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Paleoclimatic Changes and Palynocycles of The Late-Tertiary Niger Delta, Southern Nigeria

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Abstract— Palynological studies in Nigeria in the past four and a half decades were primarily based on the needs of the oil industries and information from them has remained confidential. Most of the studies were largely concerned with systematic descriptions of pollen and spores, palynological zonations, and bio-stratigraphy. Apart from the published works of on the Late Quaternary Eastern Niger Delta. This study therefore, presents vegetational and climatic changes in the Late Tertiary Niger Delta, Nigeria based on pollen record from MIC 2 well. It will serve as a contribution to the knowledge of the Niger Delta environmental changes as reflected by vegetation particularly at Miocene/Pliocene periods where there is a dearth of published information. A Late Miocene - Late Pliocene ages belonging to P850, P860, P860, P870, P880 and P920 zones of Evamy et al., (1978) were established for the interval under study. Palynocycles are recurrent palynological sequences reflecting vegetational changes determined by cyclic sea level oscillations and the associated climatic variations. During this study, six climatic cycles were recognised and used to infer the depositional cycles that indicate recurrent palynogical sequences and vegetation changes based on the sea level change. The wet cycle suggests highstand / transgressive systems tracts, while the dry cycle indicates lowstand systems tracts. Palyno-ecological communities encountered in the analysed interval of the well reveals clear crests and troughs in the microfloral abundance indicating fluctuations of dry and wet climates during the deposition of the sediments enabling three major Palynocycles within intervals 4142 – 2650, 2650 – 1450, and 1450 – 450 to be identified.

Index Terms— Paleoclimate, Pollen, Spores, Palynomorphs, Palynocycle, Paleoenvironment, Niger Delta

1 Introduction

Paleoclimate is the climate of the earth at a specified point in geologic time. The reconstruction of past environment is one of the goals of palynological research and this entails the study of the periodic changes in environment over geological time and offers another way of studying the climatic changes (especially temperature and wetness) of the past because changes in climate are reflected in the vegetation of an area. This is so because the vegetation of any area is an integral and basic component of the ecosystem and is sensitive to changes in the ecosystem. [1] pointed out that the usefulness of fossil pollen and spores to paleoecology is hinged on their potential for providing quantitative information on recorded ancient vegetation. Therefore, in the reconstruction of these past vegetations and environments, the pollen data is commonly interpreted as a reflection of the type of vegetation and climate prevalent during the period under study. Thus, with adequate evidence in the form of fossils in sedimentological data, it is possible to reconstruct and interprete past environments and biotic communities (and therefore the paleoclimate and ecology) based upon processes operative today.

1.1 Location of Study Area

The area under investigation is an offshore oil field located in the southern Niger Delta. The Niger Delta Region is situated at the southern end of Nigeria bordering the Atlantic Ocean and extends from about Longitude 30 00′E to 9000′E and Latitude 40 00′ N to 60 00′N.

1.2 Regional Geology of The Study Area

1.2.1 Tectonic Setting

The Niger delta is situated in the Gulf of Guinea on the west coast of Central Africa (Figure. 1). It is located in the southern part of Nigeria between latitudes 40 00′N and 60 00′N and longitudes 30 00′E and 90 00′E. It is bounded in the south by the Gulf of Guinea (or the 4000m bathymetric contour) and in the North by older (Cretaceous) tectonic elements which include the Anambra Basin, Abakaliki uplift and the Afikpo syncline. In the east and west respectively, the Cameroon volcanic line and the Dahomey Basin mark the bounds of the Delta, (Figure 1), The Cainozoic Niger Delta is situated at the intersection of the Benue trough and the South Atlantic Ocean where a triple junction developed during the separation of South America from Africa [2], [3].The delta is considered one of the most prolific hydrocarbon provinces in the world, and recent giant oil discoveries in the deep-water areas suggest that this region will remain a focus of exploration activities (Harry et al). Furthermore, the Niger delta is one of the world's largest deltas, with a subaerial acreage of about 75,000 km2. It is composed of an overall regressive clastic sequence, which reaches a maximum thickness of 30,000 to 40,000 ft. (9000 to 12000 m). The development of the delta has been dependent on the balance between the rate of sedimentation and the rate of subsidence [4]. This balance and the resulting sedimentary patterns were constrained by the structural configuration and tectonics of the basement (Evamy et al, 1978).
Important influences on sedimentary rates have included eustatic sea-level changes and climatic variations in the hinter-

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lands South Atlantic Ocean where a triple junction developed during the separation of South subsidence has been controlled largely by initial basement morphology and differential sediment loading of unstable shales [4].

