Journal of Geology & Geophysics
ISSN: 2381-8719
OPEN ACCESS Freely available online

Research Article

Palynostratigraphy, Paleoclimate and Paleoenvironment of a Segment of GBO-04 Well, Onshore Western Niger Delta Basin, Nigeria

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ABSTRACT

Palynological study of 50 ditch samples from a segment of GBO-04 well located onshore western Niger Delta Basin was carried out determine the age of the sediment and reconstruct the paleoclimate and paleodepositional environments. All the analyzed samples were composited at 60 ft. from stratigraphic depth interval of 3010 to 6030 ft. The lithology was made of shale and friable sandstone. Palynological slides were prepared following standard palynological preparation procedure involving sample maceration with hydrochloric (HCl) and hydrofluoric (HF) acids. The samples yielded well preserved, moderately diversified palynomorph assemblages comprising 72 taxa and belonging to pollen, spores, dinoflagellates, acritarch, algae and fungi spores. The stratigraphic distribution of floristic assemblage was highly variable. The assemblage was dominated by pollen and spores. The pollen included *Monoporites annulatus*, *Brevicolporites guinetii*, *Sapotaceoidaepollenites* spp., *Psilatricolporites crassus*, *Psilatricolporites* spp., *Zonocostites ramonae*, *Retitricolporites irregularis*, *Monocolpites marginatus*, *Monocolpites* spp., *Pachydermites diederixi*, *Proxapertites cursus*, *Verrutricolporites* spp., *Ctenolophonidites* spp., *Arecipites exilimuratus*, *Arecipites cf. crassimuratus*, *Striatricolporites catatumbus*, *Canthiumidites* spp., *Chenopodiacaea* spp., *Clavainaperturites clavatus*, *Crototricolporites crotonoisculptus*, *Echiperiporites icacinoides*, *Echiperiporites* spp. and *Inaperturopollenites* spp. The retrieved spores included *Magnastriatites howardi*, *Acrostichum aureum*, *Laevigatosporites* spp., *Polypodiaceoisporites* spp., *Verrucatosporites* spp., *Crassoratitriletes vanraadshooveni* and *Verrucatosporites usmensis*, *Charred graminae curticle*, *Cyathidites* spp. and *Foveotriletes margaritae*. The dinoflagellates included *Achmosphaera* spp., *Andulusiella polymorpha*, *Batiacasphaera* spp., *Selenopemphix nephroides* and *Spiniferites* spp. *Leiosphaeridia* spp. was the only acritarch recovered in the assemblage. The algae were *Botryococcus braunii* and *Pediastrum* spp. Fungi spores and hyphae and charred curticle constituted minor components of the assemblage. The stratigraphic interval was dated Early Miocene (Burgidalian-Langhian) based on the occurrence and distribution of *Pachydmies diederixi*, *Praedopollis flexibilies*, *Crassoretitrilete vanraadshoodveni*, *Psilatricolporites crassus* and *Laevigasporites* spp. The abundant occurrence of pollen and spores typical of low land rain forest in the assemblage indicated tropical paleoclimatic conditions. The distribution pattern of *Monoporites annulatus* (Poaceae) and *Zonocostites ramonae* (Rhizophora) suggested cyclical fluctuations of paleoclimate between wetter and drier phases. The sediments were laid down in lagoons, delta swamps and shallow marine nearshore paleoenvironments.

Keywords: Niger delta; Palynomorphs; Early Miocene; Paleoclimate; Paleoenvironment

INTRODUCTION

The Niger Delta basin is one of the deepest sedimentary basins in the southern part of Nigeria. It is located at the apex of the Gulf of Guinea in central Africa between longitudes 4° and 9°E and latitudes 4° and 9° N. Its depositional history commenced in the Early Cretaceous with the opening of the South Atlantic. It is flanked in the east and northeast by the Cameroon Volcanic Line and the Calabar hinge line, in the west and northwest by Dahomey Basin and Benin hinge line, in the north by Anambra Basin and in the south by the Gulf of Guinea as Figure 1. The basin occupies an aerial extent of about 75,000 km^2. The basin is economically important because it bears a huge amount of petroleum. The Niger Delta is ranked among the world's major petroleum provinces in the world. The Cenozoic clastic wedge contains the 12th largest known accumulation of recoverable hydrocarbons, with reserves

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Received April 14, 2019; **Accepted** May 31, 2019; **Published** June 07, 2019

Citation: Ogbahon OA, Fola-Dara AO, Enweliku DS (2019) Palynostratigraphy, Paleoclimate and Paleoenvironment of a Segment of GBO-04 Well, Onshore Western Niger Delta Basin, Nigeria. J Geol Geophys 2019, 8:463.

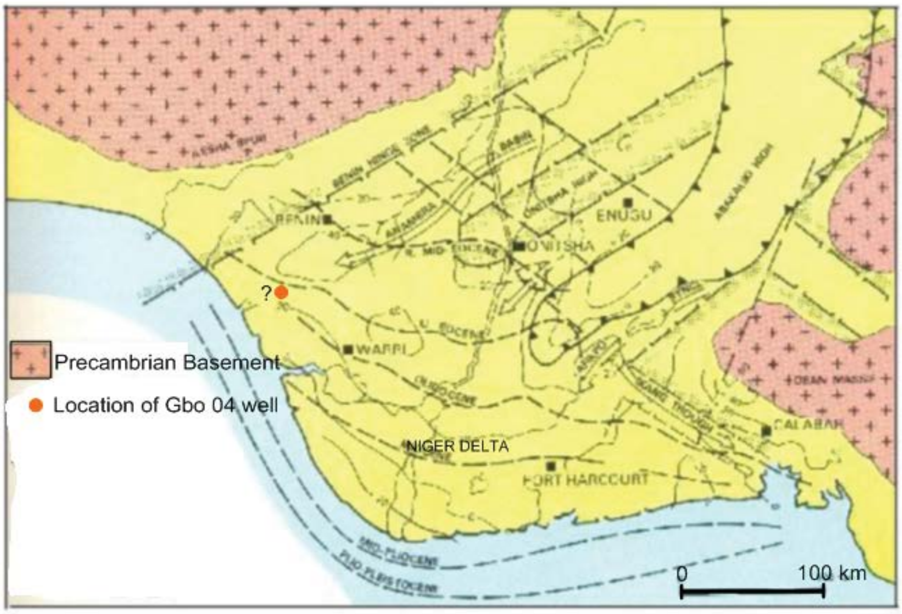


Figure 1: Geologic map of Niger Delta basin showing location of study well.

exceeding 34 billion barrels of oil and 93 trillion cubic feet of gas [1]. The economy of Nigeria largely depends on the oil and gas derived from this basin, accounting for roughly 90 % of her gross foreign earnings. Commercial accumulation of petroleum was first discovered in the basin in 1956 with the drilling of Oloibiri-1 well by Shell-BP. Nigeria joined the ranks of oil producers in 1958, producing about 5,100 barrels per day from Oloibiri field. At present, over 5000 wells have been drilled in the basin. The Niger Delta is ranked the 10th richest in petroleum resources in the world, but so far only the traditional exploration targets including fault, growth fault, and anticlinal traps have been discovered and developed. Nigeria currently produce 2.5 million barrels per day but national target of 4 million barrels per day and 40 billion barrels in reserve by the end of 2020 is yet to be met [2]. If this target is to be achieved, attention has to be shifted to the non-traditional targets such as stratigraphic traps, using high resolution techniques.

