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Palaeofloristic Variations across Oligocene / Miocene Boundary in Niger Delta, Nigeria

Alfred E Essien[1], Francis T Beka[2], Ekpedeme O Mkpong[3]

[1,2]Department of Geology, University of Port Harcourt, Rivers State, Nigeria.
[1,3]Nigerian National Petroleum Corporation, Research and Development Division, Port Harcourt

Abstract The distribution of pollen and spores in marine sediments has been found to reflect rather accurately the distribution of the vegetation on the adjacent continent. The source of pollen and spores in the Niger Delta can be confidently related to the regions traversed by Rivers Niger and Benue, which include Sahelian and Sudanian vegetation zones as well as Guinea-Congolian rainforests and the mangrove swamps. Hence, majority of the pollens in the Niger Delta come from the regions north and northeast of the Gulf of Guinea. Floristic stages which followed one another in inter-tropical Africa are closely linked to climatic changes. Since ecological changes have direct relationship with climatic changes, it can provide the best means of correlating regionally the variations and fluctuations in the distribution of the flora. This paper presents the variations or shifts in the composition of recovered terrestrially derived palynomorphs as reflected by changes in palaeoecology based on the paleoclimatic fluctuations across the period ranging between Late Oligocene and the Early Miocene transitional boundary from palynological data obtained from ten (10) wells from both the onshore and offshore settings of the Niger Delta in Nigeria. It is aimed at improving the stratigraphic understanding of the Late Oligocene (Chattian) to Early Miocene (Aquitanian/Burdigalian) transition interval as reflected by the occurrences of the spores and pollens assemblages and key marker events. However, changes in the pollen records, e.g. ranges of *Verrutricolporites laevigatus* and *Loranthacites natalie*, provide a higher stratigraphical resolution in the Upper Oligocene strata compared with the dinoflagallate cyst assemblages. The Oligocene/ Miocene boundary (O/M) boundary is marked by first downhole occurrence (FDO) of *Cicatricosisporites dorogensis* and the Last Downhole Occurence (LDO) of *Verrutricolporites laevigatus* in different well sections studied. These were supported by the co-occurrences of a number of typical Late Oligocene to earliest Early Miocene pollen such as *Praedapollis flexibilis*, *Striamonocolpites rectostriatus*, *Striamonocolpites undatostriatus*, *Verrutricolporites rotundiporus*, *Verrutricolporites scabratus* and *Verrutricolporites verrucatus.*

Keywords Palaeoflora; palaeovegetation; palynomorphs; palynoflora; palaeoclimate; palaeoecology; bioevents; Oligocene; Miocene.

Introduction

Several mechanisms have been attributed to be responsible for high rates of extinctions of land plants and marine organisms [1-3]. Some of these mechanics documented include climate change, change in temperature, increased submarine activity and sea level fluctuations, among other factors. The impact of climate change on the Neotropical flora and vegetation world-over has not yet been fully explored or documented, especially in the Neogene. In other provinces, like northern South America, a number of works devoted to the Paleogene has contributed greatly to the development of tropical palynology. Among them, those developed in Colombia [4-8] are worth mentioning. These works are mainly focused on the naming and description of relevant fossil taxa, as well as documenting their ranges through time. Some of them also consider quantitative variations and attempt palaeoenvironmental reconstruction.

Leblanc (1979) established the taphonomic conditions for pollen and spores records in the Gulf of Mexico. He found out that pollen grains from highland plants are distributed by wind transport and spread over great distances whereas spores (and pollen from lowland plants) have a smaller area of geographical distribution closer to the coastline. This is because the latter have no morphologically functional adaptations for wind transport and thus depend on an aquatic environment for their dispersion.

These palynological records have been compared and calibrated with sequence stratigraphic concepts. Gregory and Hart (1992) established a predictive model for the pollen and spore record of Gulf Coast Palaeogene with respect to relative sea level changes [9]. Chow (1995) employed the ratio of the stratigraphic occurrence of the fossils of Rhizophora and Camptostemon for sequence stratigraphic deductions in offshore Sabah and Sarawak, Malaysia. Chow (1995) identified the inverse relationship in the occurrence trends of the two genera in relation to system tracts, noting that the ratio of Rhizophora and Camptostemon was high in HST and low in Low Stand System Tract (LST) and Trangressive System Tract (TST) [10]. This discovery was used to solve problems that were beyond the resolution ability of seismic method (a limitation that was due to great depth) and recommended it for areas of poor foraminiferal and nannofossils data.

The distribution of pollen and spores in marine sediments has been found to reflect rather accurately the distribution of the vegetation on the adjacent continent [11-12]. The source of pollen and spores in the Niger Delta, according to Sowunmi (1987), can be confidently related to the regions traversed by Rivers Niger and Benue, which include Sahelian and Sudanian vegetation zones as well as Guinea-Congolian rainforests and the mangrove swamps [13]. Hence, majority of the pollens in the Niger Delta come from the regions north and northeast of the Gulf of Guinea (Figure 1).