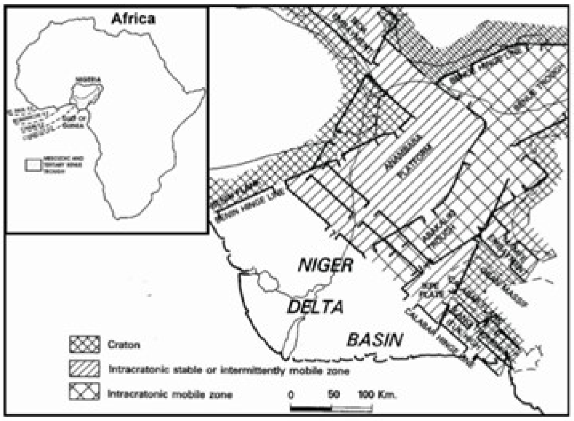

Fig. 1. Megatectonic frame of Southern Nigeria Sedimentary Basin (Mid-Albian to Santonian). Inset shows the regional setting of the basin. [5]).

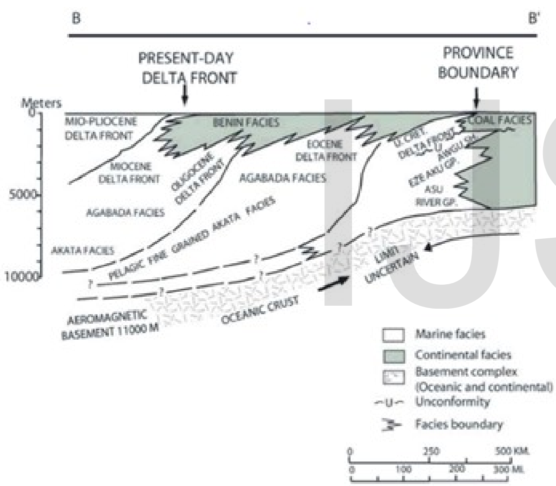

Fig. 2: Southwest-Northeast (B-B') Cross Section through the Niger Delta Region. Modified from [3].

The Delta has built out over the collapsed continental margin, and its core is located above the collapsed continental margin at the site of the triple junction formed during the middle Cretaceous. The main sediment supply has been provided by an extensive drainage system, which in its lower reaches follows two failed rift arms, the Benue and Bida basins. Sediment input generally has been continuous since the Late Cretaceous, but the regressive record has been interrupted by episodic transgressions, some of considerable extent.

The Niger delta has progaded into the Gulf of Guinea at a steadily increasing rate in response to the evolving drainage area, basement subsidence and eustatic sea level changes [6]. Initially, the delta prograded over extensionally thinned and collapsed continental crust of the West African margin (Figure 2), as far as the triple junction, filling in the basement graben-and horst topography. During the middle and lateEocenesedimentary rocks became increasinglysandy, marking the onset of a general regression of the deltaic deposition. Of dominant importance in the development of the delta, as in similar settings elsewhere in the world has been the influence of synsedimentary listric normal faults. These have been forming at least since the Paleocene and define sites of locally increased subsidence and sedimentation. They lie subparallel to the paleocoastline and are presumed to sole out at relatively shallow depths within marine shale sequences. A number of major basinwide growth fault zones define depositional realms at succeeding periods of delta history [4]. In the paralic interval, growth fault associated rollover structures trapped hydrocarbons. Faults in general play an important role in the hydrocarbon distribution. Growth faults may even function as hydrocarbon migration paths from the overpressured marine clays. There is an intimate relationship between structure and stratigraphy. They both depend on the interplay between rates of sediment supply and subsidence [7].

1.3 Lithostratigraphy of the Niger Delta

The Lithostratigraphy of the Cenozoic Niger Delta is a direct product of the various depositional environments. Ever since on – going deltaic progradation ensued in the Early Tertiary period, these environments and their characteristic lithofacies have prevailed. Well sections generally display vertical subdivisions [8] in which an Upper delta top lithofacies, the Benin Formation, is Underlain gradationally by the deltaic front parallic lithofacies, the Agbada Formation. The Agbada Formation comprises mostly sands with minor Shales in the Upper part, and an alternation of Sands and Shales in equal proportion in the lower part. Pro-delta marine shales belonging to the Akata Formation occur lower in the section, with sandstones units of deep-sea fan Origin.

Niger Delta lithostratigraphic units are strongly diachronous having begun to accumulate since deltaic progradation commenced in the Early Tertiary, in which case, the Akata Formation ranges from Paleocene to Recent, the Agbada Formation from Eocene to Recent, and the Benin Formation from Oligocene to Recent. Along the northern perimeters of the Niger Delta where the proximal parts of these lithostratigraphic units are exposed, different Formation names have been assigned, namely Imo shale (Akata), Ameki (Agbada), and Ogwashi – Asaba (Upper Agbada facies). Large clay fills of ancient submarine canyons, containing turbidites are common in the eastern and Western parts of the Niger Delta succession [2]. The submarine canyons that were subsequently filled by these clays were entrenched mainly during late Tertiary lowstands of the sea level.

