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Full Length Research

Palynological characteristics of sediments in some parts of the Niger Delta

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ABSTRACT: Palynofacies and palynological studies were carried out within Rivers and Bayelsa State in the Niger Delta area, bounded by longitudes 006°10" E and 006°50" E and latitudes 4°48" N and 5°20" N. The study area includes locations in Mbiama town in Bayelsa State and Elibrada-Emohua town in Rivers State respectively. A total number of sixteen samples comprising sandstone and siltstone were collected across a geographic spread from Mbiama town in Bayelsa State and Elibrada-Emohua town. The fieldwork was carried out with the aid of a hand auger and a hand trowel was used to collect both surface and sub-surface samples (a few meters deep) were collected using the "pinch" method. Samples were prepared for palynological analysis. About 5 grams of each sample was placed in a labelled cup in which 100 ml of 70% hydrofluoric acid (HF) was added with palynomorphs from the other rock debris by digesting the silica in the sample. The samples were then washed and the slides were prepared. A portion of the kerogen was mixed with 0.1% PVA solution, pipette onto a cover slip and allowed to dry. The coverslips were mounted upon a microscope slide using Norland adhesives. The slides were properly labelled and observed under a research microscope through which a snapshot was taken**.** The palynologic analysis yielded *Nympheapollis clarus (40%)*. *Fenestrites spinosus (20%*), *Cyperaceapollis sp (30%*), *Classpollis sp (10%)*. *Echitriporites sp (20%*) and *Praedapollis africanus* (40%) which corresponds to the *Reitricolporites sp*, *Proxaporities operculatus*, *Elaeis guineensis*, *Echitricolporites spinosus*, *Retitricolporite sp*, *Monoporites annulatus* and *proxaporities operculatus*; all from Benin formation. The samples yielded pollen, spores, fungal spores, dinoflagellate and diatom. The identification of these palynomorphs helped to generate a percentage distribution paleogeographic chart showing the occurrences of the different palynomorph groups, Six biozones were recognized, The first consists of *Echtricolporites sp*, the second, third and fourth zones (*Nympheapollis clarus*, *Elaeis guinensis*, and *Zonocostites ramonae* zones respectively) which are consistent with the presence of tidal flats environments characterized by fresh water swamp and fifth and sixth zones consists of the *Retimonocolpites sp* zone and *Psilatricolporites sp* zone respectively, indicating sedimentation in marine environments and mangrove vegetation.

Keywords: Niger Delta, palynomorphs, palynofacies, Pliocene, zonation.

INTRODUCTION

Palynology offers powerful techniques with which to infer historical changes due to human influences in depositional environments, including estuaries and wetlands. Palynomorphs are particularly useful in these endeavours, aside from possessing good sediment preservation record due to their short interval reproductive rate, they equally respond quickly to changes in nutrient availability and water quality conditions which is mostly abundant in aquatic environments, generally cosmopolitan in distribution, and have a fairly well-studied taxonomy and ecology (Powell *et al.,* 1992). Paleoenvironmental studies in coastal environments have lagged, primarily because of the more dynamic nature and presumed invulnerability of coastal ecosystems. There is often a mixture and transport of sediments after initial deposition, differential silicification and preservation of palynomorphs values. This is because