Palynology in the oil industry is a stratigraphic tool especially useful in the study of rocks deposited in continental, coastal, and shallow-marine settings [3]. Palynological analyses are used mainly for chronostratigraphic correlations, paleoenvironmental studies, and the evaluation of potential source rocks. The integration of palynology with other geoscience disciplines, such as sedimentology, geophysics, geochemistry, and petro physics, is needed for geological modeling and petroleum system studies, which in turn are essential for planning and developing better exploration strategies and for optimizing reservoir exploitation [3]. This also will enhance detection of hydrocarbon accumulation in subtle traps and permit better prediction of the lateral variability in quality of reservoir rock than is achievable only with the classical litho-seismic stratigraphic approach, thereby leading to increased oil reserves. The study of fossil flora record of sedimentary rocks has diverse range of applications in geology including biostratigraphy, geochronology (to correlate strata and determine the relative age of a bed, horizon, formation or stratigraphic sequence), paleoecology and climate change, organic palynofacies studies, geothermal alteration studies (to examine the color of palynomorphs extracted from rocks to give the thermal alteration and maturation of sedimentary sequences) [4]. This is especially true because the floristic component of layered rocks occur in high abundance permitting the use of only little amount of sample and statistical analysis [3]. Although a lot of bio stratigraphic studies have been carried out by several workers in the Niger Delta Basin [5-9], the information they provide cannot be extrapolated over a long distance because of the very complex nature of stratigraphic architecture occasioned by the numerous synsedimentary faults which mainly deformed and compartmentalized the stratigraphic interval of interest, the Agbada Formation [10,11]. Furthermore, the findings of some of these studies are kept private by the oil companies that did the research because of the rules of confidentiality and proprietary nature of basic information [12] thereby causing a lacuna in the bio stratigraphic database of the Niger Delta Basin. It is the aim of this present study therefore to use palynology to establish the age, the paleoclimate and the paleodepositional environment of the stratigraphic interval penetrated by GBO-04 well in the western onshore Niger Delta.

Evolution and stratigraphy of Niger Delta Basin

The Niger Delta Basin is located in the Gulf of Guinea on the West African continental margin at the southern tip of Nigeria. It occupies the coastal, oceanward part of the Benue Trough hence its evolution has been linked with that of this larger sedimentary complex [13]. The Benue Trough has been identified as the failed arm of the three radial rift systems that met at an R-R-R triple junction in the Gulf of Guinea which was initiated in early Cretaceous as a result of crustal doming [14]. The basin presently occupies the center of the triple junction. The Niger Delta Basin represents the third cycle in the evolution of the trough and its associated basins. The first cycle which took place during Aptian to Santonian led to the evolution of the trough as the failed arm of a rift triple junction associated with the separation of South American and African plates [15]. The Anambra and the Afikpo platforms were situated on either sides of the trough during this period. The second cycle from Santonian to Eocene began after the Santonian folding episode. The Abakaliki Trough was uplifted to form Abakaliki Anticlinorium whilst the Anambra platform was subsided to form the Anambra Basin resulting in the displacement of the trough's depositional axis towards the west. During the Paleocene- Early Eocene, the uplift of Benin and Calabar flanks initiated a major regressive phase [2]. By the end of this cycle, rifting has diminished considerably. The third cycle (Eocene-Recent) brought about the development of the Tertiary/Cenozoic Niger Delta. The general agreement is that the present-day Niger Delta is built on oceanic crust [2]. Evidence for this came from continental reconstruction which indicates an overlap of the present Niger Delta on northeast Brazil. The basin contains upper Cretaceous to Recent fluvial to marine deposits overlying both the faulted crustal blocks of the African continental margin and the oceanic crust [12,16]. The growth of the delta proper began in the Eocene with rapid southwest sediment progradation that led to the formation of major developmental stages, the depobelts. Seven depobelts have been identified in the delta and they include Northern delta, Greater Ughelli, Central swamp I, Central Swamp II and Coastal Swamp II depobelts. Each depobelt usually is fault bounded both at the proximal and distal ends. The accumulation of paralic sediments in each depobelt occurred in response to eustatic sea level oscillations active within the basin during the development of a depobelt [16,17]. The delta complex is deformed by well-developed growth faults and large-scale mud diapirs and its growth is closely related to the development of the diapirs [10]. Most of the sediments in delta derived from the catchment areas of the Niger-Benue river system. The depobelts contained thick progradational and aggradational paralic sequences intercalated with retro gradational marine shale horizons deposited during periods of marine transgression [16,17]. The Niger Delta stratigraphic sequence comprises an upward-coarsening regressive association of Tertiary clastics up to 12 km thick [11]. It is informally divided into three gross lithofacies by namely from the oldest to the youngest the Akata, Agbada and Benin Formations which were deposited in marine, transitional and continental environments, respectively (Figure 2). The three lithostratigraphic units constitute a very thick succession of progradational passive margin wedge [12]. The Akata Formation (Eocene-Recent) is the oldest lithostratigraphic and basal unit composed mainly of marine shale's believed to be the main source rock within the basin [18,19]. It is a marine sedimentary succession that is laid in front of the advancing delta and ranges from 1,968 to 19,680 ft. in thickness [19]. The formation is composed mainly of uniform under-compacted shale's, clays, and silts at the base of the known delta sequence with lenses of sandstone of abnormally high pressure at the top [20]. These streaks of sand are possibly of turbidite origin, and were deposited in holomarine (prodelta to deeper marine) environments. The shale's are rich in both planktonic and benthonic foraminifera and were deposited in shallow to deep marine environments [21]. The base of the sequence in each depobelt is composed of marine shale's and range from Paleocene to Holocene in age. They outcrop offshore as diapirs along the continental slope, and onshore in the northeastern part of the delta, where they are known as the Imo Shale [19]. The Agbada Formation (Eocene–Recent) is characterized by alternating sandstone, siltstone and shale sequence with a thickness of over 3000 m [10,22]. The sandstone facies which range from fine to coarse grained and constitutes the petroleum reservoirs of the basin. These alternating clastics are the truly deltaic portion of the sequence and were deposited in a series of deltaic environment such as the delta-front, delta-topset, and fluvio-deltaic environments [12]. The top of Agbada Formation is defined as the first occurrence of shale with marine fauna that coincides with the base of the continental-transitional lithofacies [23]. The base is a significant sandstone body that coincides with the top of the Akata Formation [21]. Some shale's of the Agbada Formation were thought to be the source rocks. However, Ejedawe

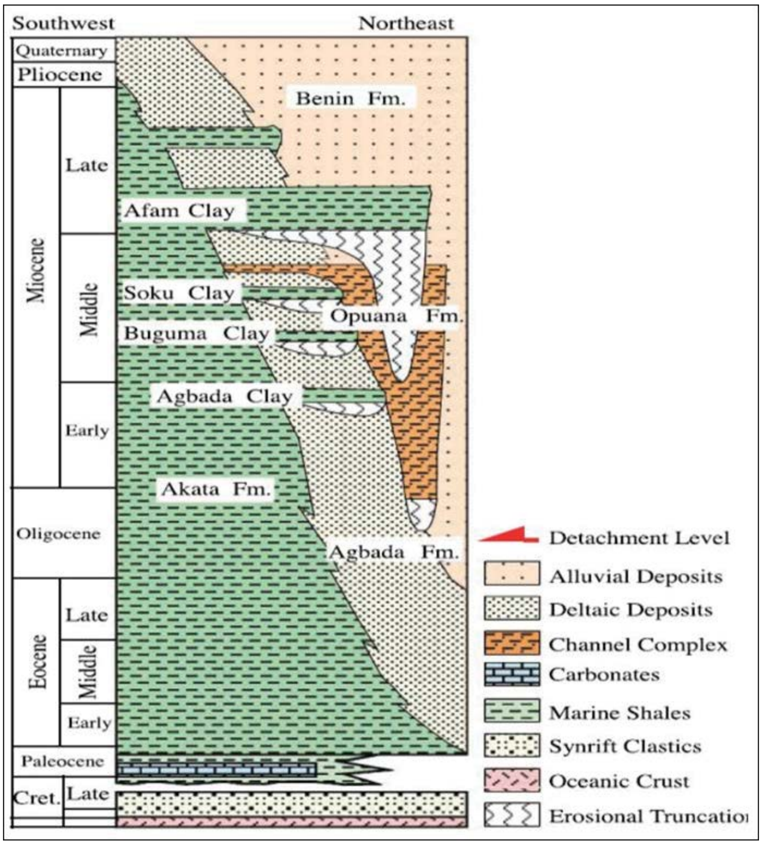


Figure 2: Stratigraphic column of the Niger Delta.