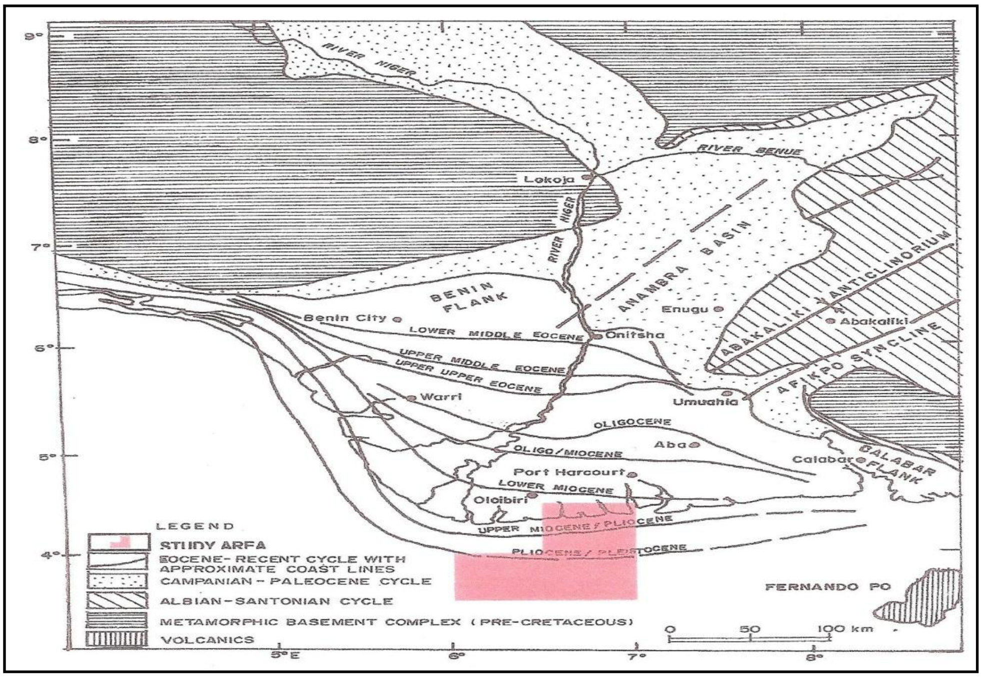
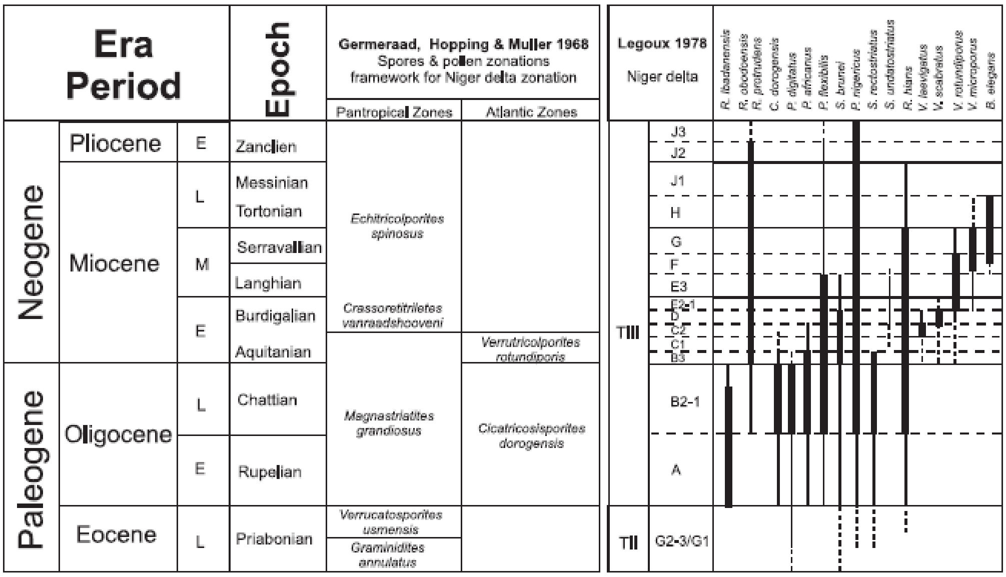


Figure 1: Map showing the delineation of the Niger Delta Petroleum Province.

Floristic stages which followed one another in inter-tropical Africa are closely linked to climatic changes [14]. Since ecological changes have direct relationship with climatic changes it can provide the best means of correlating regionally [5, 15] the variations and fluctuations in the distribution of the flora. The Late Oligocene to Early Miocene microflora from the Niger Delta basin consists mainly of pteridophytic and angiosperm elements, while the gymnosperm pollens are not very common. This probably confirms observations in the tropical regions by Germaraad et al. (1968) [5] and Legoux (1978) [16] presented in Table 1, that montane gymnosperm pollens such as *Podocarpus milanjianus* are not part of the Early to Middle Miocene assemblages, although this is not true for some regions in North Africa [17].

Table 1: Overview and correlation of the Niger Delta spore and pollen zonation schemes of Legoux (1978) and Germeraad et al. (1968) [5, 16].



This paper presents the variations or shifts in the composition of recovered terrestrially derived palynomorphs as reflected by changes in palaeoecology based on the paleoclimatic fluctuations across the period ranging between Late Oligocene and the Early Miocene transitional boundary from palynological data obtained from ten (10) wells, seven (7) from the onshore and three (3) from offshore settings of the Niger Delta in Nigeria (Figure 2). It is aimed at improving the stratigraphical understanding of the Late Oligocene (Chattian) to Early Miocene (Aquitanian/Burdigalian) transition interval as reflected by the occurrences of the spores and pollens assemblages and key marker events.

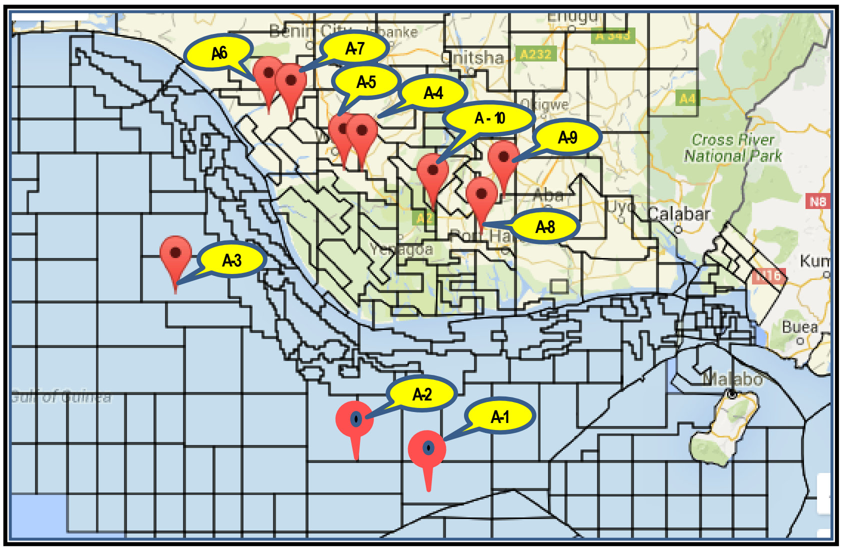


Figure 2: Location map of wells in the study area, onshore and offshore Niger Delta

Geological Setting of The Basin

The Niger Delta Basin is situated in the Gulf of Guinea, located on the West African continental margin. It extends throughout what Klett et al. (1997) [18] defined as the Niger Delta Province (Figure 3). The basin contains upper Cretaceous to Recent, marine to fluvial deposits overlying oceanic crust and fragments of the continental crust [19-20]. The delta proper began developing in the Eocene. From the Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of development [21]. The depobelts are characterised by enormous progradational and agradational paralic sequences with some retrogradational marine deposits at intervals. The sedimentary sequence in the Tertiary basin consists in ascending order of three diachronous formations, namely: Akata (marine beds), Agbada (transitional sand-shale beds) and Benin (continental sediments) Formations.

The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and south western Cameroon (Figure 1). The northern boundary is the Benin flank, an east-northeast trending hinge line south of the West Africa basement massif. The north-eastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar flank, a hinge line bordering the adjacent Precambrian. The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin (the eastern-most West African transform-fault passive margin) to the west, and the two kilometer sediment thickness contour or the 4000-meter bathymetric contour in areas where sediment thickness is greater than two kilometers to the south and southwest. The province covers 300,000 km^2 and includes the geologic extent of the Tertiary Niger Delta Petroleum System.

