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Paleoclimatic Reconstruction of Middle to Late Miocene Strata Evidenced from Palynological Study of Ida-4 Well, Eastern Niger Delta, Nigeria

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Abstract
This study presents the results of a paleoclimatic study on ditch cutting samples within the interval of 2179 – 3523 m from Ida-4 well, Eastern Niger Delta Basin. The aim is to identify the different species of palynomorphs present in the samples for the reconstruction/recognition of climatic changes during the middle to late Miocene epoch. The acid technique of sample preparation for palynomorphs recovery was used. Diverse and moderately rich pollen and spores were recovered. The biostratigraphic age control of the studied interval was identified based on the first and last downhole occurrences of *Multiareolites formosus, Peregrinipollis nigericus* and *Crassoretitriletes vanraadshoveni, Verrutricolporites rotundiporus, Racemonocolpites hians* and *Magnastriatites howardi* which are diagnostic of middle to late Miocene. The method of grouping the recovered palynomorphs into palyno-ecological groups was adopted for the paleoclimatic reconstruction. Intervals of temperate, wet and dry climatic zones were delineated from recurrent/fluctuation of the recovered palynomorphs sequences (palyno-ecological groups) at the different depth intervals. The delineated climatic zones are indications of vegetation, climate and sea level change during the Miocene.

Keywords: Ida-4 well, Miocene, Niger Delta Basin, Paleoclimate, Palynology.

Introduction

Pollens and spores are excellent tools for interpreting paleoclimate variations since the world's climatic zones are closely reflected by the distribution of vegetation types. The reconstruction of paleoclimate is one of the goals of palynological research which entails the study of periodic changes in climate over geological period. Sowunmi (1987) stated that the flora of an area provides a good reflection of the major climatic regime of that area. Consequently, reconstruction of past climates and environments are achievable through the study of fossil plants and the reconstruction of past climates and environments is based on the understanding of current distributions of nearest living relatives of fossil taxa (Mosbrugger and Utescher, 1997). The approach assumes that modern climatic distributions of extant species mirror that of their co-generics in earlier geological epochs (Ghazoul, 2012; Adebayo and Ojo, 2014). The abundance and variations of climate-sensitive taxa including mangrove and savannah affiliated pollen and spore types *Acrostichumsporites, Psilatricolporites crassus, Zonocostites ramonae* and *Graminidites annulatus* representing the mangrove and savannah vegetation cover indicate a complex interplay between periods of wetter and drier climates (Bankole *et al*., 2014). Climatic factors have more direct influence on the rainforest and savannah (hinterland) taxa and less effect on the mangrove and freshwater swamp taxa. The mangrove and freshwater swamp taxa are directly influenced by sea-level fluctuations. The concept of the palynological cycle was proposed by Van der Hammen (1957). The use of palynofloral signals to decipher sea level, climate and system tracts were introduced in the Niger Delta Basin by Poumot (1989). Rull (2002) related the cyclic character in the palynological record to astronomically driven climatic cycles. Ogbahon *et al*. (2019) used the abundant occurrence of pollen and spores typical of low land rain forest in the palynological assemblage to indicate that the studied segment of GBO-04 well was deposited in

tropical paleoclimatic conditions. The distribution pattern of *Monoporites annulatus* (Poaceae) and *Zonocostites ramonae* (Rhizophora) suggested cyclical fluctuations of paleoclimate between wetter and drier phases (Ogbahon, 2019). Itiowe and Lucas (2020) used the dominance of *Zonocostites ramonae* over Monoporites *annnulatus,* to show that the sediments penetrated by Ash-3 well in the greater Ughelli Depobelt, Niger Delta Basin were deposited in a predominantly humid climate, cooler and wetter climatic condition.

Location of the studied well and Geology of the Niger Delta Basin

The Niger Delta Basin is located between latitudes 4° and 6°N and longitudes 3° and 9°E in Southern Nigeria. IDA-4 well is situated at 4.82°N and 6.86°E in the Coastal Swamp Depobelt of the Eastern Niger Delta Basin (Fig. 1). The Niger Delta Basin is located in the Gulf of Guinea, on the West African continental margin. The basin contains Cenozoic marine to fluvial deposits overlying oceanic crust and fragments of the African continental crust (Doust and Omatsola, 1990; Ojo and Adebayo, 2012). The lithology or sedimentary deposit of the Niger Delta Basin ranges from the facies of the first major Cenozoic transgression to the depositional products of the present day, as well as materials eroded from subsurface and outcropping formations. The Delta began developing in the Paleocene. From the Eocene to the present, the delta has prograded southwest ward forming depobelts, each depobelt represent the most active portion of the delta at each stage of development (Doust and Omatsola, 1990; Ojo and Adebayo, 2012).