J, deduced that the main source rocks of the Niger Delta are the shale's of the Akata Formation [24]. The Agbada Formation forms the hydrocarbon-prospective sequence in the Niger Delta. As with the marine shale's, the paralic sequence is present in all depobelts, and ranges in age from Eocene to Pleistocene. Most exploration wells in the Niger delta have bottomed in this lithostratigraphic unit. The Benin Formation (Miocene-Recent) is the youngest lithostratigraphic unit in the Niger Delta. It has a minimum thickness of more than 6000 ft. and consists mainly of sand, gravels and back-swamp deposits [10]. The shallowest part of the sequence is composed almost entirely of continental sand. The sands and sandstones are coarse-grained, sub-angular to well-rounded and are very poorly sorted. It also contains streaks/lenses of shale, clays, etc. The sands and sandstones are white or yellowish-brown because of limonitic coatings [10]. It was deposited in alluvial or upper coastal plain environments following a southward shift of deltaic deposition into a new depobelt. The oldest continental sands are probably Oligocene, although they lack fauna required to date them directly. The formation thins towards the basin and ends near the shelf edge.

MATERIAL AND METHODS

A total of 100 ditch cutting samples from GBO-04 well in the Niger Delta Basin collected at 60 ft. interval were composited to 50 samples for this study. All the samples came from 3010-6010 ft. depth interval of GBO-04 well. The samples were stored in sample bags with depth label to avoid contamination. They were firstly washed with distilled water to remove the drilling mud stains and this was followed by sample administration. Detailed properties of rock samples including as grain size, sorting, shape and mineral composition were observed and documented. Exactly 10 g of each sample was broken to tiny bits (about 4 mm) with mortar and pestle, and transferred to labeled plastic breaker. The samples were soaked with excess 10% hydrochloric acid (HCl) to remove any carbonate that may be present in the samples and thereafter completely neutralized with distilled water prior to treatment with hydrofluoric acid. Following this, 40 % HF was added to samples and left for 24 hours to ensure complete digestion of silicate minerals and thereafter completely with distilled water. Fluoro-silicate compounded result from the last reaction was removed by treating sample with 10 % HCl, followed by complete neutralization with distilled water. Samples were not subjected to oxidation to avoid selective destruction of palynomorphs. The decanted samples were sieved using a 200 µm mesh filter to separate the residual rock particle and mega fossils from the finer disaggregated material. The filtrate (i.e. finer disaggregated material) was thoroughly washed with distilled water using the 10 µm mesh nylon sieve. The palynomorphs were separated from the residue using Zinc Bromide gel ($ZnBr_2$) and centrifugation. The $ZnBr_2$ was completely washed off by addition of distilled water and centrifugation. Pipette was used to place one or two drops of the residue at the center of each slide and allowed to dry under ultraviolet light. A single drop of warn petropoxy resin was placed on the cover slip and then placing it over the residue-bearing slide. The slide is allowed to stay for about 10 minutes to ensure that the slide is firmly glued to the cover slip. The prepared palynological slides were scanned under National Optical Microscope at Mosunmlu Nigeria Limited, Lagos. Microscopy involved preliminary examination of the prepared slides to identify flora followed by a quantitative listing of the palynomorphs. Where possible, a total of 200 palynomorphs were counted per sample during microscopy. Identification of fossil flora forms was aided by comparison of morphological features of specimens with reference illustrations from published literature [5]. The slides are archived in the Department of Applied Geology, The federal University of Technology, Akure, Nigeria. The palynological data was integrated with well gamma ray log (lithology log) and plotted in an assemblage chart using Strata bug software.

RESULTS AND DISCUSSION

Palynological assemblages

The stratigraphic distribution of the palynomorph assemblages retrieved from GBO-04 well in western onshore Niger Delta Basin is shown in Figures 3 and 4. The analyzed sediments of GBO-04 well yielded moderately rich, well preserved and diversified palynomorphs. A total number of 662 counts of palynomorphs were recorded in 50 slides. Of these, 40 were simply identified as either pollen indeterminate or fungi spore while the rest 622 counts were identified to genus or species level. The total palynoflora assemblages of GBO-04 well were comprised of 72 taxa. The 72 palynologiccal taxa were made up of 42 pollen grains, 12 spores, 2 freshwater algae, 16 dinoflagellates, and fungal spores. Photomiicrographs of some important taxa retrieved from the well are shown in Figures 3 and 4.

Quantitatively, the total assemblages were dominated by angiosperm pollen, followed by pteridophytic spores and dinoflagellages cysts. The encountered pollen grains were *Monoporites annulatus*, *Brevicolporites guinetii*, *Sapotaceoidaepollenites* spp., *Psilatricolporites crassus*, *Psilatricolporites* spp., *Zonocostites ramonae*, *Retitricolporites irregularis*, *Monocolpites marginatus*, *Monocolpites* spp., *Pachydermites diederixi*, *Proxapertites cursus*, *Verrutricolporites* spp., *Ctenolophonidites* spp., *Arecipites exilimuratus*, *Arecipites cf. crassimuratus*, *Striatricolporites catatumbus*, *Canthiumidites* spp., *Chenopodiacaea* spp., *Clavainaperturites clavatus*, *Crototricolporites crotonoisculptus*, *Echiperiporites icacinoides*, *Echiperiporites* spp., *Inaperturopollenites* spp., *Perfortricolpites digitatus*, *Pollen indeterminate*, *Praedapollis flexibilis*, *Praedapollis* spp., *Proteacidites cooksonni*, *Psilatriporites rotundus*, *Psilatriporites* spp., *Racemonocolpites hians*, *Retibrevitricolporites* spp., *Retimonocolpites* spp., *Retitricolporites guinensis*, *Retitriporites* spp., *Spirosyncolpites bruni*, *Striamonocolpites rectostriatus*, *Striatricolpites undulates*, and *Verrutricolporites rotundiporus*. The distribution of the pollen grains is highly variable. Some taxa such as *Monoporites annulatus* and *Monocolpites* spp. occurred in high abundance. For example, the occurrence of *Monoporites* spp. increased stratigraphically up section although sporadic (Figure 5). The spores were *Magnastriatites howardi*, *Acrostichum aureum*, *Laevigatosporites* spp., *Polypodiaceoisporites* spp., *Verrucatosporites* spp., *Crassoratitriletes vanraadshooveni* and *Verrucatosporites usmensis*, *Charred graminae curticle*, *Cyathidites* spp., *Foveotriletes margaritae*, and fungal spores and hyphae. The spore's abundance was dominated by *Laevigatosporites* spp., *Acrostichum aureum* and *Polypodiaceoisporites* spp. Fungi spores and hyphae occurred rather sporadically and sparsely. The two algae present in the studied samples are *Botryococcus braunii* and *Pediatrium* spp. with the latter occurring only close to the top of the studied interval. The recovered *Dinoflagellates* included *Achmosphaera* spp., *Andulusiella polymorpha*, *Batiacasphaera* spp., *Ceratiopsis granulostriata*, *Clestosohaeridium* spp., Dinocyst indeterminate, Dinoflagellate cysts, *Lejeunecysta* spp., *Lingulodinium*