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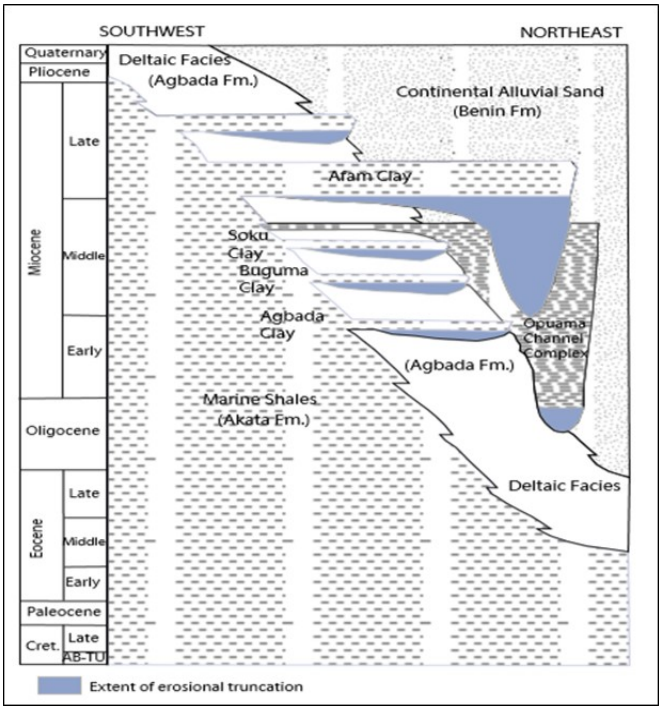

Fig 3: Stratigraphic column showing the three formations of the Niger Delta. [9] [4]

1.3 Relationship between Palaeovegetation, Palynocycles, Sea Level Change and System Tracts

The climate of an area is mirrored by its vegetation type [10]. Variations in plant communities or changes in composition / abundance of an assemblage or individual species are regularly, partly a direct consequence of change in climate and/ or palaeoenvironment. The consequence of this variation on palynofloral groups depends on whether such a prevailing climate change encourages or affects the prevailing plant community

At the initial stage of the lowstand systems tract (LST), sea levels drop rapidly, resulting in erosion and incision along coastal plain. The brackish water environments in which mangroves swamp (littoral setting) can thrive will be of minimal extent, as well as freshwater swamps (Figure 4, Figure 5a). The initial stage of the lowstand systems tract would therefore be expected to be characterised by the low abundance of coastal species [11] and a resultant increase in pollen from well-drained fluvial settings ([12]; [13]). In this case, the hinterland groups (savanna) will dominate while the littoral groups (mangrove) decrease (Figure 5, 6). Most authors agree that lowstand systems tract (LST) is also related to an abundance increase of terrestrial particles (phytoclasts) as marine palynomorphs such as dinoflagellates cysts decreases (Steffen and Gorin, 1993). Sedimentation during this phase is by fluvial processes, transported into the deep-water environment. Most terrestrially palynomorphs which become incorporated into marine sediments are mainly due to fluvial transport as against wind-transported (monsoon drive), which occur predominantly as silt-sized alluvial particles [12].

During sea level rise, sedimentation takes place in a transgressive systems tract (TST) setting (near shore – delta plain), the brackish, coastal - mangrove-dominated deltaic plain expand (Figure 4 b). This will consequently result in an obvious increase in marine sediments as compared to the lowstand systems tract. Since most sediment is deposited in the coastal – mangrove swamp region, it implies that sporomorphs abundance in deepwater settings would be much lower than in the lowstand systems tracts ([14]; [12]). As the sea level rises, the littoral groups tend to increase while the hinterland groups gradually decrease (Figure 4 b).

During the highstand, there is a development of upper delta plain (flood plain) [15]. This is controlled by freshwater and alluvial wetlands [14]. Miospores from this source could be expected to exhibit a lowest representation during the highstand (Figure 4c, Figure 5). This is related to a decrease rate of sea-level rise and initial sea-level fall [16]. The presence of mangrove-derived sporomorphs in marine depositional environments is likely to show a related trend. This occurs as deposition takes place on the proximal to lower delta plain and the representation of mangrove pollen will increase. In this case the freshwater swamp and open forest vegetation tend to increase and expand until there is a fall in sea level [12]

2 Materials and Methods

2.1 Review Stage

Ditch cutting samples from MC-2 well, an exploratory well drilled in the coastal swamp of the Niger Delta, Nigeria were used for this study. The studied section ranged from 460 to 4142m with a total of thirty-seven samples selected for palynological analysis. Samples were treated using standard palynological methods. These include HF treatment to remove siliceous materials and HCl and heavy liquid separation and finally acetolysis to dissolve cellulose and to darken palynomorphs for easy identification (Faegri and Iversen, 1989).In the identification of pollen and spores, the atlases of photomicrographs in the photo-album of the Palynology Laboratory, Department of Geology, Akwa Ibom State University, Nigeria, as well as those published in literature such as - [17] [18] [19, 20] , [21], [22, 23]. Reference pollen slides of modern taxa are domiciled in the Palynology laboratory, Department of Geology, Akwa Ibom State University, Nigeria were also consulted.