The sedimentary sequence of the basin consists in ascending order of three diachronous formations, namely: Akata (marine beds), Agbada (transitional sand-shale beds) and Benin (continental sediments) formations. These formations together form an overall thick, progradational passive-margin wedge (Short and Stauble, 1967; Ola and Adewale, 2014**).** The lithofacies equivalent of these subsurface formations on the surface are: the Imo, Ameki, Ogwashi-Asaba and Benin formations (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). 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 nearshore shelf domain.

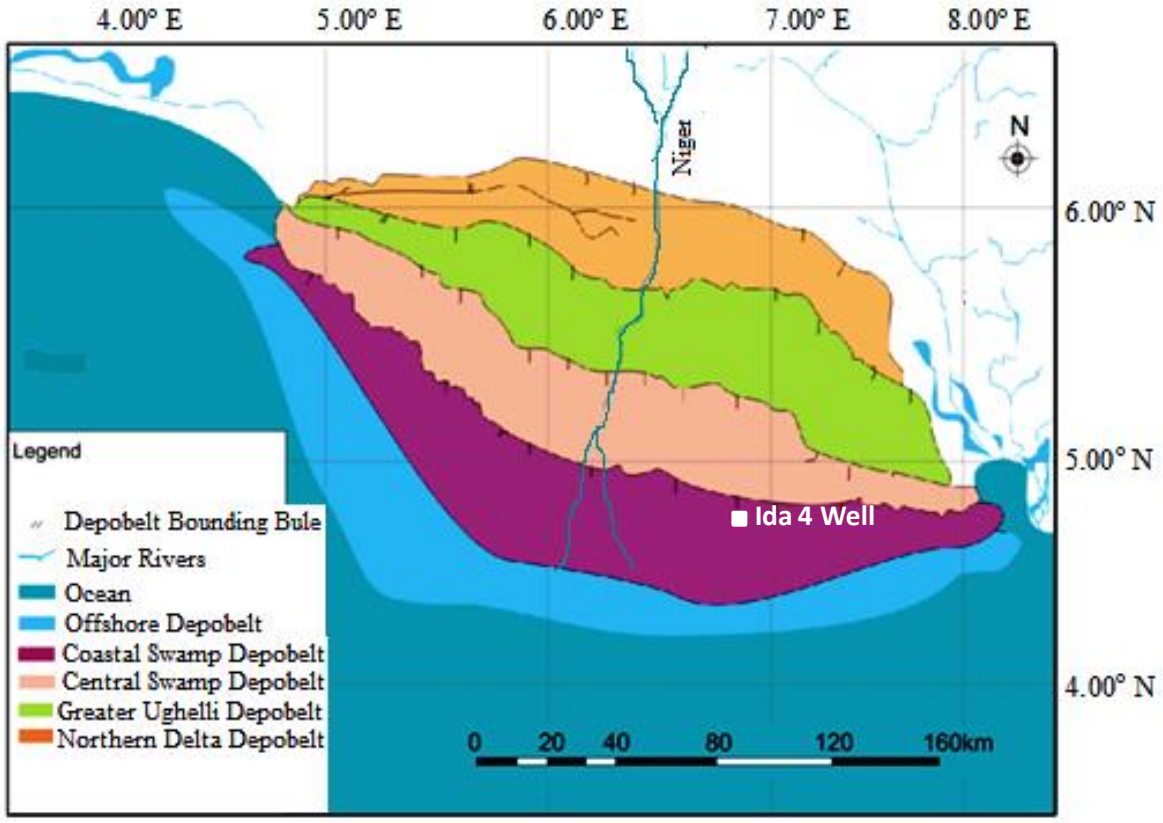

Fig. 1: Location of the studied well on the Niger Delta Basin. (Modified after Okosun and Osterloff, 2014).