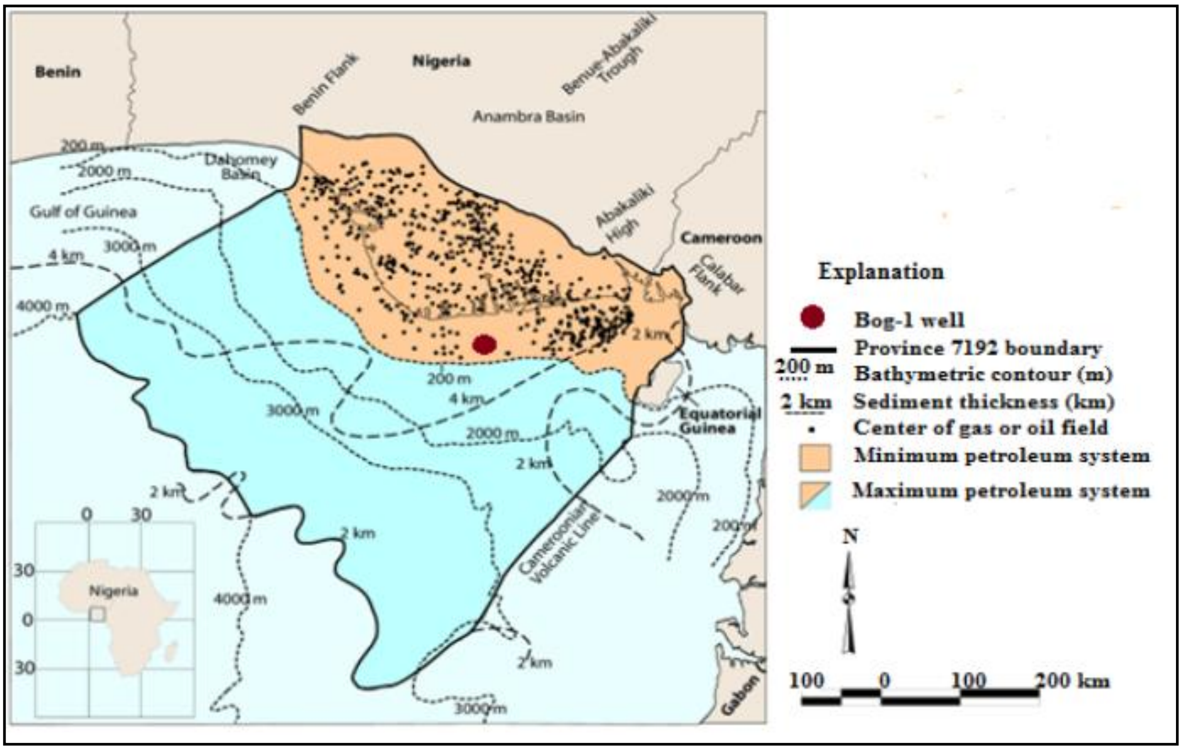


Figure 3: Map of the Niger Delta Basin Showing the Study Area and Province Outline [22]

The Niger Delta is ranked among the major prolific deltaic hydrocarbon provinces in the world and is the most significant in the West African continental margin. Oil and gas in the Niger Delta are principally produced from sandstones and unconsolidated sand predominantly in the Agbada Formation, however, turbidite sands in the upper Akata Formation is presently the target in deep water offshore and possibly beneath currently producing intervals onshore. The goal of oil and gas exploration is to identify and delineate structural and stratigraphic traps suitable for economically exploitable accumulations and delineate the extent of discoveries in field appraisals and development.

Aim and Objectives

This paper presents the variations or shifts in the composition of recovered terrestrially derived palynomorphs as reflected by changes in palaeoecology based on the paleoclimatic fluctuations across the period ranging between Late Oligocene and the Early Miocene transitional boundary from the studied wells. It is aimed at improving the stratigraphical understanding of the Late Oligocene (Chattian) to Early Miocene (Aquitanian/Burdigalian) transition interval as reflected by the occurrences of the spores and pollens assemblages and key marker events.

Its major objectives are to establish the existence of shift in the occurrences of pollens and spores during the Late Oligocene and Early Miocene transition as reflected by the changes in paleo-climates within this interval, demonstrate the significance of this shifts in understanding the stratigraphic nomenclature of the Oligocene/Miocene boundary, and attempt to provide more geologic information capable of enhancing the development of new play concepts based on the knowledge of the palaeoecological and palaeoclimatic fluctuations across the study interval.

Materials and Methods

The materials available for this study include existing reports and data on wells A-1, A-2 and A-3 (offshore) and A-4, A-5, A-6, A-7, A-8, A-9 and A-10 (onshore) from Niger Delta, fossils distribution charts, maps and Stratabugs software. The method adopted for this study involved the review and evaluation of existing reports and data from the wells under review and other previous publications, definition of key stratigraphic and ecological fossil markers used for the study, identification of trends of fossils assemblages and distribution within the period, reconstruction of palaeo-depositional setting using standard palaeo-bathymetric scheme in line with the global events, and reconstruction of palaeo-ecological setting using recognize palaeo-climate, palaeo-salinity variations and proximity to shorelines.

Results

The results show that out of the ten wells studied, four (A-4, A-5, A-6, A-7 wells) penetrated the Late Oligocene, while the remaining six (A-1, A-2, A-3, A-8, A-9 and A-10 wells) penetrated Early Miocene. The recovered sporomorphs were differentiated into paleoecological groups based on the main source areas (vegetation zones) of the extant parent plants or the Nearest Living Relatives (NLR). The grouping follows the order of the present positioning of the vegetation zones from shore. This method of grouping pioneered by Poumot (1989) was based on the fact that the nature, quantity and quality of recovered pollen and spores are functions of their proximity to shore, ecology and eustacy.

Some of the recovered pollen and spores in the studied wells, their botanical affinities and the palynoecological groups as classified by Dale, 1996 [23]; are shown in Tables 2 and 3 respectively.

Table 2: Some of the Recovered Pollen and Spores and their Botanical Affinities

Pteridophytes **Family**	**Botanical Nomenclature**	**Morphogeneric Name**
Parkeriaceae	*Ceratopteris cf cornuta*	*Magnastriatites howardii*
Polypodiaceae	*Pteris* sp.	*Polypodiaceisporites gracilimus*
	Adiantum Sp.	*Leotriletes adriannis*
		Laevigatosporites gracilis
	Polypodium sp.	*Verrucatosporites* spp.
	Polypodium vulgare	*Verrucatosporites usmensis*
Spermatophytes		
Angiosperms		
Monocotyledons		
Arecaceae/Palmae	*Elaies guineensis*	*Trichotomonosulcites* sp.
	aff. *Iriartea* sp.	*Racemonocolpites hians*
Poaceae		*Monoporites annulatus*
Dicotyledons		
Acanthaceae	*Justicia* sp.	*Multiareolites formosus*
	Issoglossa lactea	*Nummulipollis neogenicus*
Annonaceae	*Cleistopolis patens*	*Gemmamonocolpites* spp.