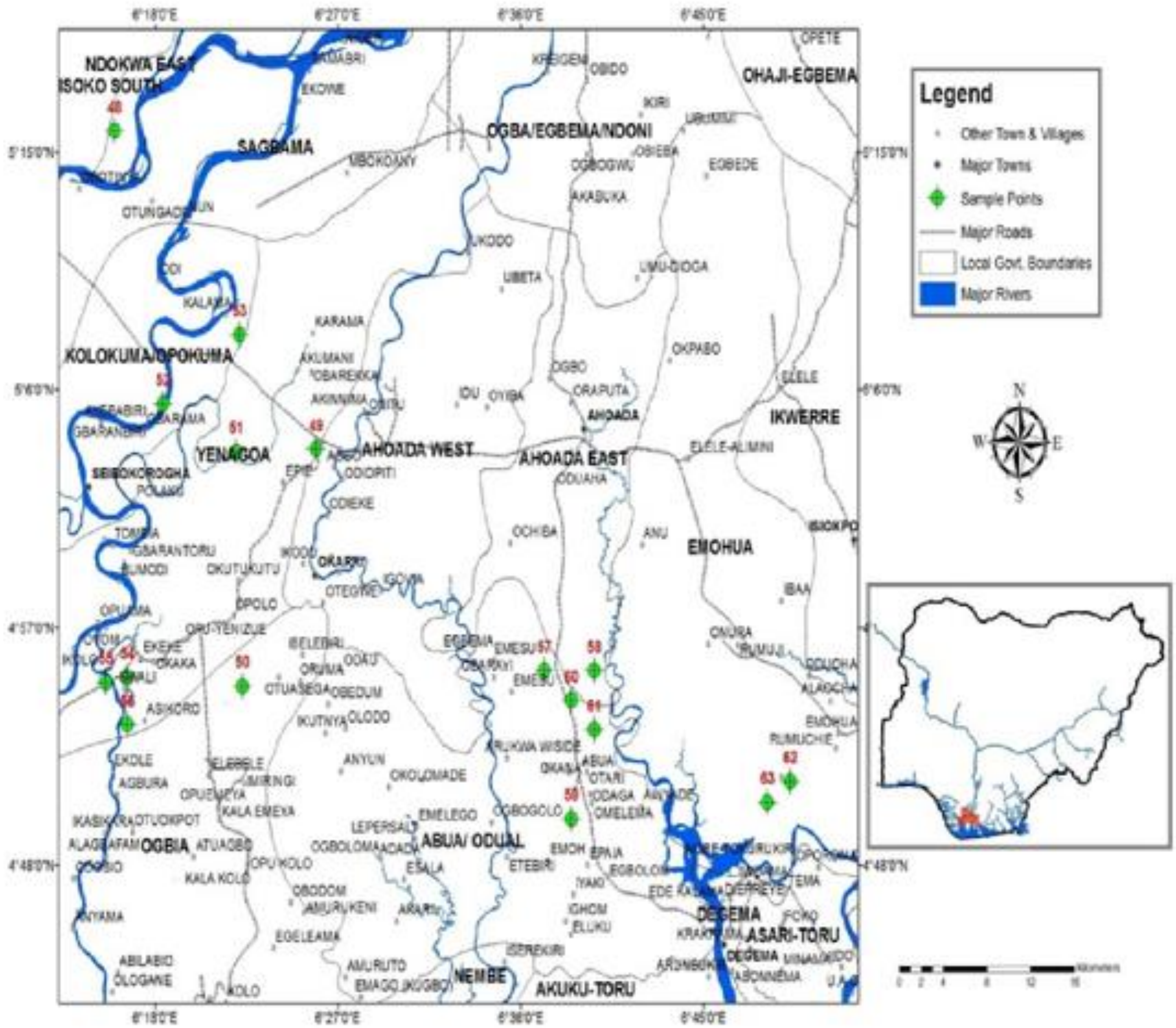

Figure 1. Map showing location of study area.

vegetation in any area is an integral and basic component of the ecosystem and is sensitive to changes in the ecosystem. According to Ivanor *et al*. (2007), the distribution pattern of vegetation strongly depends on climatic conditions and thus vegetation reconstructions help to understand past climates and environment; they reported that a close relationship exists between vegetation and the rest of the environment, particularly climate and soil. Generally, the flora of an area provides a good reflection of the major climate of another regime of that area. The influence of climate on other components of the environment is so great that every particular zone has its characteristic vegetation type. It is possible to reconstruct and interpret past environments and biotic communities based on processes operative today. As pointed out; the usefulness of fossil pollen and spores to paleoecology is hinge on their potential for providing quantitative information on recorded ancient vegetation.

The aim and objectives of this study is to examine the palynological characteristics within the study area, description of pollen trend association present, description of Paleoenvironment and paleoecology as well as dating of the investigated rocks of the study area.

MATERIALS AND METHODS

Location and accessibility of the study area

The study area is located within some parts of the Niger Delta basin and lies between longitudes 006°10" E and 006°50E and latitudes 4°48" N and 5°20" N (Figure 1).