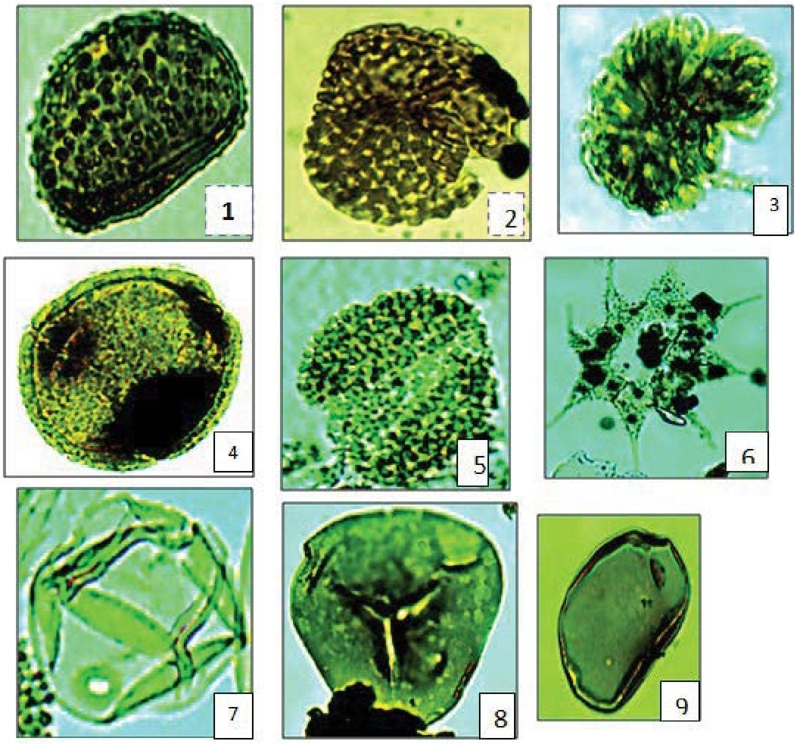


Figure 3: Photomicrographs of some important palynomorphs retrieved from GBO-04 well with depth of recovery in brackets. (1) *Verrucatosporites* spp. (3550-3610 ft.), (2) *Crassoretitriletes vanraadshooveni* (3370-3430 ft.), (3) *Botryococcus braunii* (5170-5230 ft.), (4) *Psilatricolporites crassus* (4810-4870 ft.), (5) *Racemonocolpites hians* (3090-3550 ft.) (6) *Pediastrum* spp. (3010-3070 ft.).(7) *Monoporites annulatus* (3250-3310 ft.), (8) *Acrostichum aureum* (3790-3850 ft.), (9) *Laevigatosporites* spp. (4810-4870 ft.)

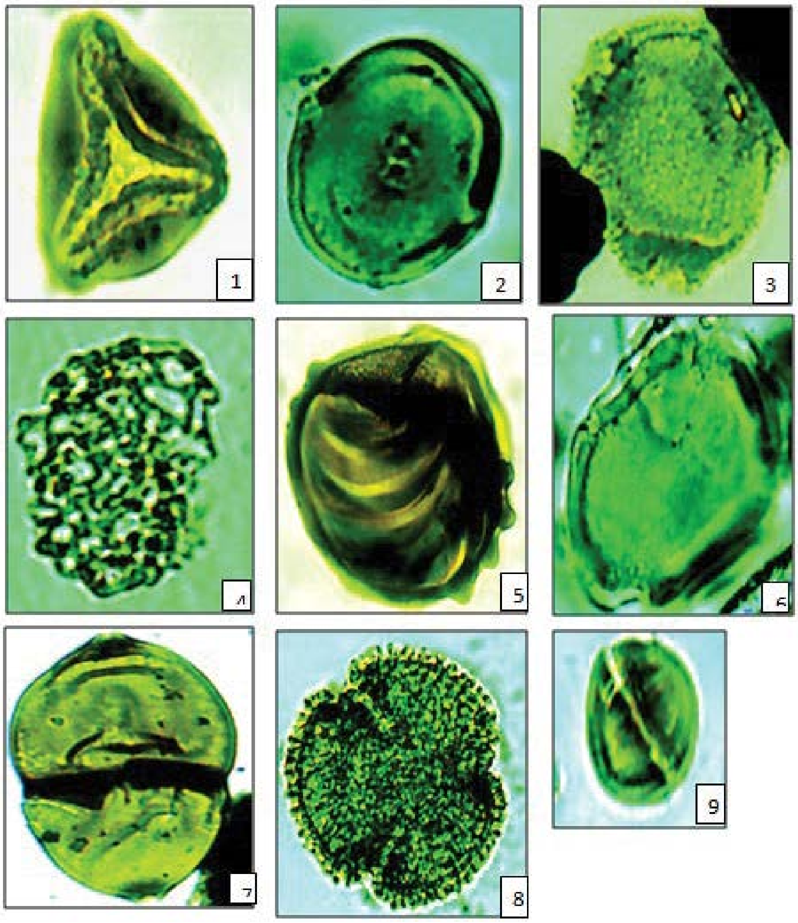
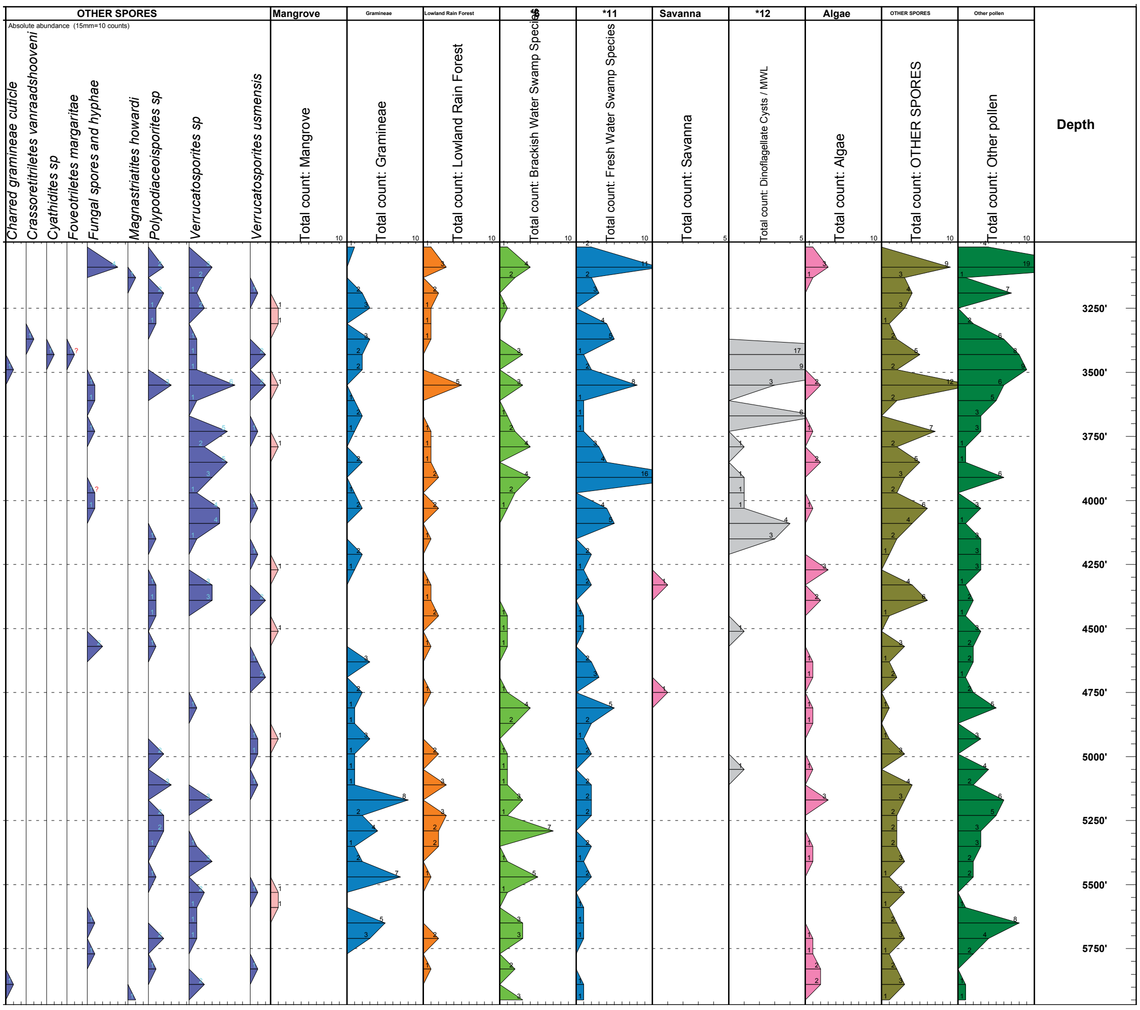


Figure 4: Photomicrographs (400x) of some important palynomorphs retrieved from GBO-04 well (depth of recovery in parentheses). (1) *Polypodiaceoisporites* spp. (3550-3610 ft.) (2) *Sapotaceoidaepollenites* spp. (3430-3490 ft.), (3) *Retibrevitricolporites obodoensis* (3910-3970 ft.), (4) *Praedapollis flexibilis* (5410-5470 ft.), (5) *Magnastriatites howardi* (3070-3130 ft.), (6) *Pachydermites diederixi* (3430-3490 ft.), (7) Fungal spore (3070-3130 ft.), (8) *Retitricolporites irregularis* (4990-5050 ft.), (9) *Zonocostites ramonae* (3790-3850 ft.).