Table 1: Formations of the Niger Delta Basin (Modified after Whiteman, 1982; Oboh-Ikuenobe *et al*., 2005)

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

The Benin Formation consists predominantly of cross-bedded, coarse, pebbly continental sands, with clay lenses and lignites. Marine shale breaks have been identified within the formation. The bulk of the sediments were deposited in the upper delta plain as freshwater, backswamp, and meander belt facies and lower flood (delta) plain setting (Whiteman, 1982). Short and Stauble (1967) designated a type section for the Benin Formation in Elele-l. 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). Reijers (2011) has proposed elevation of the Benin, Agbada and Akata lithostratigraphic units classified as formations to group level.

The Imo Formation consists mainly of dark gray to bluish gray shales, with

occasional admixtures of clay, ironstone, thin sandstone bands with lenses of coal, bituminous sand, and limestone intercalations in some places (Whiteman, 1982). 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). 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).

Methods

Fifty sandy shale and shaly ditch cutting samples within the interval of 2179 – 3523 m, from Ida 4 well were subjected to palynological analysis. Sample preparation and analysis were carried out at Crystal Age Laboratory Nigeria Limited, Ikorodu, Lagos State, Nigeria.

The laboratory techniques of digesting samples in hydrochloric and hydrofluoric acids for silicates and carbonates removal were followed to process the samples for recovery of palynomorphs. Twenty-five grams of each sample was weighed, poured into well labelled plastic cups and arranged in a fume cupboard. Each sample was digested for 35 minutes in 40% hydrochloric acid for removal of carbonate and 24 hours in 40% hydrofluoric acid for removal of silicate. Sieving was done using brason sonifier to filter away any remaining inorganic matter (silicates, clay, and mud) and heavy minerals to concentrate organic matters present in the sample. Controlled oxidation was given to the sieved residue using concentrated nitric acid (HNO_3). The residue was stained with Safranin O, before being mounted on glass slides and analyzed with the aid of Olympus CH30 binocular light transmitted microscope. Identification of palynomorphs was done by comparing observed forms under the microscope with palynological albums and published works of previous researchers (Germeraad *et al*., 1968; Ige, 2009; Ige *et al*., 2011; Ajaegwu *et al*., 2012; Bankole, 2010; Durugbo and Aroyewun, 2012).

The approach of grouping the recovered palynomorphs into palyno-ecological groups based on the present-day natural distribution of their modern relatives was adopted for the paleoclimatic reconstruction (Sowunmi, 1981; Ige, 2011). The recovered palynomorphs were grouped into savannah, montane, freshwater swamp, rainforest swamp and mangrove swamp taxa.

Results and Discussion

The result of the palynological analysis is presented in the Table 2, with the recovered palynomorphs being recorded according to their palyno-ecological groupings. The table shows that the stratigraphic distribution of the palynomorphs varies considerably from one depth to another. The recovered palynomorphs are moderately rich, diverse, and well preserved at almost all the depth intervals (Table 2). The palynofloral assemblages were dominated by pollen and spores. The poorly preserved forms are recorded as indeterminate.

The spores recorded include the species of *Laevigatosporites, Verrucatosporites, Aletisporites, Cyperaceaepollis, Pteris, Crassoretitriletes, Acrostichum* and *Magnastriatites.*