In order to reconstruct the palaeovegetation communities from which inferences about the environmental conditions prevailing at the time of deposition of the sediments of these wells can be made, the pollen types were grouped into vegetation zones or phytoecological units based on the present-day natural distribution of their modern analogues. The approach of Sowunmi [22]was followed in classifying the taxa into different phytoecological groups based on the assumption that the physiology and environmental requirements of the fossil species were identical to their extant analogues [24].

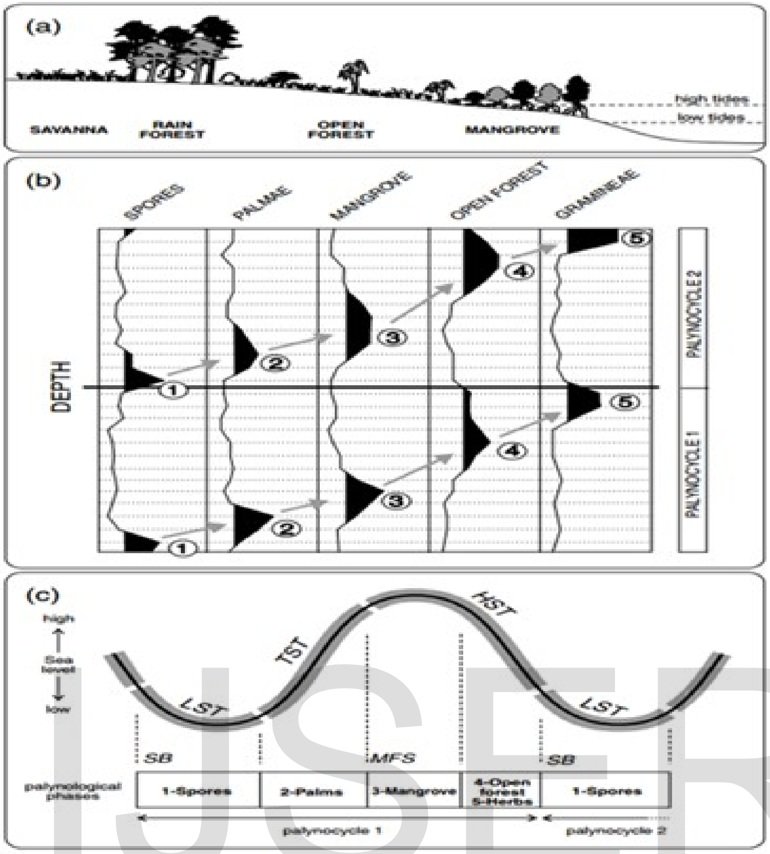

Fig. 4: Generalized transect of coastal vegetation zones for the tropics of Asia and west Africa [14]. (b) Theoretical expression showing the stratigraphic example of palynocycles [14, 25]. (c) Interaction between the phases of the palynocycles and the depositional cycles of the sequence stratigraphic concepts [14, 25]. HST highstand systems tract, TST transgressive systems tract, LST lowstand systems tract, SB sequence boundary, MFS maximum flooding surface.

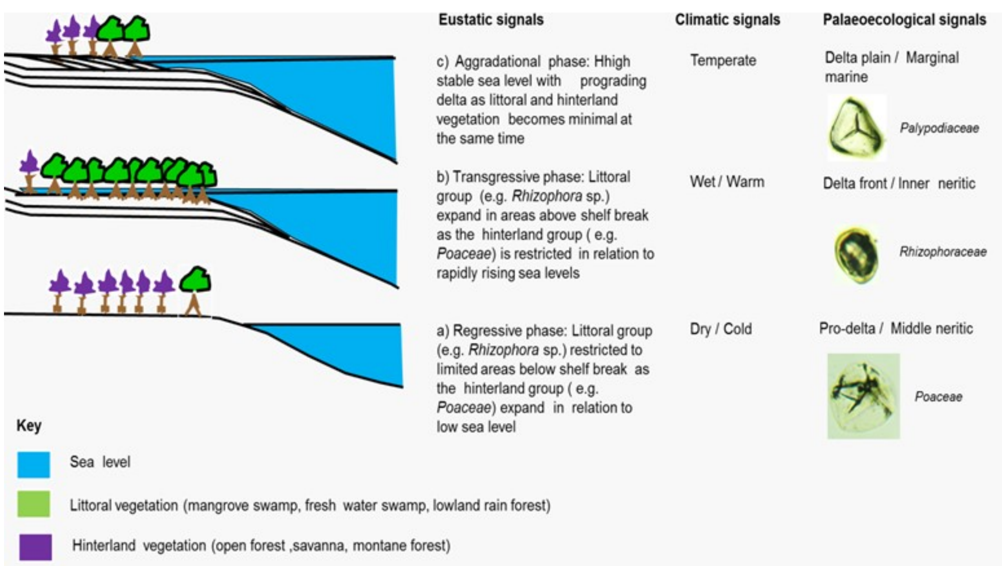

Fig. 5: Relationship between Paleovegetation, Eustacy, Climate and Paleoecology for the tropical setting [13]

3.0 RESULTS, INTERPRETATIONS AND DISCUSSIONS.

3.1 Data Analysis and Interpretation

3.1.1. Sedimentology

MIC 2 well shows a clastic regressive succession with predominance of sand. It is made up of alternating sand and shale including a good percentage of siltstone. The shale/sand ratio increases progressively towards the base of the studied interval.