Note: The variations in lithologies on the left hand side of the chart.
Figure 5: Palynological assemblage chart of GBO-04 well.

machaerophorum, *Nematosphaeropsis* spp., *Paleocystodinium* spp., *Phelodinium* spp., *Polysphaeridium* spp., *Selenopemphix nephroides* and *Spiniferites* spp. Of these, Dinocyst indeterminate, Dinoflagellate cysts and *Paleocystodinium* spp. dominated the assemblage. The acritarch recorded is *Leiosphaeridia* spp. Most occurrences of the Dinoflagellate cysts were confined to the interval 4270 to 3370 ft. Both pollen and spores occurred almost consistently throughout the stratigraphic succession represented by GBO-04 well except for non-occurrence at a few horizons which may be attributed to lack of preservation as a result of oxidation.

Consideration of paleoecology of palynomorph types

On the basis of Figure 3 and 4 pale ecological groupings, the whole palynoflora assemblages retrieved from GBO-04 well can be characterized into five ecological gatherings to be specific freshwater swamp and water edges species (FWSP), brackish water swamp species (BWSP), lowland rainforest species (RAIN), savannah species (SAVANN), and marine alongside fungal elements and other forms without specific ecological affinities (Table 1). These groupings were dependent on the botanical affinities of the fossil palynoflora recouped from the well with new plants or closest living relatives. The freshwater swamp and water edge species were typified by *Ctenolophonidites costatus*, *Laevigatosporites* spp., *Retitricolporites irregularis* and *Striatricolpites catatumbus*. Of these, *Laevgatosporites* Spp. showed the most consistent occurrence, followed by *Retitricolporites irregularis*. The records of the other two are rather sporadic. The brackish water swamp species were dominated by *Acrostichum aureum*, *Psilatricolporites crassus*, *Proxapertites cursus* and *Verrutricolporites* spp. listed in order of decreasing abundance. Large amounts of fossil pollen (mostly Angiosperms) having botanical affinities that can be assigned to tropical rain forest plants were also retrieved from the well. Noteworthy ones are *Brevicolporites guinetii*, *Polypodiaceoisporites* spp. and *Sapotaceoidaepollenites* spp. The savannah elements were typified by *Monoporites annulatus* and *Proteacidites cooksonni*. The occurrence of the former was more consistent in the studied stratigraphic succession than that of the latter which was quite sparse and sporadic, occurring only in the upper part of the well (Figure 5). *Monoporites annulatus* is grass (or Graminae) pollen that can be traced botanically to the family *Gramineae* (or *Poaceae*) and is mainly confined to more open vegetation, coastal savannas and river valleys [5]. The main mangrove elements recovered from the investigated well section included the taxa *Zonocostites ramonae*, *Acrostichum aureum*, and *Psilatricolporites* spp. The species, *Acrostichum aureum* has been identified as a principal fern currently growing within mangrove vegetation [26,27]. According to these authors, *Acrostichum aureum* is adapted to coastal areas associated with mangrove vegetation, areas inundated with saline waters, open salt marshes, coastal swamps and areas along estuarine rivers.

Marine-derived elements included *Dinoflagellates* and a single

Table 1: Ecological groups, species diversity, abundance and marine index values of Gbo-04 well.

S/N	Depth (ft)	FWSP	BWSP	SAVANN	RAIN	FUNG	ALG	MAR.	PMI	SD.	Frequency
1	3010-3070	3	0	1	1	0	1	0	100	6	8
2	3070-3130	15	7	6	9	4	3	0	100	21	64
3	3130-3190	3	2	0	0	0	1	0	100	5	8
4	3190-3250	3	0	2	2	0	0	0	100	11	16
5	3250-3310	0	2	3	1	0	0	0	100	5	8
6	3310-3370	4	1	0	1	0	0	0	100	8	10
7	3370-3430	5	0	3	3	0	0	0	106	10	16
8	3430-3490	1	3	2	0	0	0	17	141	17	32
9	3490-3550	2	2	2	0	0	0	10	133	16	27
10	3550-3610	10	4	0	5	1	2	3	108	20	39
11	3610-3670	1	0	1	0	1	0	0	100	7	9
12	3670-3730	1	2	2	0	0	0	7	144	10	16
13	3730-3790	3	2	2	2	1	2	0	100	10	20
14	3790-3850	3	5	0	0	0	0	0	100	6	11
15	3850-3910	6	0	2	1	0	2	0	100	6	15
16	3910-3970	8	3	0	0	0	0	1	106	5	18
17	3970-4030	0	2	1	0	1	0	1	117	5	6
18	4030-4090	5	1	2	2	1	1	1	106	12	19
19	4090-4150	5	0	0	0	0	0	4	129	6	14
20	4150-4210	0	0	0	1	0	0	3	138	7	8
21	4210-4270	2	0	2	0	0	0	0	100	4	7
22	4270-4330	4	1	2	0	0	3	0	100	7	10
23	4330-4390	2	0	1	1	0	0	0	100	5	7
24	4390-4450	2	0	0	2	0	2	0	-	6	10
25	4450-4510	0	1	0	2	0	0	0	100	5	5
26	4510-4570	1	2	0	0	0	0	1	100	6	7
27	4570-4630	0	1	0	1	2	0	0	100	6	7
28	4630-4690	3	0	3	0	0	1	0	100	5	8
29	4690-4750	4	0	0	0	0	1	0	100	4	7
30	4750-4810	0	1	3	1	0	0	0	100	5	6
31	4810-4870	6	4	1	0	0	1	0	100	9	17
32	4870-4930	3	2	1	0	0	1	0	100	5	6
33	4930-4990	1	1	3	0	0	0	0	100	7	9
34	4990-5050	2	1	1	2		0	0	100	5	7
35	5050-5110	1	1	1	0		1	1	100	7	8
36	5110-5170	2	1	1	3		0	0	100	6	10
37	5170-5230	5	6	8	0		3	0	100	10	28
38	5230-5290	2	6	2	3		0	0	100	8	17
39	5290-5350	0	7	4	2		0	0	100	9	18
40	5350-5410	3	0	1	2		1	0	100	9	10
41	5410-5470	2	1	2	0		1	0	100	7	10
42	5470-5530	2	5	5	1		0	0	100	7	14
43	5530-5590	0	4	0	0		0	0	100	4	7
44	5590-5650	1	1	0	0		0	0	100	4	4
45	5650-5710	1	3	5	1	1	0	0	100	9	19
46	5710-5770	2	3	3	3		1	0	100	10	15
47	5770-5830	1	0	0	0	1	1	0	100	4	4
48	5830-5890	2	2	0	1		2	0	100	5	6
49	5890-5950	3	0	0	0		2	1	100	5	7
50	5950-6010	3	3	0	0		0	0	100	6	6

Note: FWSP: Fresh Water Swamp Species; BWSP: Brackish Water Swamp Species; SAVANN: Savannah Species; RAIN: Lowland Rainforest Species, FUNG: Fungi; ALG: Algae; PMI: Palynological Marine Index [(Rm/Rt +1) × 100]; Where: RM: Richness of Marine Palynomorphs (Dinoflagellates, Acritarch and Foraminiferal Wall Linings) Counted as the Number of Taxa Per Sample RT: Richness of Terrestrial Palynomorphs (Sporomorphs); SD: Species Diversity.

taxon of archritarch *Leiosphaeridia* spp. They were observed to be commonly associated with the mangrove pollen/spores component of this setting. The *Dinoflagellates* identified ranged from those adapted to shallow and open marine environments, such as *Lejeunecysta*, *Lingulodinium* and *Paleocystodinium* for shallow marine to *Polysphaeridium* and *Spiniferites* for the relatively open marine settings [17]. The records of marine elements in the studied stratigraphic succession were mainly restricted to the upper part of the section in the interval between 5050-5110 ft. and 3430-3490 ft. There is however a scanty sporadic occurrence below this interval. The maximum diversity (7) and abundance (14) of marine elements was recorded at a depth slice of 3430-3490 ft. The other lesser peak abundance occurred at 4090-4150 ft. horizon (Table 1).