Asteraceae	*Aspillia Africana*	*Echitricolporites spinosus*
Cyperaceae	*Cyperus* sp.	*Cyperaceaepollis* sp.
Euphorbiaceae	*Amanoa oblongifolia*	*Retitricolporites irregularis,*
	Alchornea cordifolia	*Psilatricolporites operculatus*
	Rhizophoraceae *Rhizophora* sp.	*Zoncostites ramonae*
Rubiaceae	*Borreria verticilatta*	*Retistephanocolpites gracilis*
	Canthium sp.	*Canthiumidites* sp./*Retitriporites* sp.
Sapotaceae	*Butryrospermum* sp.	*Sapotaceoidaepollenites* spp.
Apocyanaceae	*Tabernaemontana crassus*	*Psilatricolporites crassus*
		Psilamonocolpites spp.
	Psychotria sp.	*Retitricolpites bendensis*
Clusiaceae	*Symphonia globulifera*	*Pachydermites diederixi*
	Brachystegia cf. *eurycoma*	*Peregrinipollis nigericus*
Caesalpiniaceae	*Anthonotha gilletti*	*Striatricolporites catatumbus*
Lythraceae	*Crenea* sp.	*Verrutricolporites rotundiporis*

Table 3: Palynoecological Group/ Vegetation Zone

MANGROVE	*Zonocostites ramonae Foveotricolporites crassiexinous* (*Avicennia* type), *Psilatricolporites crassus* (*Tabermaemontanacrassa*) *Spinizonocolpites baculatus* and *S. echinatus* (*Nypa fruticans*).
FRESHWATER SWAMP (FS)	*Circulinaparvus* (*Nymphaelotus*), *Pachydermites diederixi* (*Symphonia globulifera*), *Proteacidtes* spp (*Protea* spp), *Retibrevitricolporites obodoensis* and *Uacapa* spp.
OPEN COASTAL VEGETATION (OCV)	*Echitricolporites spinosus* (Asteraceae), *Nummilipollisneogenicus* (*Isoglossa lactea*), *Perfotricolporites digitatus*, **Chenopodiaceae/Amaranthaceae and Asteraceae.**
RAINFOREST	*Elaeis guineensis* (Palmae), *Daniellaogea*, Sapotaceae and *Canthium* spp.
SPORES	*Verrucatosporites usmensis*, Monolete and Trilete spores
POACEAE	*Monoporites annulatus*
RIVERINE	*Peregrinipollis nigericus (Brachystegia cf eurycoma*) and *Psilatricolporites operculatus* (*Alchornea cordifolia*).
SAVANA	*Polyadopollenites* spp, *Striatricolpites catatumbus (Anthonotha gilletti)*, *Retistephanocolporites gracilis* (*Borreria* spp), *Bridellia cf feruginea*, *Entada* spp, *Parkia biglobosa* and *Lannea* spp. and *Hymenocardia acida*
MONTANE	*Podocarpus milanjianus*, *Multiareolites formosus* (Justicia spp), *Alnipollenites versus* (Alnus spp) and *Ilex mitis* type. (*Rhizophora* spp.)

The assemblages retrieved are dominated by terrestrially derived palynomorphs, such as spores (ferns and fungi), pollens and brackish to freshwater and brackish-water colonial algae (Pediastrum) (Figures 4, 5, 6 & 7). The recovery of marine indicator palynomorphs, including dinoflagellate cysts and foraminiferal internal linings, were relatively low, but increases slightly towards the Miocene. Also, in the Miocene interval, freshwater colonial algae belonging to Pediastrum and Botryococcus groups were recovered, and tend to increase in abundance on the Early Miocene (Aquitanian - Burdigalian). Averagely, the diversity of dinoflagellate cysts appears higher in the Early Miocene than in the Late Oligocene strata. Similarly, the spores diversity increased gradually from Oligocene to Miocene.

Spores and pollens

Preservation of the spores and pollen species recorded varies from good to excellent in almost all the well sections examined.

Late Oligocene

The species *Retibrevitricolporites ibadaensis* and *Loranthacites natalie* are observed in Oligocene and Early Miocene strata from three of the studied wells. This agrees with the work of some researchers including Salard-Cheboldaff who recorded *Loranthacites natalie* from Oligocene to Eocene strata in Cameroun, Gabon and Congo [14]. The occurrence of *Retibrevitricolporites protrudens, Retibrevitricolporites obodoensis* and *Retibrevitricolporites ibadaensis* in the same stratigraphic interval in some of the studied wells (Wells A-5, A-6 & A-7) suggests a similarity with Legoux's latest Oligocene spores and pollens zone [16].

The LDO of *Praedapollis flexibilis* is not observed in all the wells, which suggests that the stratigraphically oldest sample examined is not older than the Late Oligocene. Also, *Peregrinipollis nigericus* has a quantitative base within this zone, but occurs scantily throughout the interval examined, supporting a Late Oligocene (Chattian) age for the oldest sample examined.

The late Oligocene interval is also characterised by considerable decrease in percentage of occurrences of *Zonocostites ramonae* and *Psilastephanocolporites laevigatus,* increase in occurrences of *Retimonocolpites irregularis* compared to the overlying zone, quantitative top occurrences of *Striamonocolpites rectostriatus* and quantitative base occurrences of *Peregrinipollis nigericus*, which indicates the transition into the Middle Miocene age. Others include scanty occurrences of *Spirosyncolpites bruni,* fair and regular occurrences of *Verrucatosporites usmensis* within this interval.

Early Miocene

The interval comprises several pollen species characteristic of the Early Miocene, *Verrutricolporites rotundiporis* zone of Legoux [16]. One of the index markers of this zone *Verrutricolporites rotundiporis* occurred throughout the Late Oligocene and Early Miocene intervals, but the basal part of Early Miocene is generally characterised by quantitative base occurrence of this marker specie and a reduction towards the base of the interval.

The marker specie *Crassoretitriletes vanraadshooveni* appeared for the first time at the top of this zone (Figure 5). *Verrutricolporites laevigatus* has its FDO (top) at the top of the early Miocene interval and its LDO (base) in the stratigraphically oldest Miocene (Early Miocene). *Verrutricolporites verrucatus, Magnastriatites howardi, Retibrevitricolporites irregularis, retibrevitricolporites protrudens* and *Psilastephanocolporites perforatus* were recorded only in the Early Miocene interval. *Striamonocolpites undatostriatus* occurred sporadically across the Late Oligocene/Early Miocene transition. In the contrast, *Striamonocolpites rectostriatus* has a consistent occurrence in the Late Oligocene (Chattian) through to early Middle Miocene (Langhian) in some of the wells.

The occurrence of *Praedapollis flexibilis* is relatively common in the Early Miocene in most of the studied wells intervals. This also confirms Legoux (1978) [16] earliest Early Miocene to latest Late Oligocene spores and pollen zones. *Proteacidites cooksonii* is relatively rare in the Early Miocene, but consistent from the Late Oligocene interval and is known to have a stratigraphic range from Oligocene to Early Miocene (Okonkwo, 2001). Other important taxa include quantitative base occurrence of *Pachydermites diederixi* and *Racemonocolpites hians* (Figures 4 - 6). The assemblage is similar to those reported by Evamy et al. (1978) for the Niger Delta, Nigeria. The Oligocene/Miocene boundary index spore *Cicatricosisporites dorogensis* marked by its last downhole occurrence was recorded only in A-6 well interval.

