

Durugbo, E.U. and Aroyewun, R.F., 2012, Palynology and Paleoenvironments of the Upper Araromi Formation, Dahomey Basin, Nigeria. *Asian Journal of Earth Sciences,* **5,** pp. 50–62. doi: 10.3923/ajes.2012.50.62.

Durugbo, E.U. and Uzodimma, E., 2013, Effects of lithology on palynomorph abundance in wells X1 and X2 from the Western Niger Delta, Nigeria. *International Journal of Geology, Earth and Environmental Sciences,* **3**, pp. 170–179.

Evamy, B.D., Haremboure, J., Karmerling, P., Knaap, W.A., Molloy, F.A. and Rowlands, P.H., 1978, Hydrocarbon habitat of the Tertiary Niger Delta. *American Association of Petroleum Geologists, Bulletin,* **62**, pp. 1–39.

Germeraad, J.J., Hopping, G.A. and Muller, J., 1968, Palynology of Tertiary sediments from tropical areas. *Review of Palaeobotany and Palynology,* **6**, pp. 189–348. doi: 10.1016/003667(68)90051-1.

Ige, O.E., 2009, A Late Tertiary Pollen record from Niger Delta, Nigeria. *International Journal of Botany,* **5,** pp. 203–215. doi: 10.3923/ijb.2009.203.215.

Ige, O.E., Datta, K., Sahai, K. and Rawat, K.K., 2011, Palynological Studies of Sediments from North Chioma-3 Well, Niger Delta and its Palaeoenvironmental Interpretations. *American Journal of Applied Sciences,* **8**, pp. 1249–1257.

Jennifer, Y.E., Mebradu, S.M., Okiotor M.E. and Imasuen, O.I., 2012, Palaeoenvironmental studies of well "AX", in the Niger Delta. *International Research Journal of Geology and Mining,* **2**, pp. 113–121.

Morley, R.J., 1997, Offshore Niger Delta palynological zonation, prepared for the Niger Delta Stratigraphic Commission. *Palynova*, **1**, pp. 1–6.

Murphy, M.A. and Salvador, A., 1999, International Stratigraphic Guide—An abridged version, International Subcommission on Stratigraphic Classification of IUGS, International Commission on Stratigraphy, *Special Episodes,* **22**, 4, pp. 255–272.

Okosun, E.A. and Chukwuma-Orji, J.N., 2016, Planktic Foraminiferal Biostratigraphy and Biochronology of KK-1 Well Western Niger Delta, Nigeria. *Journal of Basic and Applied Research International,* **17**, pp. 218–226.

Olajide, F.A., Akpo, E.O. and Adeyinka, O.A., 2012, Palynology of Bog-1 Well, Southeastern Niger Delta Basin, Nigeria. *International Journal of Science and Technology*, **2**, pp. 214–222.

Olayiwola, M.A. and Bamford, M.K., 2016, Petroleum of the Deep: Palynological proxies for palaeoenvironment of deep offshore upper Miocene-Pliocene sediments from Niger Delta, Nigeria. *Palaeontologia Africana,* **50**, pp. 31–47.

Ojo, A.O. and Adebayo, O.F., 2012, Palynostratigraphy and paleoecology of chev-1 well, southwestern Niger delta basin, Nigeria. *Elixir Geoscience,* **43**, pp. 6982–6986.

Osokpor, J., Lucas, F.A., Osokpor, O.J., Overare, B., Elijah, I.O. and Avwenagha, O.E., 2015, Palynozonation and lithofacies cycles of paleogene to Neogene age sediments in PML-1 well, Northern Niger Delta Basin. *The Pacific Journal of Science and Technology,* **16**, pp. 286–297.

Oyede, A.C., 1992, Palynofacies in deltaic stratigraphy. *Nigerian Association of Petroleum Explorationist Bulletin,* **7**, pp. 10–16.

Reijers, T.J.A., Petters, S.W. and Nwajide, C.S., 1997, The Niger Delta Basin, sedimentary geology and sequence stratigraphy. In *African Basins*, edited by Selley, R.C., (Amsterdam: Elsevier), pp. 151–172.

Selley, R.C., 1978, Concept and methods of subsurface facies analysis. *American Association of Petroleum Geologists, Bulletin, Education course notes*, **9**, pp. 1–86.

Short, K.C. and Stauble, A.J., 1967, Outline of the geology of Niger Delta. *American Association of Petroleum Geologists, Bulletin*, **51**, pp. 761–779.

Thomas, M.L., Pocknall, D.T., Warney, S., Bentley, S.J. Sr., Droxler, A.W. and Nittrouer, C.A., 2015, Assessing palaeobathymetry and sedimentation rates using palynomarceral analysis: a study of modern sediments from the Gulf of Papua, offshore Papua New Guinea. *Palynology*, **39**, 3 pp. 1–24. doi/abs//10.1080/01916122.2015.1014526.

Weber, K.J., 1971, Sedimentological aspects of oil fields in the Niger Delta, *Geologie en Mijnbouw*, **50**, pp. 559–576.

Weber, K.J. and Dankoru. E.M., 1975, Petroleum geology of Niger Delta. In *Proceedings of the 9th annual conference on world petroleum congress*, (Tokyo: London Applied publishers' Ltd), **2,** pp. 209–221.