Palynological zonation

Palynology, because of its occurrence in wide spectrum of depositional environments, its abundance in the rock record, and wide age range is veritable tool for biostratigraphic and peleoecological studies [4]. Palynological chronostratigraphic zones were erected dependent on the identification of some key parameters of fossil palynotaxa like first appearance datum (FAD), last appearance datum (LAD), peak development and their absence. Some stratigraphic marker palynomorphs retrieved from the well section facilitated zonation. The studied interval 3010 to 5950 ft. was sub divisible into three zones: XI, XII and XIII zones. The XI, XII and XIII zones corresponded with the subzone P670, P680 P720 [6]. The recognized zones are discussed below:

Zone: XI

Subzone: P670

Interval: 6010-5170 ft.

Age: Early Miocene

Diagnosis: This is the first and oldest zone in the studied section GBO-04 well. The top of zone XI is marked by the quantitative base occurrence of *Pachydermites diederixi* in 5170-5230 ft. slice which coincided with the base of Zone XII. The age of the zone is Burgidalian of Early Miocene which is also equivalent to the subzone P670 [6]. The highest occurrences were seen for *Acrostichum aureum*, *Monoporites annulatus*, *Verrucatosporites* spp. and *Psilatricolporites Crassus.*

The zone is delineated by the presence of *Praedopollis flexibilis* at depth 5410-ft. The lithology of this interval is composed mainly of shale with thin sandstone intercalations.

Zone: XII

Subzone: P680

Interval: 5170-3370 ft.

Age: Early Miocene

Diagnosis: The top of zone XII is identified by the base or first appearance datum (FAD) of *Crassoretitriletes vanraadshooveni* which is the base of zone XIII. The base of the zone is defined by the quantitative first appearance datum of *Pachydermites diederixi* at 5170-5230 ft. The age of the zone is Burdigalian of Early Miocene and is equivalent to the subzone P680 of [6]. The zone is characterized by the Peak occurrence of *Laevigatosporites* spp. within a depth interval of 3910-3970 ft. and marked by abundant *Psilatricolporites crassus* (4810-4870 ft.). The zone is characterized by low occurrence of *Achomosphaera* spp., *Andulusiella polymorpha*, *Arecipites cf. crassimuratus*, *Arecipites* spp., *Batiacasphaera* spp., *Brevicolporites guinetii*, *Ceratiopsis granulostriata*, *Charred gramineae cuticle*, *Chenopodiaceae* spp., *Clavainaperturites clavatus*, *Cleistosphaeridium* spp., *Crassoretitriletes vanraadshooveni*, *Crototricolporites crotonoisculptus*, *Cyathidites* spp., Dinoflagellate cysts, *Echiperiporites icacinoides*, *Foveotriletes margaritae*, *Inaperturopollenites spp*., *Lejeunecysta* spp., *Monocolpites marginatus*, *Nematosphaeropsis* spp., *Pachydermites diederixi*, *Paleocystodinium* spp., *Pediastrum* spp., *Perfortricolpites digitatus*, *Phelodinium* spp., *Polysphaeridium* spp., *Praedapollis* spp., *Proteacidites cooksonni*, *Proteacidites cooksonni*, *Proxapertites cursus*, *Psilatricolporites crassus*, *Psilatriporites rotundus*, *Psilatriporites* spp., *Retimonocolpites* spp., *Retitricolporites guinensis*, *Retitriporites* spp., *Selenopemphix nephroides*, *Spiniferites* spp., *Striamonocolpites rectostriatus*, *Striatricolpites undulatus*, *Verrutricolporites rotundiporus* and a high occurrence of *Acrostichum aureum*, *Botryococcus braunii*, *Laevigatosporites* spp., *Monocolpites* spp., *Monoporites annulatus*, Pollen indeterminate, *Polypodiaceoisporites* spp., *Verrucatosporites* spp., *Verrucatosporites usmensis*, *Polypodiaceoisporites* spp., *Verrutricolporites rotundiporus*.

Zone: XIII

Subzone: P720

Interval: 3370-3010 ft.

Age: Early Miocene

Diagnosis: This is the youngest zone recognized in the studied section of the GBO-04 well. The top of zone XIII was not encountered but its base is at 3370-3430 ft. and it is defined by the base of *Crassoretitriletes vanraadshooveni* at the top of subzone XII. The age of the zone is Langhian of Early Miocene and is equivalent to the subzone P720 [6]. The zone is characterized by low occurrence of *Zonocostities ramonae*, *Pediastrum* spp., *Perfortricolpites digitatus*, Pollen indeterminate, *Proxapertites cursus*, *Psilatricolporites Crassus*, *Psilatricolporites* spp., *Retitricolporites irregularis*, *Retitricolporites* spp., *Retitriporites* spp., *Striamonocolpites rectostriatus*, *Striatricolpites undulatus*, and *Verrucatosporites usmensis*. *Laevigatosporites* spp., *Monocolpites* spp. and *Monoporites annulatus* attained their highest occurrence in this zone.

4.4 Paleoenvironmental interpretation

Paleoenvironmental reconstruction involves the study of periodic changes in environment over geologic time and is an integral part of palynological research [28]. Climate exerts a primary control on vegetation and therefore temporal changes in paleoclimate can be interpreted by studying variations in vegetation. The paleoenvironmental deductions are dependent upon the variation in the lithology (mudstone/sand ratio), abundance and diversity of pollen and spores, presence or absence of marine elements (dinoflagellates and acritarch), algae and fungi spore [25]. Environmental changes are usually reflected in the palynological assemblages [29]. It is on this ground that the composition and relative proportions of different groups of palynomorphs are utilized in this study for interpretation of paleo environment. The major groups used in the study are pollen/spores and dinoflagellates, and other associated elements. The studied stratigraphic section of the well is subdivided into three segments based on the distribution of marine elements dinoflagellates and acritarch (Figure 3), temporal variations between *Zonocostites ramonae* (representative mangrove element) and *Monoporites annulatus* (representative savannah element) (Table 2).

Table 2: *Monoporites annulatus* and *Zonocostites ramonae* composition of GBO-04 well.

S/n	Depth (ft.)	*Monoporites annulatus*	*Zonocostites ramonae*	Total	% *Monoporites annulatus*	% *Zonocostites ramonae*
1	3010-3070	1	-	1	100	0
2	3070-3130	6	3	9	66	34
3	3130-3190	-	-	-	-	-
4	3190-3250	2	-	2	100	0
5	3250-3310	3	1	4	75	25
6	3310-3370	-	1	1	-	100
7	3370-3430	3	-	3	100	0
8	3430-3490	2	-	2	100	0
9	3490-3550	2	2	4	50	50
10	3550-3610	-	1	1	0	100
11	3610-3670	1	-	1	100	0
12	3670-3730	2	-	2	100	0
13	3730-3790	2	-	2	100	0
14	3790-3850	-	1	1	0	100
15	3850-3910	2	-	2	100	0
16	3910-3970	-	-	-	-	-
17	3970-4030	1	-	1	100	0
18	4030-4090	2	-	2	100	0
19	4090-4150	-	-	-	-	-
20	4150-4210	-	-	-	-	-
21	4210-4270	2	-	2	100	0
22	4270-4330	2	1	3	66.7	33.3
23	4330-4390	-	-	-	-	-
24	4390-4450	-	-	-	-	-
25	4450-4510	-	-	-	-	-
26	4510-4570	-	1	1	0	100
27	4570-4630	-	-	-	-	-
28	4630-4690	3	-	3	100	0
29	4690-4750	-	-	-	-	-
30	4750-4810	2	-	2	100	0
31	4810-4870	1	-	1	100	0
32	4870-4930	1	-	1	100	0
33	4930-4990	3	-	3	100	0
34	4990-5050	1	-	1	100	0
35	5050-5110	1	-	1	100	0
36	5110-5170	1	-	1	100	0
37	5170-5230	8	-	8	100	0
38	5230-5290	2	-	2	100	0
39	5290-5350	4	-	4	100	0
40	5350-5410	1	-	1	100	0
41	5410-5470	2	-	2	100	0
42	5470-5530	5	-	5	100	0
43	5530-5590	-	3	3	0	100
44	5590-5650	-	1	1	0	100
45	5650-5710	5	-	5	100	0
46	5710-5770	3	-	3	100	0
47	5770-5830	-	-	-	-	-
48	5830-5890	-	-	-	-	-
49	5890-5950	-	-	-	-	-
50	5950-6010	-	-	-	-	-