In some of the wells examined *Perfotricolpites digitatus* has its LDO directly above the Oligocene/Miocene boundary. However, in some of the well the LDO marked the top of the Late Oligocene. The Oligocene/Miocene boundary index spore *Cicatricosisporites dorogensis* was observed to be sporadic and irregular in some of the wells in Late Oligocene samples examined, while in some the LDO was located at the Oligocene/Miocene boundary. The mangrove pollen, *Zonocostites ramonae* are common to abundant in the Early Miocene intervals.

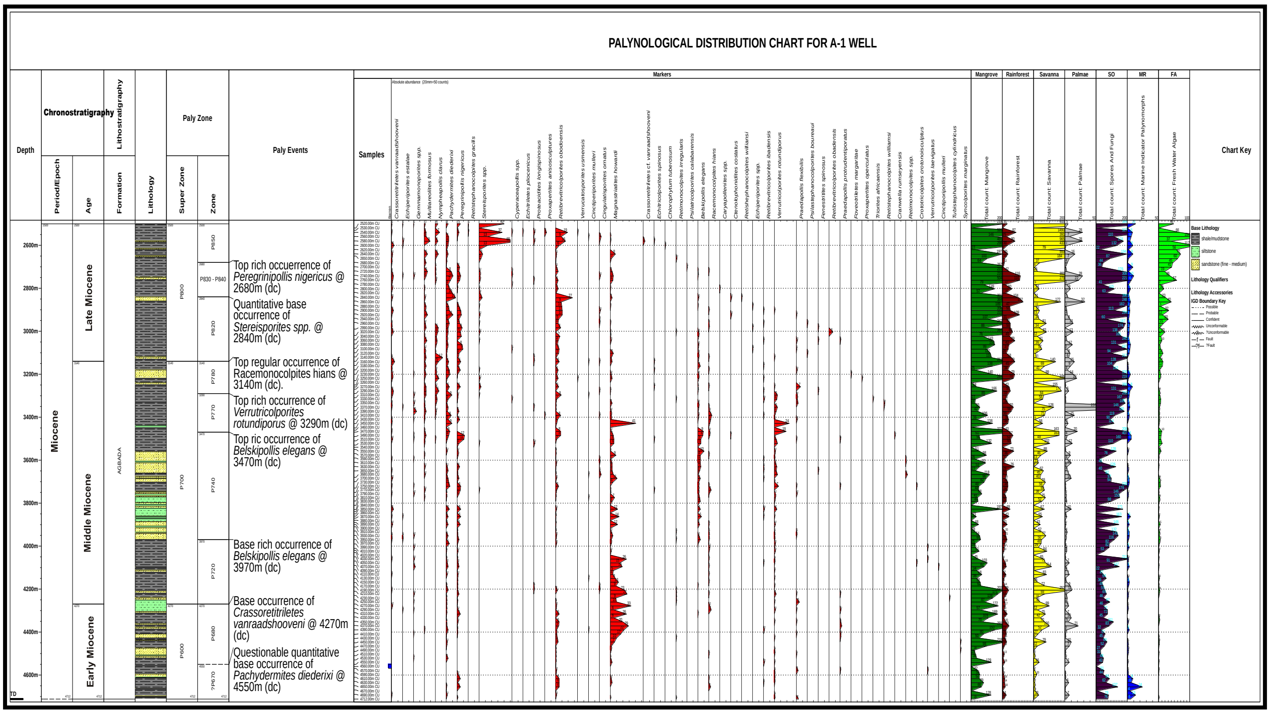


Figure 4: Stratigraphic succession in Well A-1, showing the key ecological communities within Early Miocene in Niger Delta.

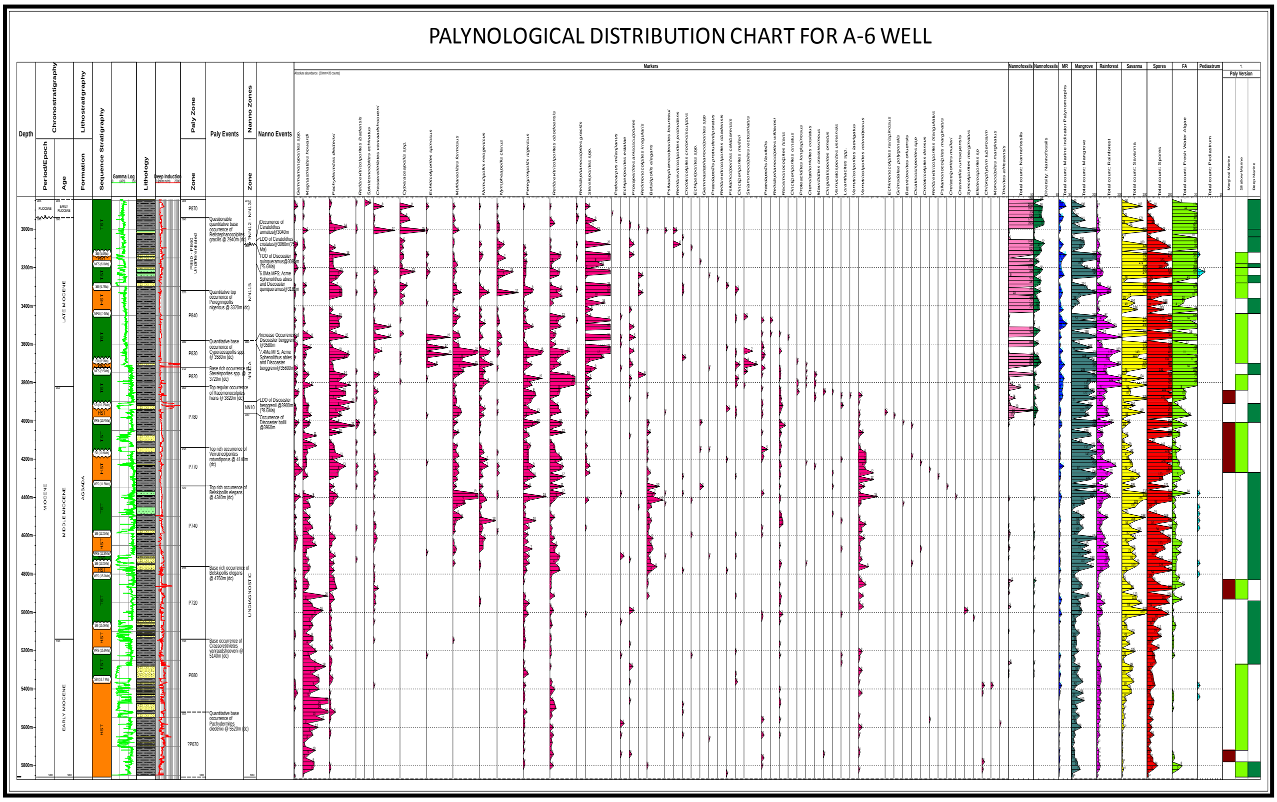


Figure 5: Stratigraphic succession in Well A-2, showing the key ecological communities within Early Miocene in Niger Delta.