Table 2: Palyno-ecological Groups of Palynomorphs from Ida-4 well

		Savana Taxa										Montane						Rainforest Taxa					Fresh water swamp Taxa															Mangrove Taxa					Others			
S/N	Sample depth (meters)/Taxa	*Pteris* sp.	*Cyperaceaepollis sp*	*Coryus* sp.	*Numulipollis neogericus*	*Podocarpus milanjianus*	*Retibrevitricolporites protrudence*	*Chenophodipollis* sp.	*Fungal spores*	Total Savana Taxa	*Praedapollis flexibilis*	*Alnipollenites verus*	*Aletisporites*	*Podocarpidites* sp.	*Monoporites annulatus*	*Total Montane Taxa*	*Elaies guineensis*	*Pachydermites diederixi*	*Peregrinipollis nigericus*	*Sapotacea*	Total Rainforest Taxa	*Striatricolporites catatumbus*	*Verrutricolporites rotundiporus*	*Gemmamonoporites* sp.	*Magnestriatites howardi*	*Racemonocolpites hians*	*Retricolporites irregularis*	*Retricolpites* sp.	*Canthium* sp.	*Multiarreolites formosus*	*Arecipites*	*Crassoretitriletes vanraadshooveni*	*Laevigatosporites* sp.	*Botryococcus braunii*	*Verrucatosporites* sp.	Total freshwater swamp taxa	*Zonocosites ramonae*	*Psilatricolporites crassus*	*Acrostichum aureum*	*Proxapertites cursus*	Total mangrove Taxa	Pollen indeteminate	*Retitricolporites* sp.	*Lycopodium* sp.	*S. myosurus*
1	2179									0					1	1				1	1											6	3		9	15				15	1			
2	2207						1		1	2					2	2					0										2	5		7	23	1			24				
3	2234	2							2	4					17	17	1		1		2	2	1	1				1		1	22		17	46	111	7	12		130				
4	2262	1								1						0				4	4		1								7		5	13	12	2	3		17				
5	2289	2				1		1	2	6					4	4		4		1	5	2									23	4	5	34	130		1		131				
6	2316	2			1		3		3	9					4	4		2	1	3	6			2			7	1			23	2	1	36	223	2	12		237				
7	2344								1	1					3	3					0						1				1	1	1	4	32		1		33				
8	2371	2								2					3	3					0	2		1					1	1	10	3		18	100	1	1	1	103				
9	2399	4	1				1			6					3	3		3		4	7		2		1	3					22	1	4	33	153	8	11		172		1		
10	2426									0					1	1		1			1	2				1					13	2	2	20	52	2	1		55				
11	2454									0					1	1					0										4		1	5	12	1			13				
12	2481									0						0		1		1	2												1	1	33	1	2		36				
13	2509									0					1	1		1		2	3										9		3	12	65	1			66				
14	2536									0						0					0		1								1			2	50	2	1		53				
15	2563	1								0						0		1			1					1					1	1	2	5	20	1			21				
16	2591	1							1	2						0				1	1										1	2	1	4	28		1		29				
17	2618	1								1					2	2				1	1										5		1	6	4	1	1		6				
18	2646	1							1	2					1	1				1	1		1								18	1	1	21	18	1	1		20				1
19	2673	1								1					3	3		1			1		2								11	2	5	20	53		1		54				
20	2701									0						0				1	1										7		2	9	23		4		27				
21	2728	2	1							3					1	1					0		1								3		1	5	3				3				
22	2755									0						0				1	1		1								1	1	3	6	14		1		15				
23	2783									0					2	2				2	2	1												1	16	1			17		1		
24	2810									0					2	2					0			1							7		2	10	7				7				
25	2838									0					4	4					0		1								9	7	3	20	53		1		54				
26	2865									0	1					1				1	1										4			4	8				8	1			
27	2893	2								2					1	1		1		1	2										6	17	3	26	67		1		68				
28	2920	1								1					1	1				1	1				1						3		2	6	18		1		19				
29	2947									0					1	1					0		1								1		1	3	14				14				
30	2975									0						0					0										12	2	2	16	18	1			19				
31	3002									0					2	2					0		1								7	2	2	12	21				21				
32	3030			1						1						0					0		1								1			2	11				11				
33	3057						1			1					1	1				1	1										6		2	8	47	1	1		49				
34	3085									0					1	1					0	1										2		3	7				7				
35	3112									0						0					0											4	1	5	9				9				
36	3139									0					2	2					0												1	1	13		1		14				
37	3167									0						0					0										8	7	2	17	15		1		16				
38	3194			2						2					1	1					0												1	1	18		4		22				
39	3222									0						0				2	2		1								3	1		5	12				12				
40	3249									0			1			1				3	3			1								3	1	5	2				2				
41	3277									0					1	1					0		2			1								3	4		1		5				
42	3304									0					2	2					0	1									1	3		5	5				5				
43	3636									0						0				5	5	1									1	1		3	5	1			6				
44	3359	1								1						0					0		2								5	3		10	12				12				
45	3386									0					2	2					0	1									4	2	2	8	50				50				
46	3417	1								1					1	1				1	1										1		1	2	22				22				
47	3441	1								1						0					0										2	2		4	13				13				
48	3469			2						2		2		1		3					0		1			1					11		8	21	45				45				
49	3496						1			1						0					0	1									2	6	2	11	30		1		30				
50	3523			3						3		1		1		2				1	1										2	1		3	6				6				

The pollen taxa recovered are: *Zonocostites ramonae, Monoporites annulatus, Racemonocolpites hians, Praedapollis flexibilis, Striatricolpites catatumbus, Retibrevitricolporites protudens, Pachydermites diederixi, Psilatricoloporites crasssus, Retitricolporites irregularis, Peregrinipollis nigericus, Gemamonocolpites* sp., *Multiareolites formosus, Verrutricolporites rotundiporus, Nummulipollis neogericus, Canthium* sp., *Coryius* sp., *Alnipollinites verus, Podocarpidites* sp. and *Retitricolporites* sp. The algal cysts of *Botryococcus braunii* were recorded. Some of these forms are illustrated in photomicrographs plate I.