Zone 1 (5950- 4150 ft.): Lagoonal/estuarine/delta plain environments

This segment contained the oldest stratigraphic successions from the deepest section of the well between 5950 ft. and 4150 ft. The interval is characterized by high abundant record of *Monoporites annulatus* (*Poaceae*) that signifies dry climatic conditions and a low frequency of *Zonocostites ramonae* (*Rhizophora*) that signifies wet and warm (humid) climatic conditions which occurred only at depth slice of 5590-5530 ft. with a total of 2 counts, suggesting a predominantly dry climatic condition during the time of sediment deposition. *Zonocostites ramonae* is known to be produced by different species of the genera *Rhizophoracaea* namely *Ceriops*, *Bruguiera* and *Carallia*. However, the taphonomic condition of fossil pollen does not permit discrimination between pollen grains of various species. Within the depth slice of 5530-5590 ft. *Rhizophora* (*Zonocostites ramonae*) has a maximum record of 100 % and within this interval, there is a complete absence of *Poaceae* (*Monoporites annulatus*) indicating a brief period of wet climatic condition (Table 2). This probably indicates complete replacement of grass by the rainforest vegetation during this brief interval, at least in the vicinity of depositional site. The record of grass pollen in this interval is dominated mainly by *Monoporites annulatus* with subordinates or scarce occurrence of *Proteacidites cooksonii* at a depth of 4810-4870 ft.

The zone is characterized by high percentage of ferns spore ranging from 0-100 %. The record of Furthermore, the common occurrence of other brackish water swamp species represented by *Acrostichum aureum*, *Psilatricolporites Crassus* and *Verrutricolporites* spp. within the depth slice suggested development of dense coastal vegetation. In addition, the zone is marked by near complete absence of marine elements, except for the single record of the *Acritarch*, *Leiosphaerdia* spp. within the 4510-4570 ft. depth slice and a single count of *Polysphaeridium* spp. (Dinoflagellates) at the level of 5050-5110 ft. The near complete absence of marine indicator species (*Dinoflagellates* and *Acritarch*) alongside the high frequency of Algae (*Botryococcus braunii*) which is a fresh water indicator, and common occurrence of brackish water species signify lagoonal or estuarine to delta plain environment of sediment deposition. The inferred depositional environment is corroborated by the low palynological marine index (PMI) of this zone, further suggesting minimal marine influence during the period of sedimentation (Table 1). The sporadic and low record of freshwater algae *Botryococcus braunii* within the zone suggests intermittent freshwater influx from rivers and stream into the site of deposition. The common to abundant records of lowland rain forest palynomorphs represented by *Polypodiaceoisporites* spp., *Brevitricolporites guinetti*, *Potaceoidaepollenites* spp. and *Verrutricolporites rotundipotes* as well as the high frequency of *Monoporites annulatus* which is a typical grass pollen suggests that the vegetation consisted of lowland rain forest vegetation with patches of grass vegetation occupying the spaces between them while a thick mangrove/coastal vegetation strived close to the sea. The zone is also characterized by highly variable pollen/spore ratio, with roughly equal the proportions of pollen and spores (Table 3).

Zone II (4150-3430 ft.): Nearshore Shallow marine/swamp/ lagoon

The zone was marked by high frequencies of pollen and spores but the pollen grains occur more consistently compared to the spores, only missing at the 3910 ft. depth. It was also noted that at instances where the spores were absent they were compensated by higher frequency of pollen and vice-versa. As in the previously defined Zone I, there was dominance of *Poaceae* (*Monoporites annulatus*) over *Rhizophora* (*Zonocostites ramoae*) in the zone. The zone was characterized by upward increase in species diversity and frequencies of palynomorphs per sample (Table 1). Furthermore, the zone was characterized by high diversity of marine elements with abundance and diversity increasing stratigraphically up-section. The maximum diversity of marine elements (9 taxa) in the zone occurred at depth of 3430 ft. with counts of 17 marine palynomorphs whereas diversity and frequency at the base of the zone was 3 and 3 respectively. Generally, species diversity and frequency of palynomorphs within the zone followed the same trend, increasing from 7 and 8 at the base of zone II (4150-4210 ft.) to 17 and 32 respectively at the top. This stratigraphic increase in the diversity of marine indicators suggested a rising sea level and increasing paleowater depth which possibly reflects marine transgressive event resulting in colonization of hitherto continental paleodepositional site by open marine taxa like *Polysphaeridium* and *Spiniferites*. Such variations in paleowater depths may have been caused by either eustatic changes or sedimentological factors such as witching of delta lobes [30]. The occurrence of *Z. ramonae* was rather sporadic suggesting alternation of dry and wet climatic conditions during the deposition of the sedimentary succession within the zone. The deduced intermittent wet and dry paleoclimatic condition was corroborated by the sporadic occurrence of fungi spores and hyphae as well as charred Gramineae curticle in the interval 3490 to 3550 ft. within the zone which was indicative of warm humid and dry/hot climatic conditions respectively. Thus, the paleoclimatic conditions during sediment deposition were marked by alternation of dry and wet conditions. The sporadic occurrence of fungi spore within the zone suggested warm humid tropical condition. According to Rao et al. [26], fungi spores and their fruiting bodies, which are usually abundant in mesophytic forests of tropical and subtropical climate, require heavy rain fall for their development. The rain forest species occurring within the zone were *Sapotaceoidaepollenites* spp., *Polypodiaceoisporites* spp., and *Brevicolporites guinetii*, listed in order of decreasing abundance.

The FWSP occur consistently within the zone and are more abundant compared with the rather sporadic occurrence of BWSP, suggesting an expansion of river flood plain vegetation during marine transgressive event. The FWSP with the zone were represented mainly by *Laevigatosporites* spp., *Retitricolporites irregularis*, *Botryococcus braunii* and *Striatricolpites catatumbus* while the brakish water swarm species were represented by *Acrostichum aureum*, *Zonocostites ramonae*, *Proxapertites cursus*, and *Psilatricolporites Crassus*. Also, the zone contained a few counts of *Arecaceous* pollen (Palmae) represented by *Arecipites* spp., *Monocolpites marginatus* and *Racemoncolpite hians*. Other palynomorphs present in the zone included *Retitricolporites guinensis* of unknown affinity. A few counts of freshwater algae *Botrococcus braunii* occurred sporadically (Figure 3 and Table 1). Abundant record of palm pollen in palynological assemblage which can be observed close to the top of zone I at depth interval of 4330 to 4150 ft. suggested the incipient stage of marine transgression and is marked by the appearance of *Arecipites* and *Monocolpites*. According to Rull [3], the peak frequency of palm pollen was usually recorded at the commencement of sea

Table 3: Numerical and percentage pollen and spores spectra.