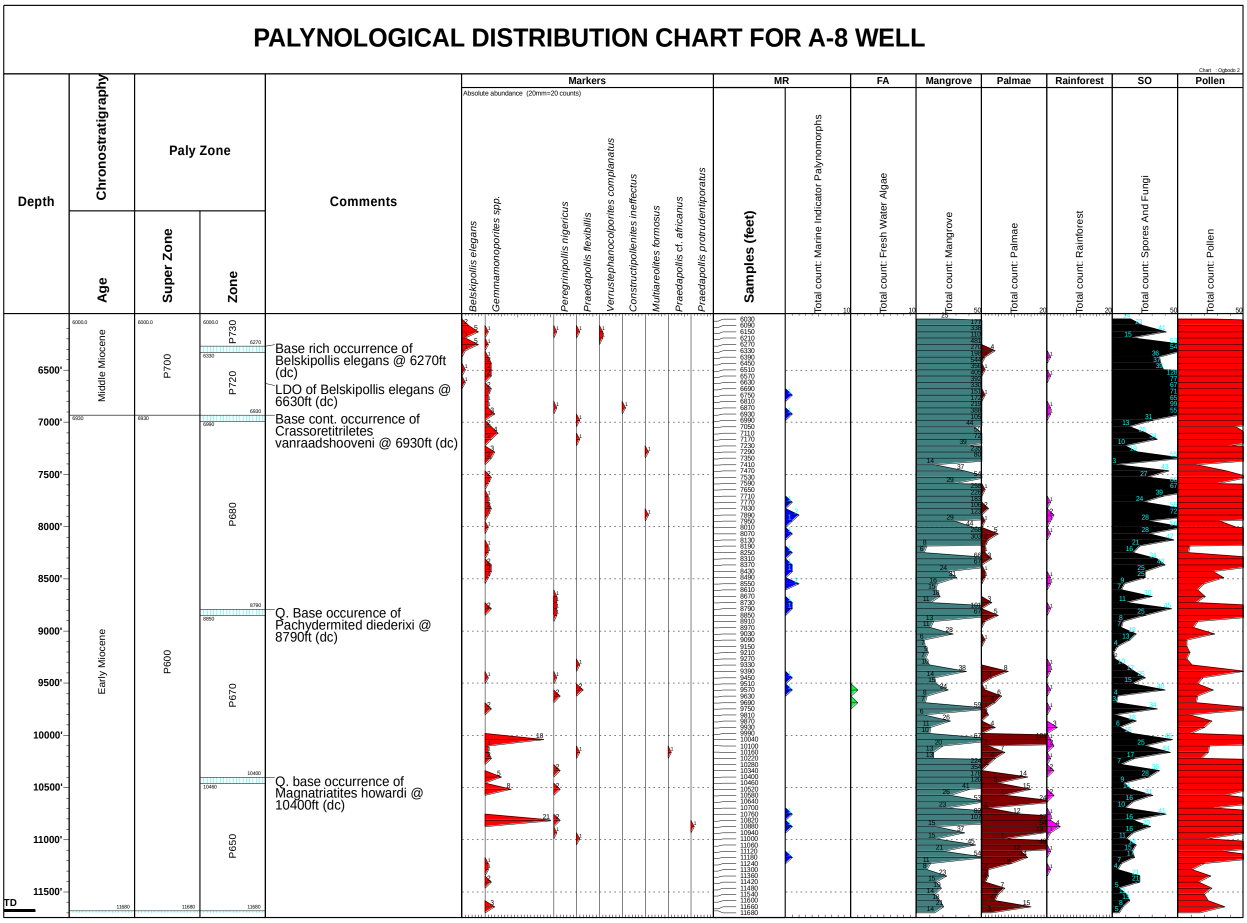


Figure 6: Stratigraphic succession in Well A-8, showing the key ecological communities within Early Miocene in Niger Delta

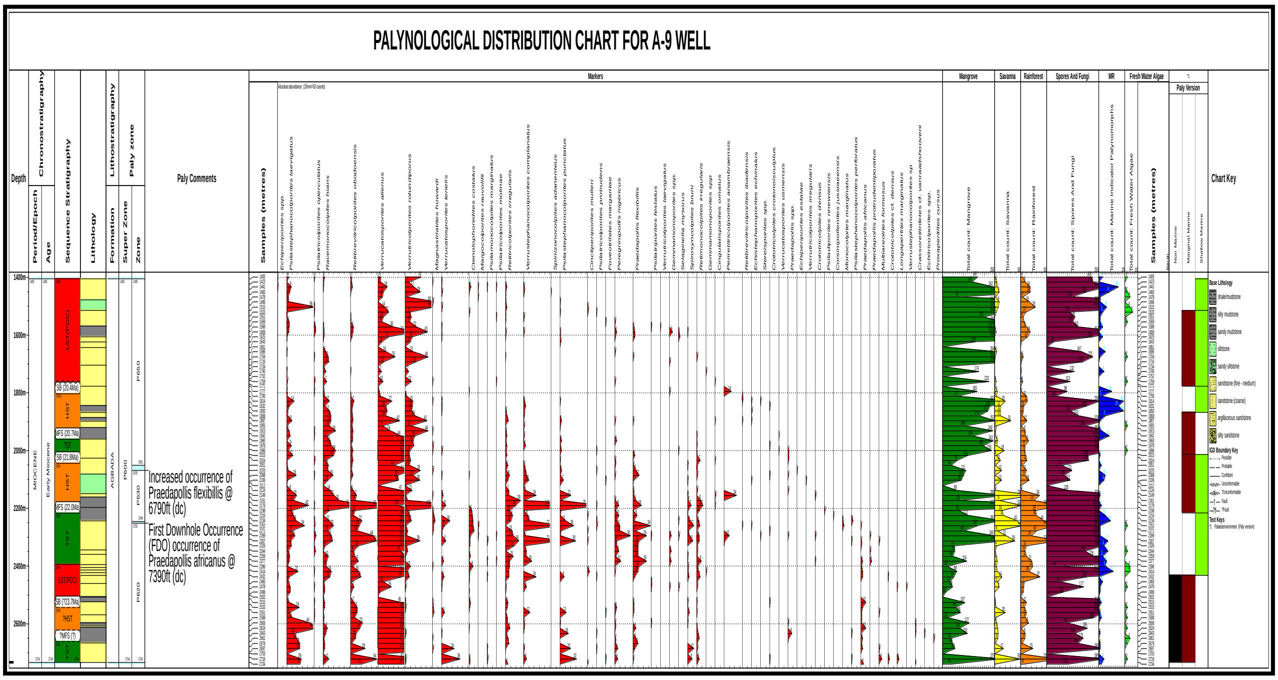


Figure 7: Stratigraphic succession in Well A-9, showing the key ecological communities within Early Miocene in Niger Delta

Table 4: Summary of Stratigraphic succession in Well A-6, showing the transition from Late Oligocene to Early Miocene in Niger Delta, Nigeria.