Glauconite pellets were common within the studied interval. Shell fragments, ferruginous materials, pyrite and mica flakes are rare to few. The sands are predominantly clean white to grayish, brownish, fine to coarse grained, sometimes pebbly, angular to well rounded, moderately to poorly sorted and occasionally well sorted in some samples. The shales are light to dark grey or brownish, soft to moderately indurated, platy, flaggy, slabby and blocky in appearance. Based on sedimentological and palynological data, the interval studied in MIC-2 belongs to the paralic Agbada Formation.

3.1.2 Biostratigraphic analysis

Over a thousand palynomorphs were counted after screening, comprising spores, pollen grains, fungal spores, Botryococcus, and foram test linings. Some of the corroded or highly distorted palynomorphs were not counted since they could not be placed within any group. Marine indicators found were foram test linings. The biozonation of the studied section was based on the pollen and spores. The reference scales used were those of Evamy [7] and Morley [12]. Some of the subzones of these two schemes were lumped together because some of diagnostic fossils that mark their boundaries were not found. The sediments in the studied section yielded a rich palynomorph assemblage. Specifically, the forms recovered included.

Mangrove Pollen: *Zonocostites ramona, Psilatricolporites crassus,* Savanna Indicators: *Monoporites annulatus, Proteacidites cooksonii, Echistephanoporites echinatus Cyperaceaepollis sp., Polyadopollenites vancampori.*

Fresh Water/Forest elements: *Pachydermites diederixi, Retitricolporites irregularis, Striatricopites catatumbus, Retibrevitricolporites* spp., *Psilatricolporites operculatus Retibrevitricolporites protudens Gemmamonoporites sp Retibrevitricolporites obodoensis, Nymphaeapollis clarus, Retitricolporites spp, and Psilamonocolpites spp.*

Montane pollen: *Nummulipollis neogenicus, Podocarpus milanjianus.*

Other pollen includes: *Corylus spp., Gemmamonoporites spp., Retibrevitricolporites spp., Arecipites spp., Nymphaeopolis clarus Cyperaceapollis spp., Polypodiaceisporites spp., Psilatricoporites sp, Retrimonocolporites obaensis, Echistephanosporites sp,*

The following spores were also recovered; *Verrucatosporites spp, Stereiosporitessp, Smooth trilete spore Crassoretitrilletes vanraadshooveni, Lycopodiumsporites spp. Magnastriatites howardii, Verrucatosporites usmensis* and fungal spores.

Also recorded were Organic Walled Microplanktons (dynocysts, and microforaminiferal wall linings) and Fresh water algae like *Concentricystes circulus, Pediastrum sp,* and *Botryococcus brauni.* were also recovered from the sediments.

3.2 Palynological Zonation of MIC-2 Well

Five (5) palynological zones demarcated.

Zone: P850, Late Miocene

This zone is recognized in well MIC-2 at the depth interval of 4142- 3300ft.This zone is defined by the first regular appearance of *Nympheapollis clarus*.

Zone: P860, Late Miocene-Early Pliocene

This zone is recognised in well MIC-2 at the depth interval of 3300-2600. The top of this zone is marked by the first occurrence of *Retistephanocolpites gracilis* while its base coincides with the top of the underlying P850 zone.

Zone: P870, Early Pliocene

This zone is recognised in well MIC-2 at the depth interval of 2600-1500. The top and base of the zone aredefined by the occurrence of *Gemmamonoporites sp.*and first appearance of *Retistephanocolpites gracilis* respectively.

Zone: P880, Early Pliocene

This zone is recognised in well MIC-2 at the depth of 1500 – 600m. The top of the zone is defined by in the study by the occurrence of *Gemmamonoporites sp.* while the base is defined by the first appearance of *Podocarpus milanjianus* at the depth of 600m.

Zone: P920, Late Pliocene

This zone is recognized at the depth interval of 600-460ft by the occurrence of *Podocarpus milanjianus*.

3.3 Paleoclimate Interpretation

The communities include Mangrove swamp Savanna, Fresh water swamp/Forest elements marine indicators. In this interpretation however, the main focus is on the mangrove and savanna elements though other groups are also considered. This is because high mangrove assemblage is known to reflect wet period while high savanna portrays a dry climatic condition. Abundant occurrence of Gramineae pollen in some sections of the well enabled delineation of the sequences that were deposited under dry conditions while the abundance of mangrove pollen; *Zonocostites romanae* (*Rhizophora)* in some sections of the well enabled delineation of the sequences that were deposited under wet conditions in this study, three climatic changes were observed; wet, dry and drier climates.