S/n	Depth (ft)	Spores	Pollen	Total	% Spores	% Pollen	Ratio p/s
1	3010-3070	9	19	28	32.14	67.86	2.1
2	3070-3130	3	1	4	75	25	0.33
3	3130-3190	4	7	11	36.36	63.64	1.75
4	3190-3250	3	-	3	100	0	0
5	3250-3310	1	2	3	33.33	66.67	2
6	3310-3370	2	6	8	25	75	3
7	3370-3430	5	8	13	38.46	61.54	1.6
8	3430-3490	2	9	11	18.18	81.82	4.5
9	3490-3550	12	6	18	66.67	33.33	0.5
10	3550-3610	2	5	7	28.57	71.43	2.5
11	3610-3670	-	3	3	0	100	-
12	3670-3730	7	3	10	70	30	0.42
13	3730-3790	2	1	3	66.67	33.33	0.5
14	3790-3850	5	1	6	83.33	16.67	0.2
15	3850-3910	3	6	9	33.33	66.67	2
16	3910-3970	2	-	2	100	0	0
17	3970-4030	6	3	9	66.67	33.33	0.5
18	4030-4090	4	1	5	80	20	0.25
19	4090-4150	2	3	5	40	60	2.5
20	4150-4210	1	3	4	25	75	0.3
21	4210-4270	-	3	3	0	100	-
22	4270-4330	4	1	5	80	20	0.25
23	4330-4390	6	2	8	75	25	0.33
24	4390-4450	-	-	-	-	-	-
25	4450-4510	-	2	2	-	100	-
26	4510-4570	-	3	3	-	100	-
27	4570-4630	3	2	5	60	40	0.67
28	4630-4690	1	1	2	50	50	1
29	4690-4750	2	1	3	66.67	33.33	0.5
30	4750-4810	-	2	2	-	100	-
31	4810-4870	1	5	6	16.67	83.33	5
32	4870-4930	-	-	-	-	-	-
33	4930-4990	1	3	4	25	75	3
34	4990-5050	2	-	2	100	-	0
35	5050-5110	-	3	3	-	100	-
36	5110-5170	4	2	6	66.67	33.33	0.5
37	5170-5230	3	5	8	37.5	62.5	1.67
38	5230-5290	1	4	5	20	80	4
39	5290-5350	4	2	6	66.67	33.3	0.5
40	5350-5410	2	3	5	40	60	1.5
41	5410-5470	3	1	4	75	25	0.33
42	5470-5530	1	1	2	50	50	1
43	5530-5590	3	-	3	100	-	0
44	5590-5650	1	1	2	50	50	1
45	5650-5710	2	8	10	20	80	4
46	5710-5770	4	3	7	57.14	42.86	0.75
47	5770-5830	1	2	3	33.33	66.67	2
48	5830-5890	2	-	2	100	-	0
49	5890-5950	3	-	3	100	-	0
50	5950-6010	-	1	1	-	100	-

level rise due to their ability to colonize incipient prograding sandy accumulations. *Botryococcus braunii*, a freshwater indicator had a sparse record in this zone, thus indicating an increase in paleowater depth (marine transgression) and was characterized by the high diversity of the dinoflagellate species (marine elements). It also probably indicated a period of no influx of fresh water to the depositional site since freshwater flow would be terminated further landward of the site of deposition. The upward increase in the frequency and diversity of marine element in Zone II is consistent with gradual increase in sea level during marine transgressive events leading to the replacement of brackish and fresh water by saline water. The presence of *Botryococcus braunii* suggested freshwater, brackish water swamps or marginal marine waters because of its adaptation to a wide range ecological niche. The species has been recovered from a lascustrine, fluvial, lagoonal, and nearshore marine sediments, reported the common occurrence of Chlorophycean agae including Botryococcus from the shallow brackish water embayment facies in the Lambeth Group of southeastern England and interpreted it as indicative of shallow marine/estuarine depositional environment [31]. According to, the occurrence of dinocysts and mangrove taxa indicated marginal marine conditions [26]. The PMI (Palynological marine index) was proposed by Helenes et al. [32] to assist in paleoenvironmental interpretation of palynological assemblage. PMI of 100 signifies absence of marine species which implies that the environment is continental. The PMI of Zone II ranges from 100 to 144 (Table 1) which is the highest for the well. The PMI value greater than 100 indicates the mutual occurrence of both the marine palynomorphs specie and the terrestrial derived palynomorphs. The high PMI values are observed fluctuate within the zones of the section studied confirming fluctuations between the continental and marginal marine depositional environments. The vegetation was a typical rain forest with a stretch of open forest separating it from the coastal evergreen lowland mangrove vegetation. The presence of dicotyledonous pollen (*Ctenolophonidites* and *Clavainaperturites clavatus*) and palm pollen suggest predominance of angiosperm dominated forest [26].

Zone III (3430-3010 ft.): fluvial, coastal swamps and marshes

The paleoclimatic fingerprint indicated fluctuations between dry and wet climatic conditions considering the composition of *Monoporites annulatus* and *Zonocostites* of GBO-04 well. It can be observed that the *Monoporites annulatus*, which signified dry climate was more abundant with a near constant appearance in the zone compared to *Z. ramonae*. The presence of *Botryococcus braunii* (a fresh water indicator) and the total absence of Dinoflagellate assemblage (marine element) signify the influx of fresh water and confirm that the sediments of the zone is of continental origin. Also, the zone is marked by high abundance of spores and pollen (Table 3), with the pollen having higher frequencies compared to the spores. Zone III was dominated by the FWSP represented by mainly by *Laevigatosporites* spp., *Striatricolpites catatumbus* and *Retitricolporites irregularis* and lowland rainforest taxa, including *Polypodiaceoisporites* spp., *Sapotaceoidaepollenites* spp., and *Brevicolporites guinetii* which occurred constantly and was only missing in the interval 3070 to 3250 ft. respectively. Also, the common presence of Arecaceous pollen grains (*Racemonocolpites hains* and *Arecites* spp.) suggested the prevalence of low land rain forest vegetation during deposition of sediments in the stratigraphic interval. Also a low occurrence of BWSP represented by *Acrostichum aureum*, *Psilatricolporites crassus* and *Proxapertites cursus* was recorded within this zone. The high occurrence of FWSP and RAIN was indicative of continental deposition due to the influx of freshwater from river runoff as shoreline moved seaward following marine regression. The sedimentary sequence was presumably deposited in freshwater/ brackish water swamps or fluvial settings. Evidence for terrestrial origin is further strengthened by the low PMI value which is 100 for this zone showing the absence of marine influence. This deduction was supported by the essentially sandy lithofacies that typify the interval (Figure 3). The preponderance of grass pollen, mainly *Monoporites annulatus* confirmed the presence of dry climate within this interval. The occurrence of low frequencies mangrove taxa in this zone was probably as a result of minor local short-lived transgressions of the sea, thereby allowing only very limited extension of mangrove vegetation [18]. Drastic depletion of mangrove vegetation is expected during marine regressive phase. According to periods of sea level falls are characterized by drastic shrinkage in sizes of coastal mangrove swamps [30]. The extent of mangrove swamps on delta plain setting is dependent on whether the delta is wave and river-dominated or tide- dominated delta. River and wave dominated delta have minimal mangroves, whereas tide dominated settings may have large mangrove tracts [30-32].

CONCLUSION

The study showed the sediments collected from GBO-04 well in Niger Delta contained moderately rich, diversified and well preserved palynomorphs that enabled delineation of palynological zones. The studied sediments were of Early Miocene age (Burdigalian-Langhian with palynological assemblages that were dominated by pollen and spores. GBO-04 well micro floral assemblage revealed a typical Niger Delta Early Miocene palynological signature, which was characterized (in order of abundance and diversity) by pollen, spores and dinoflagellates. The main ecological groups (mangrove, coastal swamp forest, savanna and lowland rainforest) identified in the study largely belonged to the humid tropical ecosystem which might have persisted in the Niger Delta of Nigeria since the Neogene. The paleoclimate varied dry and wet climatic conditions, which is characterized by the alternating Poaceae and Rhizophora. The sediments were laid down in lagoonal, coastal swamp, fluvial and shallow marine settings.

CONFLICT OF INTEREST

There is no conflict of interest in this research.

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