DEPTH (FT)	STRATIGRAPHIC INTERVAL (FT)	AGE	PALYNOLOGICAL ZONES		BIOEVENTS / REMARKS
			Evamy et al. (1978)		
4,500	4,520 -5,550	MIDDLE MIOCENE	P700	P720	Base occurrence of *Crassoretitriletes vanraadshooveni* @ 5,550'
7,500	5,550 - 8,250	EARLY MIOCENE	P600	P670 - P680	Base continous occurrence of *Pachydermites diederixi @* 7800' Quantitative base occurrence of *Magnasriatites howardi @* 8250'
	8,250 - 8,790			P630 - P650	Top occurrence of *Praedapollis africanus* @ 8250'
	8,790 - 9,200			P620	Top occurrence of *Cicatricosisporites dorogensis* @ 9200'
10,500	9,200 - 10,540	LATE OLIGOCENE	P500	P580	?Quantitative base occurrence of *Peregrinipollis nigericus* & increase in occurrences of *Retibrevitricolporites obodoensis / protrudens* group @ 10540'
12,820	10,540 - 12,820	MIDDLE OLIGOCENE		?P540 - P560	

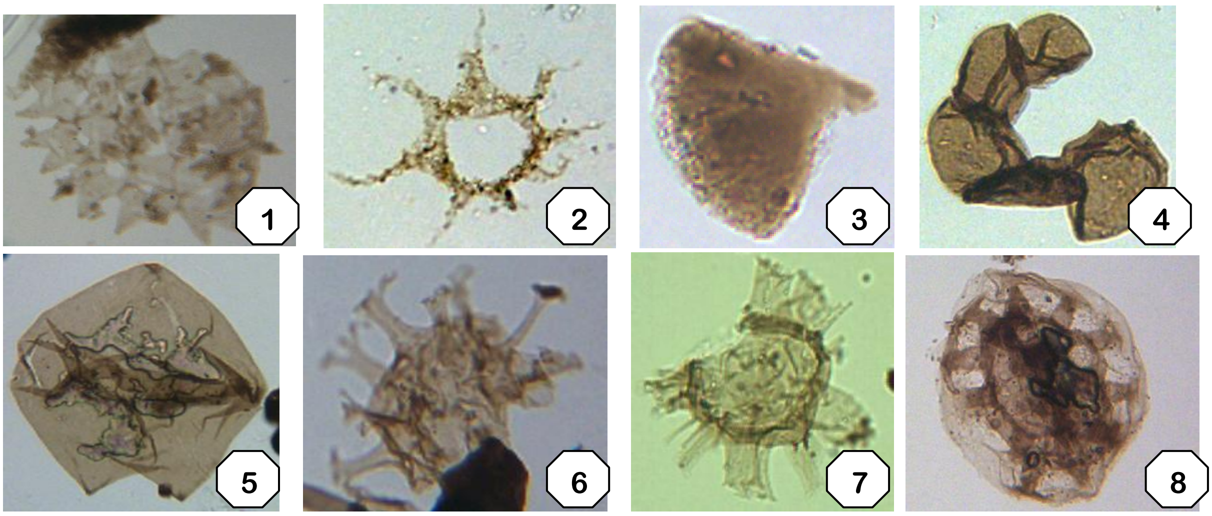


Figure 8: Photomicrograph of some Fresh water Algae and marine indicator palynomorphs recovered from some of the wells studied (1) Pediastrum bifidites (2) Pediastrum kajaities (3) Botryoccoccus brauni 4.Lycopodiumsporites sp(5) Lajeunecysta brasensi (6) Homotryblium floripes, (7) Hystrichokolpoma rigauda and (8) Tuberculodinium vancampoae.

Figure 9: Photomicrograph of some marker species recovered from some of the wells studied (1) Retibrevitricolporites protrudens (2) Retibreitricolporites obodoensis (3) Striatricolpites catatumbus (4) Verrutricolporites laevigatus (5) Belskipollis elegans (6) Retimonocolpites irregularis (7) Peregrinipollis nigericus (8) Praedapollis africanus.

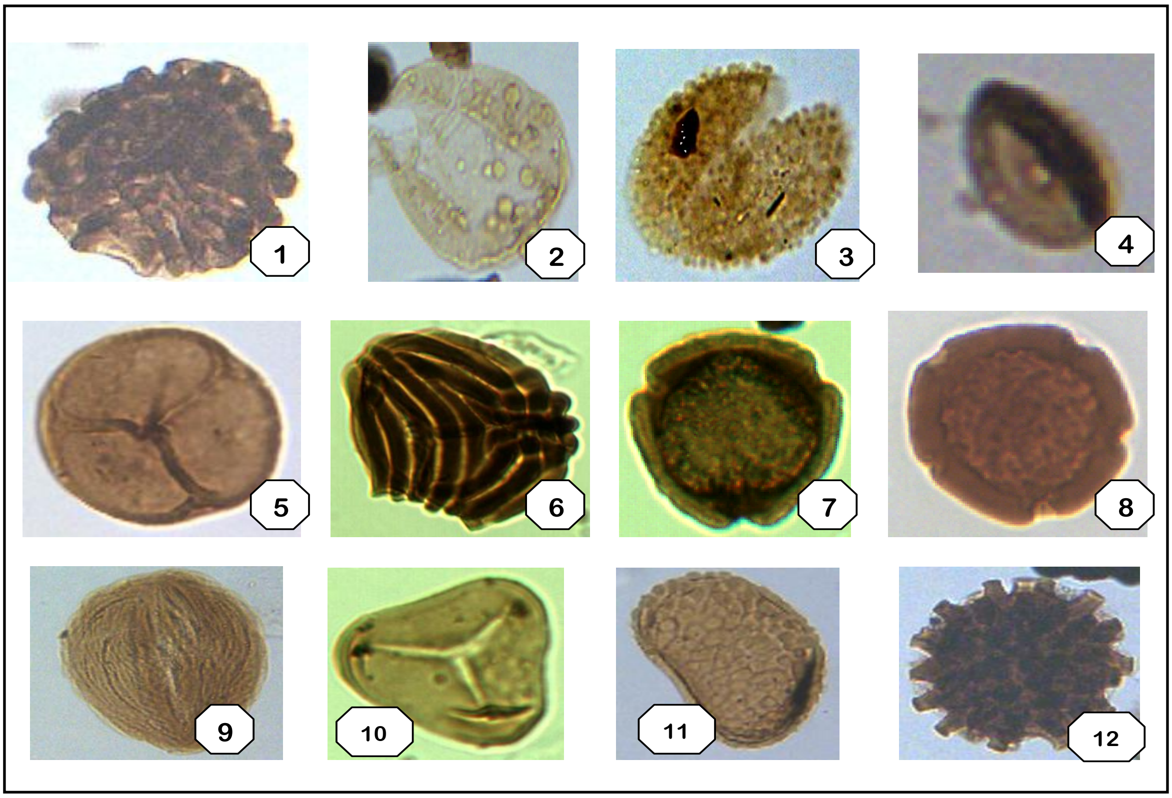


Figure 10: Photomicrograph of palynomorps recovered from some of the wells studied (1) Crassoretitriletes vanraadshooveni (2) Gemmamonocolpites spp. (3) Racemonocolpites hians (4)Verrutricolporites rotundiporus (5) Stereisporites spp, (6) Magnastriatites howardi (7) Psilatricolporites crassus (8) Pachydermites diederixi (9) Striatricolpites catatumbus (10) Acrostichum spp. (11) Verrucatosporites alienus (12) Fungal spore

In all the wells studied, there was a general increase in spore diversity upwards towards the top of the Early Miocene, whereas the graminae decreased within the early Middle Miocene interval. These include *Laevigatosporites* and *Leiotriletes* assemblages. The Oligocene Miocene boundary for the studied wells delineated as follows: A-4 well (6750ft), A-5 well (9200ft), A-6 well (11,483ft) and A-7 well (10,187ft).