3.4 Palynocycles

Palynocycles are recurrent palynological sequences reflecting vegetational changes determined by cyclic sea level oscillations and the associated climatic variations the following wet and dry climatic cycles were derived based the abundance and diversity of index palynomorphs. The following Paleoclimatic and Palynocycle insights were derived from the study, disaggregated by studied sedimentary intervals.

Depth 4142- 2650 m

The quantitative (numerical) count of mangrove pollen Zonocostites ramonae and the savanna pollen *Monoporites annulatus* within this interval were low. Their percentage compositionsare similar and almost alternate of each other though savanna indicator is slightly higher indicating a slightly dry climate phase with warm temperatures. However, the abundance of the fresh water algae *Botryococcus braunii* recordedwith common rainforest/fresh water swamp species within this interval suggest a certain degree of wetness in the climatic condition. There were also noticeable fluctuations in the occurrence of fungi, *Verrucatosporites spp*. and *Stereiosporite*s spp. within this interval. The presence of savanna species like *Echistephanoporites echinatus*, *Cyperaceaepollis sp.,* and *Polyadopollenites vancampori* further confirms the prevalence of a dry climate within this interval. The occurrence of small quantities of mangrove pollen in this zone was probably due to minor local short-lived transgressions of the sea, thereby allowing only very limited extension of mangrove vegetation.
The periods covered by this interval can be suggested to be periods of rapid and unstable climatic conditions culminating in rapid sea-level changes (rise and fall). This may account for the rapid changes noticed in the pollen assemblages in this zone particularly, *Rhizophora* and *Poaceae*.

An initial rise in sea level with the mangrove vegetation increasing in extent is suggested for this zone. The fluctuations in percentage occurrence of *Zonocostites ramonae* may probably be a result of variations in the intensity and extent of the tidal streams thereby causing fluctuations in the extent of mangrove forest. This rise and fall of the tides may also bring about drier conditions resulting in a reduction of forest vegetation and subsequently promoting expansion of the savanna . This agrees with the reports of which revealed cyclic fluctuations in the vegetation and continental climatic condition of North-West Africa in the Pliocene, when river discharge ceased, wind transport of pollen grains prevailed over fluvial transport.

Depth 2650 – 1450

At the time of deposition of the sequences within this interval, the pollen record indicates that mangrove swamp forest vegetation was generally low. There is an overall increase in the recorded quantities of grass pollen, *Monoporites annulatus*, both numerically and in ratio to mangrove pollen. At 3250m depth, *Monoporites annulatus* attained higest percentage ratio of (100%) within the zone. This shows the prevalence of dry climate to wet. Also, there was a common occurrences of fresh water swamp species like *Retitricolporites irregularis*, *Retibrevitricolporites protudens*, *Pachydermites diederixi*, with rare occurrences of other fresh water sporomorphs *Magnastriatites howardii*, *Verrucatosporites usmensis*, as well as low to common occurrences of fresh water algae.A drier condition than the preceding interval resulting in a reduction of forest vegetation and subsequently promoting expansion of the savanna can be suggested at this period. Fluctuations in percentage occurrence of *Zonocostites ramonae* may be as a result of variations in the intensity and extent of the tidal streams.

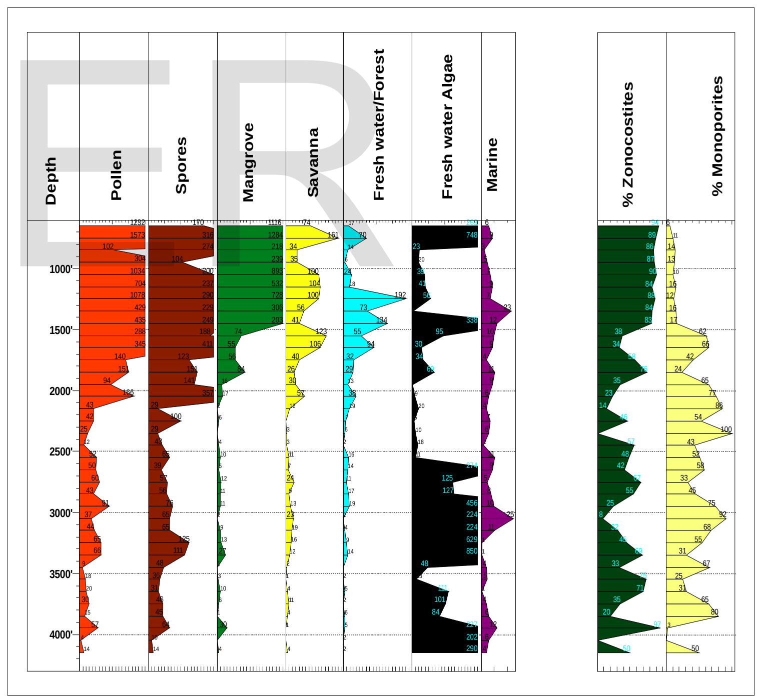

Fig.6: Pollen spectrum for studied well.