The biostratigraphic age control of the study section was identified based on the First or Last Downhole Occurrence (LDO) of the recovered diagnostic marker species such as *Verrutricolporites rotundiporus, Racemonocolpites hians,* and *Magnastriatites howardi. Retibrevitricolporites protrudens,* and *Racemonocolpites hians* are diagnostic of Middle Miocene (Morley, 1997; Bankole *et al*., 2014; Ola and Adewale, 2014; Adojoh *et al*., 2015). Last Downhole Occurrence (LDO) of *Multiareolites formosus, Peregrinipollis nigericus* and *Crassoretitriletes vanraadshoveni* are diagnostic of Late Miocene (Morley and Richard, 1993; Morley, 1997; Olayiwola and Bamford, 2016; Chukwuma-Orji *et al*., 2017). *Striatocolporites catatumbus* has been assigned Early-Middle Miocene in Nigeria (Germeraad *et al*., 1968). *Crassoretitriletes vanraadshooveni* is a Miocene marker and has not been reported earlier than Miocene age (Germeraad *et al*., 1968). *Zonocostites ramonae* has been assigned Early Miocene to Pleistocene in Nigeria (Germeraad *et al*., 1968). The recovery of the above mentioned palynomorphs at different intervals in the well is an indication that the stratigraphic interval studied was deposited during the Miocene (particularly Middle to Late Miocene).