Discussions

The paleoecological deduction in this study is guided by the work of Poumot (1989) and other researchers [24-35]. However, it has been recognized that, because of the degree of taxonomic precision possible with sporomorph identifications, the palynoecological groupings in this study only include the taxa with known botanical affinities [36]. This is because it has been recognized that extant cogenerics often vary widely in their modern climatic envelopes. Inferences about palaeoclimates using palaeobotanical evidence is, therefore, better based on a taxonomically broad range of fossil taxa and their nearest living relatives, and ideally taxa that are entirely distributed within narrow climatic boundaries [32, 37-38].

Earlier research works showed that a major global cooling event occurred at the Oligocene/Miocene transition period which was associated with build-up of permanent ice masses on Antarctica and the transition from a green house to ice house world. The LDO of some dinoflagellate cysts marker species *Distatodinium craterum* and *Lejeunecysta beninensis* can be used regionally to distinguish Upper Oligocene (Chattian) from Early Miocene (Aquitanian) strata [39]. However, changes in the pollen records observed in this study, e.g. ranges of *Verrutricolporites laevigatus* and *Loranthacites natalie*, provide a higher stratigraphical resolution in the Upper Oligocene strata compared with the dinoflagallate cyst assemblages. Based on terrestrially derived palynomorphs, the Oligocene/Miocene boundary can be delineated based on the LDO of *Cicatricosisporites dorogensis* and *Verrutricolporites laevigatus* and the co-occurrence of a typical earliest Miocene succession of species within the genus *Verrutricolporites* [16].

The transition to the Miocene was characterized by a strong cooling pulse, the Mi-1 event [40]. Subsequently, starting at ~20 million years before present (Ma), global temperatures increased, culminating in the Mid-Miocene Climatic Optimum (MMCO) between ~17 and ~14Ma [3]. This overall warm interval was, however, interrupted and followed by several centennial-scale cooling events, e.g. further Mi events [41-42] associated with growth of the Antarctic ice sheet, which also influenced the North Atlantic realm [43-44] and caused a relative sea-level fall of ~60m in the some parts of the world [45]. Furthermore, the early Miocene witnessed the spread of biomes dominated by grasses (Poaceae) [46-48].

The occurrence of more grass pollens (Graminae) upward towards the top (late) Early Miocene and the Middle Miocene intervals (Late Burdigalian to Langhian) in most of the wells studied, probably indicate a drier and perhaps warmer climate, during which the savanna developed. This more gradual change reflected by vegetational variation might be a result of the Mid- Miocene Climate Optimum (MMCO) which has been dated ca.17-14Ma [3].

Kender et al., (2009) [49], reported three Miocene foraminiferal dissolution events in fan deposits in West Africa at ca. 16Ma, 15.5Ma and 14Ma. These periods were correlated with increased North African weathering and expansion of the Oxygen Minimum Zone (OMZ) in West Africa. The spores and pollens assemblages also reflect local occurrences and extinctions in the hinterland and large scale palaeoenvironmental variations from wet to dry conditions in West Africa tropical climate system [50-51].

This spread and the loss of forest cover during the Miocene may have weakened the biotic weathering feedback [52] and thus contributed to the climate development from the Miocene until today [42]. The MMCO was followed by a gradual cooling and ice sheet expansion during the late Miocene, while atmospheric CO_2 remained relatively stable compared to Eocene to Early Miocene oscillations. This cooling trend and increasing seasonality is generally reflected in pollen records from fluvial deposits from the middle Atlantic margin [53], but these records could only be correlated roughly with marine records.

Conclusion

Spore and pollen assemblages within the Late Oligocene/Early Miocene transition interval from most of the studied wells correlate with Legoux's (1978) [16] Late Oligocene (Chattian) spore and pollen zone B2-1 (Table

1). The key marker species of dinoflagellate cysts and some pollen species that have their FDOs within the Late Oligocene strata especially in Well A-6 provide regional biostratigraphical tool for correlation of uppermost Oligocene strata.

The O/M boundary is marked by FDO (Top) of the key marker specie, *Cicatricosisporites dorogensis* in Well A-6, while some were delineated based on the LDO of *Verrutricolporites laevigatus*. This is supported by the co-occurrences of a number of typical Late Oligocene to earliest Miocene pollen such as *Praedapollis flexibilis, Striamonocolpites rectostriatus, Striamonocolpites undatostriatus, Verrutricolporites rotundiporus, Verrutricolporites scabratus* and *Verrutricolporites verrucatu*s. An increase in relative abundance of the freshwater algae Pediastrum and the coastal dinoflagellate cyst genus *Homotryblium* within the Early Miocene (Aquitanian) is interpreted to reflect a change to less saline surface water resulting from the seawards expansion of the Congo River freshwater plume. This event is perhaps due to a climatic shift resulting in warmer and possibly also more humid conditions following the Mi-1 glaciation. A transgressive phase, due to a global relative sea level rise, following the Mi-1 event, may account for the flushing of Pediastrum and low-salinity coastal *Homotryblium* cysts into the deeper part of the basin.

Grass pollen (Gramineae) is very common in some intervals from few wells examined, indicating a drier and perhaps also warmer climate around the late Early Miocene (Burdigalian) to early Middle Miocene (Langhian) intervals, during which the savanna developed [54]. This more gradual change reflected by a vegetation shift might be a result of the Miocene Climatic Optimum dated at ca. 17–15 Ma.

This pattern is observed to reflect a regional event as it has been observed from other studies in Congo and Angolan basins [55]. It possibly reflects a period of relatively stronger upwelling, perhaps due to changes in wind intensity and access to nutrients within the offshore current systems [49]. The similarity in variations or shifts from drier and warmer conditions to more humid and wetter climates observed in the Early Miocene/Middle Miocene transition requires more attention, a more detailed study on the palaeoecological dynamics of deposition of the sedimentary strata should be carried out, as most of the producing reservoirs in the offshore Niger Delta of Nigeria are derived from these intervals.

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