Depth 1450 - 450

By the time of deposition of the sequences within this interval, the pollen record indicates that mangrove swamp forest vegetation was now well established, with the consistent and abundant occurrence of *Zonocostites ramonae*. Also recorded was a common to abundant occurrence of fresh water swamp species, *Retitricolporites irregularis, Retibrevitricolporites protudens, Pachydermites diederixi, Gemmamonoporites spp., Magnastriatites howardii, and Verrucatosporites usmensis*, as well as low to abundant occurrences of fresh water algae, *Pediastrum sp.*and *Botryococcus braunii*, coupled with common to high occurrences of lowland rainforest species. There is also an overall increase in the recorded quantities of grass pollen, *Monoporites annulatus*, but this is greatly outweighed by the humid elements causing a marked decrease in the percentage ratio of *Monoporites annulatus* to *Zonocostites ramonae*. portraying the prevalence of wet climate over dry one. A humid climate is therefore inferred for this interval

Table 1: MIC 2 Ecological Abundance

	DEPTH	MANG	SAVA	FWF	FWA	MAR
1	460-550	I69	29	11	65	8
2	550-650	1116	74	17	283	6
3	650-750	1284	161	70	748	9
4	750-850	218	34	14	23	3
5	850-950	239	35	6	20	5
6	950-1050	893	100	24	39	7
7	1050-1150	532	104	18	41	9
8	1150-1250	729	100	192	56	7
9	1250-1350	306	56	73	4	23
10	1350-1450	203	41	134	338	12
11	1450-1550	74	123	55	95	10
12	1550-1650	55	106	94	30	9
13	1650-1750	56	40	32	34	4
14	1750-1850	84	26	29	69	11
15	1850-1950	16	30	13	1	9
16	1950-2050	17	57	38	9	6
17	2050-2150	2	12	19	20	4
18	2150-2250	6	7	13	6	7
19	2250-2350	-	3	6	10	6
20	2350-2450	4	3	2	18	2
21	2450-2550	10	11	16	11	11
22	2550-2650	5	7	14	274	9
23	2650-2750	12	24	11	125	5
24	2750-2850	11	9	17	127	8
25	2850-2950	11	33	19	456	10
26	2950-3050	2	23	2	224	25
27	3050-3150	9	19	4	224	11
28	3150-3250	13	16	9	629	1
29	3250-3350	27	12	14	850	1
30	3350-3450	1	2	-	48	4
31	3450-3550	3	1	2	13	5
32	3550-3650	10	4	5	111	1
33	3650-3750	6	11	2	101	4
34	3750-3850	1	4	6	84	6
35	3850-3950	30	1	5	227	12
36	3950-4050	-	-	2	202	6
37	4050-4150	4	4	2	290	4

MANG= Mangrove, SAVA= Savanna, FWF= Fresh water/Forest, FWA= Fresh water Algae, MAR = Marine

Table 2: Numerical and percentage pollen and spore spectra.

DEPTH (ft)	SPORES	POLLEN	TOTAL	%SPORES	%POLLEN
460-550	77	208	285	**27.0**	**73.0**
550-650	170	1232	1402	**12.1**	**87.9**
650-750	316	1573	1889	**16.7**	**83.3**
750-850	102	274	376	**27.1**	**72.9**
850-950	104	304	408	**25.5**	**74.5**
950-1050	200	1034	1234	**16.2**	**83.8**
1050-1150	237	704	941	**25.2**	**74.8**
1150-1250	290	1078	1368	**21.2**	**78.8**
1250-1350	229	429	658	**34.8**	**65.2**
1350-1450	249	435	684	**36.4**	**63.6**
1450-1550	188	288	476	**39.5**	**60.5**
1550-1650	411	345	756	**54.4**	**45.6**
1650-1750	123	140	263	**46.8**	**53.2**
1750-1850	151	151	302	**50.0**	**50.0**
1850-1950	141	94	235	**60.0**	**40.0**
1950-2050	357	166	523	**68.3**	**31.7**
2050-2150	29	43	72	**40.3**	**59.7**
2150-2250	100	42	142	**70.4**	**29.6**
2250-2350	29	25	54	**53.7**	**46.3**
2350-2450	43	12	55	**78.2**	**21.8**
2450-2550	65	52	117	**55.6**	**44.4**
2550-2650	39	50	89	**43.8**	**56.2**
2650-2750	57	60	117	**48.7**	**51.3**
2750-2850	56	43	99	**56.6**	**43.4**
2850-2950	76	91	167	**45.5**	**54.5**
2950-3050	65	37	102	**63.7**	**36.3**
3050-3150	65	44	109	**59.6**	**40.4**
3150-3250	125	65	190	**65.8**	**34.2**
3250-3350	111	66	177	**62.7**	**37.3**
3350-3450	48	9	57	**84.2**	**15.8**
3450-3550	36	18	54	**66.7**	**33.3**
3550-3650	31	20	51	**60.8**	**39.2**
3650-3750	46	30	76	**60.5**	**39.5**
3750-3850	45	15	60	**75.0**	**25.0**
3850-3950	64	47	111	**57.7**	**42.3**
3950-4050	10	4	14	**71.4**	**28.6**
4050-4150	14	14	28	**50.0**	**50.0**