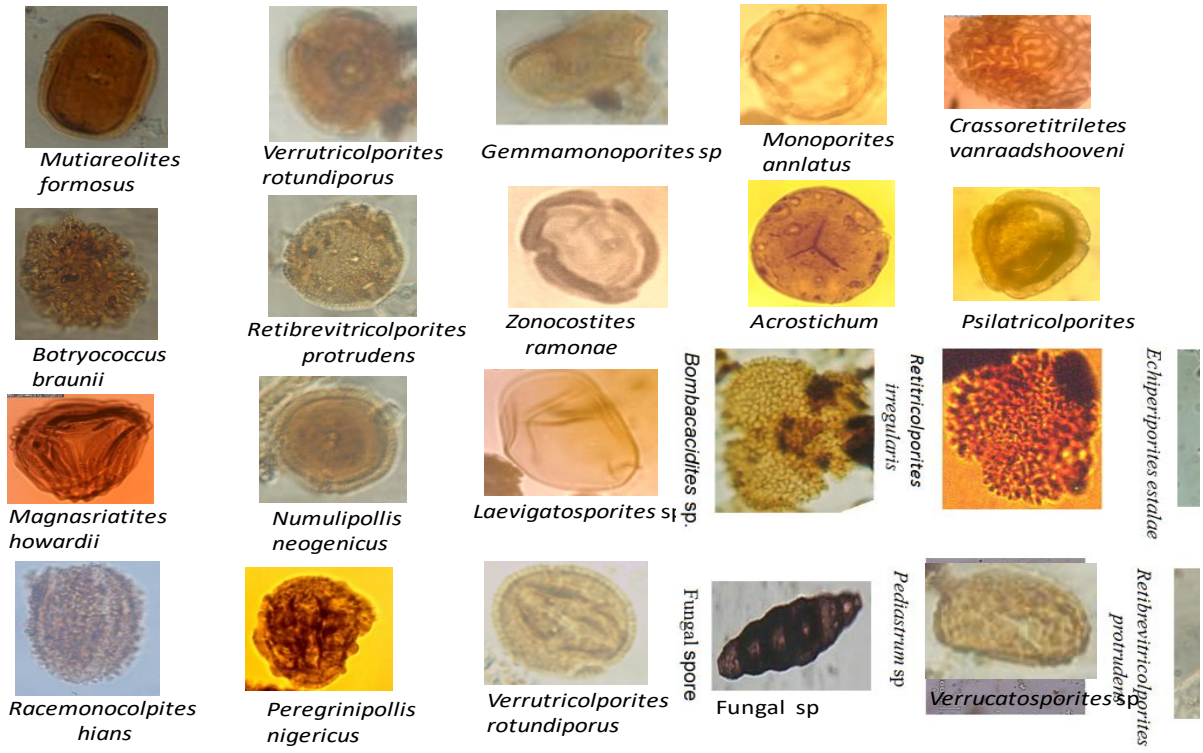

Plate I: Palynomorphs recovered from the studied well onshore Niger Delta (x400)

Paleoclimate

Paleoclimatic changes reflected in the studied wells have been determined from the relative abundance of microfloral elements of the palyno-ecological groups established in the wells. Generally, the palyno-ecological groupings of the palynomorph taxa indicate that the mangrove taxa (257.3%) have highest representation of the total recovery, followed by freshwater taxa (74.9%) and montane taxa (11%). Rainforest swamp and savannah taxa have equal and lowest representation (8.04%) in the well (Fig. 2). Wet, temperate and dry climatic zones have been delineated from the stratigraphic sequence penetrated in the studied well. The wet, temperate and dry climatic zones inferred indicate the fluctuation of the climate and sea level change during the Middle to Late Miocene. The wet climatic zone suggests highstand/transgressive systems tracts, while the dry climatic zone suggests lowstand systems tracts (Adojoh *et al.*, 2015).

Temperate climatic zone: 2179 – 2426, 3386 – 3523

Temperate climatic condition is associated with the increase representation of mangrove pollen and tendency to increased representation of freshwater swamp and open forest vegetation (Morley, 1995; Rull, 2002; Adojoh *et al.*, 2015).

Within the intervals of 2179 – 2426 m, there was a numerical increase in savannah (fungal spore, *Pteris* sp., *Retibrevitricolporites protudens*, *Nummulipollis neogericus*) and montane taxa *Monoporites annulatus*, with an observed increase in the wet climate indicator: mangrove taxa (*Zonoccostites ramonae*, *Psilaticolporites crassus* and *Acrostichum aureum)*, freshwater taxa (*Striatricolporites catatumbus*, *Sapotaceae*, *Verrutricosporite rotundiporus Levigatosporites* sp., *Botryococcus braunii*, *Verrucatosporites* sp. and *Gemmamonoporites* sp.) and rainforest taxa such as *Pachydermites diederixi* and *Sapotacea* (Fig. 3, Table 2).

Within the interval of 3386 – 3523 m, the following taxa were recorded: *Pteris* sp., *Coryius* sp., *Retibrevitricolporites protudens* (savannah taxa), *Alnipollinites verus, Podocarpidites* sp., *Monoporites annulatus* (montane taxa), *Levigatosporites* sp., *Botryococcus braunii*, *Verrucatosporites* sp., *Verrutricolporites rotundiporus, Striatricolporites catatumbus* (freshwater swamp taxa), and mangrove swamp taxa (*Zonoccostites ramonae*, *Psilaticolporites crassus* and *Acrostichum aureum)*. Adojoh *et al*. (2015) and Olayiwola and Bamford (2016) stated that high representation of coastal miospores (mangrove, beach, brackish and rainforest taxa) compared to slightly increaced representation of hinterland miospores (savannah and montane taxa) are characteristics of highstand sediments that were deposited during highstand of the sea level (Highstand Systems Tracts). The abundance of *Rhizophora* pollen above 40% in sediments indicates a good representation of mangrove swamp, suggesting a temperate/humid tropical lowland climate during the deposition of the interval (Sowunmi, 1981).

A wet condition would have been suggested for these intervals due to the high record and the regular occurrence of mangrove, rainforest and fresh water swamps taxa but for the slight numerical increase in savannah and montane taxa and rare record of *Cyperraceaepollis* sp., which is a temperate (humid) climate indicator (Dupont and Agwu, 1991; Ola and Adewale, 2014). Therefore, it is inferred that these intervals were probably experiencing a temperate/humid climate during their time of deposition.

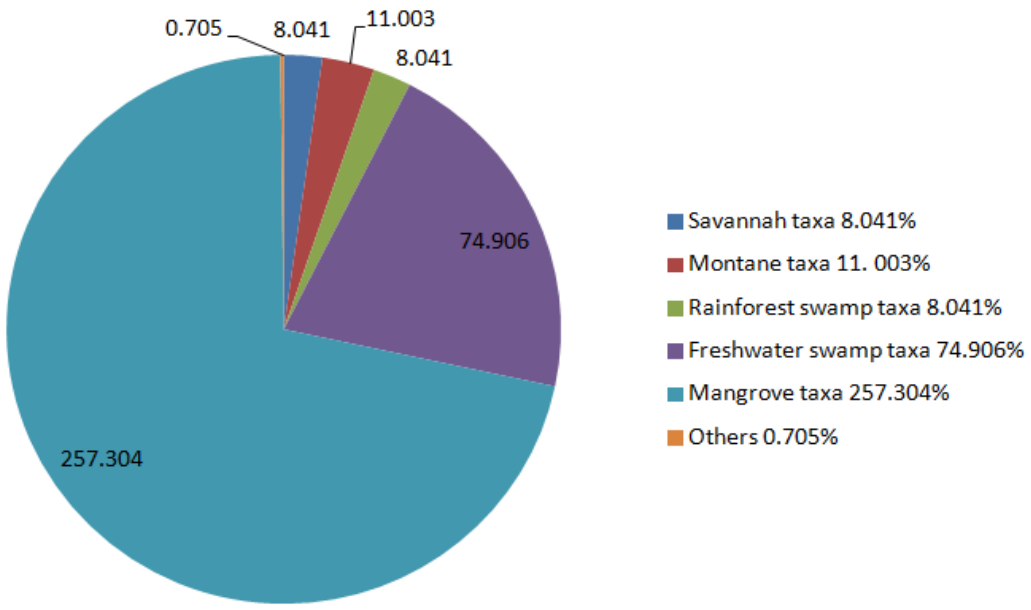

Fig. 2: Palyno-ecological groups of palynomorphs from Ida-4

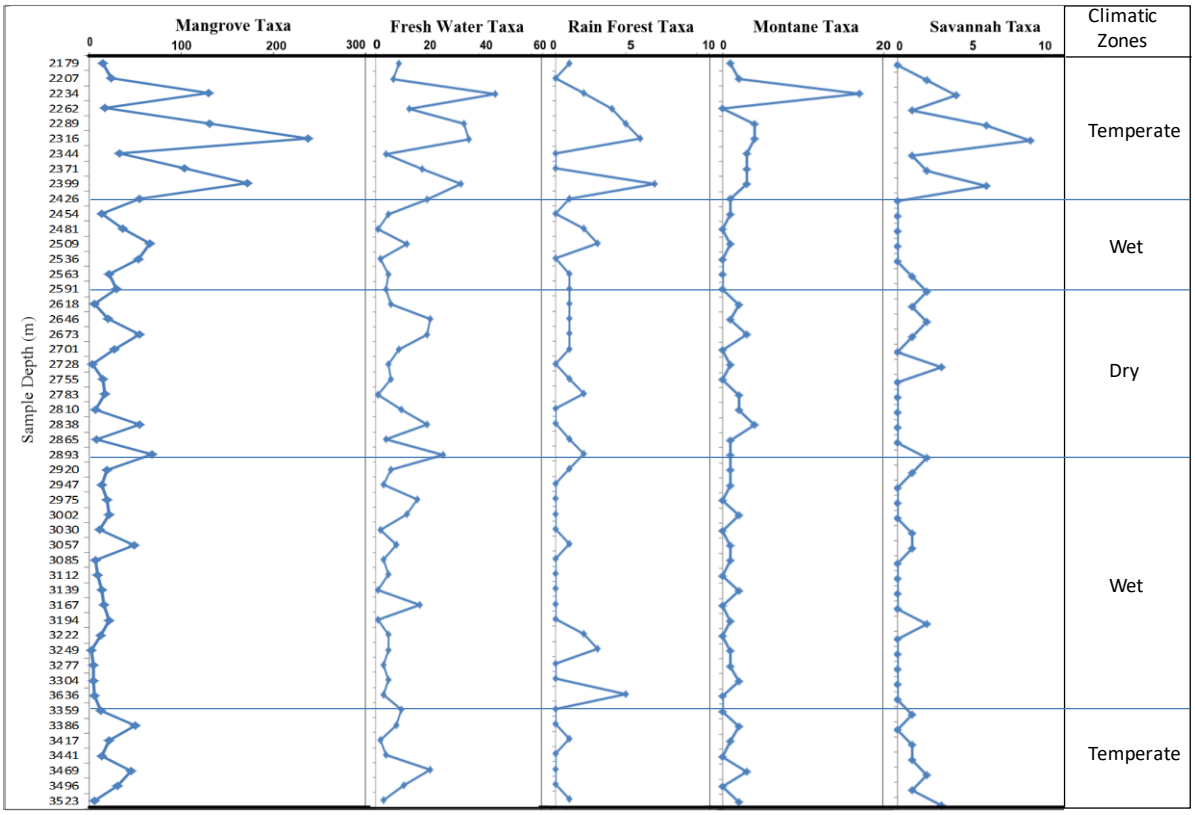

Fig. 3: The abundance (population count) of the palyno-ecological groups and paleoclimatic zones of Ida-4 well

Wet climatic zones: 2426 – 2591, 2893 - 3386

The intervals delineated to have been deposited under wet climatic conditions are 2426 – 2591 m and 2893 – 3386 m (Fig. 3). These intervals show increased and good representation of mangrove taxa (*Zonoccostites ramonae*, *Psilaticolporites*

crassus and *Acrostichum aureum)*, freshwater taxa (*Striatricolporites catatumbus*, *Levigatosporites* sp., *Botryococcus braunii*, *Verrucatosporites* sp. and *Gemmamonoporites* sp.) and rainforest taxa such as *Pachydermites diederixi* and *Sapotacea*. This is also supported by none to rare occurrences of montane and savannah taxa within the intervals such as *Monoporites annulatus*, *Coryius* sp., *Pteris* sp., fungal spores and *Cyperaceapollis* sp. High representation of coastal miospores (mangrove, beach, brackish and rainforest taxa) compared to minimal representation of hinterland miospores (savannah and montane taxa) are characteristics of transgressive 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; Ige, 2011; Adojoh *et al*., 2015; Olayiwola and Bamford, 2016). The maximum occurrences of mangrove, rain forest and freshwater taxa are indications that the prevailing climatic conditions supported the flourishing of the mangrove, rain forest and fresh water vegetations. The wet climatic zones of this study agree with that of some previous researchers in the Niger Delta (Durugbo *et al*., 2010; Ige, 2011; Ola and Adewale, 2014 as well as Bankole *et al*., 2014). The author utilised high percentage occurrences of mangrove taxa (*Zonoccostites ramonae* - Rhizophora), fresh water and rainforest taxa to delineate wet climatic zones which were also indication of rise in sea level.