Table 3: Monoporites annulatus and Zonocostites ramonae composition of MIC-2 Well

DEPTH (m)	MONO	ZONO	TOTAL	%MONO	%ZONO
460-550	29	I69	198	14.6	85.4
550-650	74	1116	1190	6.2	93.8
650-750	161	1284	1445	11.1	88.9
750-850	34	218	252	13.5	86.5
850-950	35	239	274	12.8	87.2
950-1050	100	893	993	10.1	89.9
1050-1150	104	532	636	16.4	83.6
1150-1250	100	729	829	12.1	87.9
1250-1350	56	306	362	15.5	84.5
1350-1450	41	203	244	16.8	83.2
1450-1550	123	74	197	62.4	37.6
1550-1650	106	55	161	65.8	34.2
1650-1750	40	56	96	41.7	58.3
1750-1850	26	84	110	23.6	76.4
1850-1950	30	16	46	65.2	34.8
1950-2050	57	17	74	77.0	23.0
2050-2150	12	2	14	85.7	14.3
2150-2250	7	6	13	53.8	46.2
2250-2350	3	-	3	100.0	0.0
2350-2450	3	4	7	42.9	57.1
2450-2550	11	10	21	52.4	47.6
2550-2650	7	5	12	58.3	41.7
2650-2750	24	12	36	66.7	33.3
2750-2850	9	11	20	45.0	55.0
2850-2950	33	11	44	75.0	25.0
2950-3050	23	2	25	92.0	8.0
3050-3150	19	9	28	67.9	32.1
3150-3250	16	13	29	55.2	44.8
3250-3350	12	27	39	30.8	69.2
3350-3450	2	1	3	66.7	33.3
3450-3550	1	3	4	25.0	75.0
3550-3650	4	10	14	28.6	71.4
3650-3750	11	6	17	64.7	35.3
3750-3850	4	1	5	80.0	20.0
3850-3950	1	30	31	3.2	96.8
3950-4050	-	-	-	0.0	0.0
4050-4150	4	4	8	50.0	50.0

MONO = **Monoporites annulatus,** ZONO= **Zonocostites ramonae**

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Plate 1: Palynological assemblages of MIC 2 Well.

Table 4: Palaeocological groupings and climatic indicators from pollen and spores [13]

Paleaocological Groupings	Miospores	Climatic indicators
Coastal Vegetation	*Echiperiporites estalae*	wet
Mangroves Swamp Forest	*Zonocostites romanae*	wet
Fresh Water Swamp Forest	*Verrutricoporites rotundiporus*	wet
Tidal Estuaries,Creek	Spinizonocolpites sp.	wet
Fresh Water Swamp Forest	*Parchydemite diderixi*	wet
Fresh Water Swamp Forest	*Syncolporites marginatus*	wet
Mangroves Swamp Forest	*Psilatricolporites* sp.	wet
Guinea Lowland Rainforest	*Verrucatosporites* sp.	wet
Mangrove Swamp Forest	*Elaeis gunnensis*	wet
Savanna Vegetation	Aff. *asteraceae*	dry
Savanna	*Monoporites annulatus*	dry
Savanna Vegetation	*Retibrevitricolporites* sp.	dry
Savanna	*Retitricoprites* sp.	dry
Marine	*Spiniferites* sp., *Selenopemphix nephroides*	wet
Marine	*Kiokonsum* sp., *Operculodinium centrocarpum*	wet

4.0 CONCLUSION

In summary, a total of five pollen zones P850, P860, P860-P870, P880 and P920 zones of Evamy et al., (1978) and three major climatic and vegetational regimes occurring within intervals 4142 – 2650, 2650 – 1450, and 1450 – 450 were identified. Interval 2650 – 1450, was the most arid being dominated by the savanna communities while the interval 1450 – 450 was the most humid as it was dominated by the mangrove and forest elements. Lithological and palynological analyses of the Mic-2, well have contributed to the stratigraphic study of the section. A combination of spores and pollen is the basis for dating the section as Late Tertiary. Abundant occurrence of *Monoporites annulatus,* spores of pteridophytes and fungi. in some sections of the well enabled delineation of the sequences that were deposited under wet conditions during the Miocene. Dry conditions were extrapolated by the abundance of *Zonocostites ramonae* in some sections. During this study, six climatic cycles were recognised and used to infer the depositional cycles that indicate recurrent palynogical sequences and vegetation changes based on the sea level change. The wet cycle suggests highstand / transgressive systems tracts. While on the other hand, the dry cycle indicates lowstand systems tracts
The palynological zonation conformed to those of Evamy [7] and Morley [12] and shows that the two zonation schemes can be combined for better resolution. The combination of parameters showed the environments of deposition to be coastal to marginal marine which was further subdivided into coastal deltaic, coastal deltaic inner neritic and inner neritic

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