Dry climatic zone: 2591 - 2893

This interval was delineated to have been deposited under dry climatic conditions (Fig. 3). The interval showed minimal occurrences of mangrove, freshwater and rainforest taxa with increased occurrence of savanna and montane taxa such as fungal spores, *Monoporites annulatus*, *Cyperaceapollis* sp and *Pteris* sp., indicating dry climate and sea level fall. Ige (2011) equally used low representation of mangrove taxa (Rhizophora), fresh water and rain forest taxa and high representation savanna and montane taxa to delineate dry climatic zones. Other workers that have utilized this approach include Durugbo *et al*. (2010) and Bankole *et al*. (2014).

Conclusion

Ditch cutting samples from Ida-4 well were analysed for palynomorph content. The analysis yielded moderately rich, diverse, and well-preserved pollen and spores. The studied sediments are of Middle to late Miocene age based on the recovery of *Zonocostites ramonae, Multiareolites formosus, Peregrinipollis nigericus* and *Crassoretitriletes vanraadshoveni Verrutricolporites rotundiporus, Racemonocolpites hians* and *Magnastriatites howardi*. The ecological groupings of the recovered palynomorph taxa revealed that the studied intervals were deposited under alternation of temperate, wet and dry paleoclimatic conditions. The temperate and wet climatic zones indicated good representation of coastal miospore and minimal hintherland miospores. The dry climatic zone showed little increase in the population of hintherland miospores and reduced occurrence of coastal palynomorph taxa. The temperate and wet climatic zones were indications of relative sea level rise (Highstand and Transgressive Systems Tracts) while the dry climatic zone represented fall in sea level (Lowstand System Tract) during the deposition of the sediments.

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