Geology of Niger Delta

Akata Formation is characterized by shale as revealed

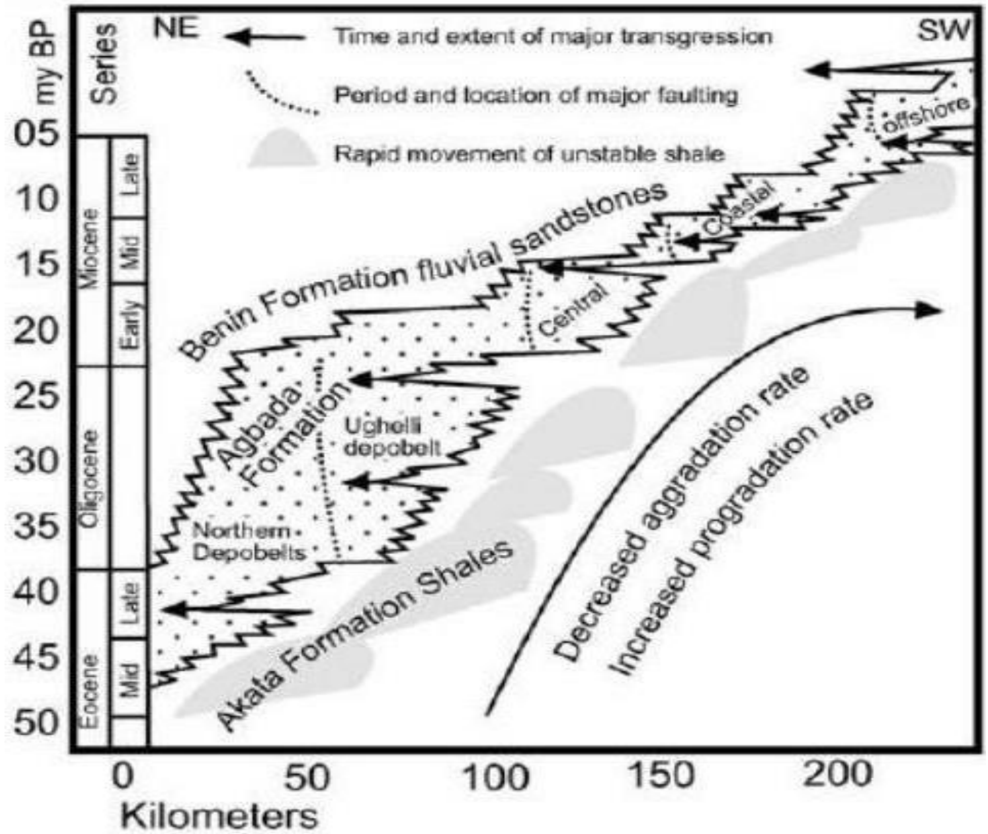

Figure 2 Stratigraphical column showing the three formations of the Niger Delta Modified from Doust and Omatsola, 1990.

through gamma and S.P. logs (Ihunda *et al*. 2017). Though it is locally interbedded by sands and/or siltstones, it is predominantly characterized by low density, plastic, high pressure and under-compacted shallow marine to deepwater shale. The advancement of high energy delta into deep water led to the deposition of Akata shales. Overpressuring of the shale provides the mobile base for subsequent growth faulting and also the deposition of the overlying paralic sequence (Avbovbo, 1978). The source rock that is responsible for the majority of the hydrocarbon in the Niger Delta basin is the Akata shale as the majority of wells drilled in the Niger Delta penetrated it. It is characterized by a medium to dark grey colour, fairly hard, or at places soft, gumbo-like and sandy or silty deltaic shale with a total depth of up to 7,000 m (Evamy *et al*., 1978; Doust and Omatsola, 1990).

Agbada Formation is characterized by sequences composed of alternation of sandstones and shale. Its origin is associated with syn-sedimentary growth faulting as shown by Weber (1971) and Avbovbo (1978) to be a cyclic sequence of fluvial and marine deposits. The sandstones in this formation are medium to fine-grained and relatively clean. Shale acts as caprock and the sandstones serve as the main reservoir of the delta even while they are locally calcareous, glauconitic and shaly. The thickest portion of this formation is present at the centre of the delta with a total depth of about 3,940 m (Aigbedion and Aigbedion 2011).

Benin Formation is predominantly characterized by sandstones that are highly porous, massive and freshwater–bearing, interbedded with thin shale considered to originate from the braided stream (Figure 2). The formation at the north is of Oligocene age and becomes younger to the south. To date, this highly porous formation has been studied to house minimal hydrocarbon deposits.

The Benin Formation has described outcrops in Benin, Onitsha and Owerri provinces as coastal plain sands that extend across the whole Niger Delta from the west (Evamy *et al*. 1978; Doust and Omatsola 1990).

Data acquisition

Sixteen (16) ditch-cutting samples were collected using the “pinch” method: collecting 10 pinches of soil throughout each sampled location of about 50 to 100 square meters. These pinches were combined into a single, sterile, plastic bag and then sealed. used for both palynological studies and the lithologic description of the samples was done by examining them under the binocular microscope by noting the textural characteristics such as colour, grain size, shape (roundness), sorting, effect of ferruginization, and fossil content in terms of plant remains. Palynological slides were prepared by subjecting the samples to initial digestion by adding dilute hydrochloric acid into them in order to remove calcium carbonate ($CaCO_3$) that might be present. This is followed by hydrofluoric acid (HF) digestion overnight for sieving with a nylon sheet of 10μm in order to remove clay particles present; this is followed by oxidation, heavy liquid separation and mounting of the residue on glass slides. Taxa counts were made to determine the relative frequency of each species in each sample, after which the diagnostic species photographs were taken using Koolpix camera 6000 model.

RESULTS AND DISCUSSION

The results of this study are hereby separated into Lithology, Percentage distribution of palynomorphs, Pollen assemblage zones, Paleoecology and paleoenvironment.

Percentage distribution of palynomorphs

Location 1

Sample I consist of (30%) pollen, (40%) spore, (10%) fungal spore, (10%) dinoflagellate and (6%) diatom. The dominance of pollen and spore indicates a terrestrial depositional environment. The low number of dinoflagellate and diatom probably indicates the environment of deposition was not favourable (Oloto and Ihunda, 2013).

Location 2

Sample 2 is poor in palynomorphs and the numerical counts show that they are dominated by pollen and spore with (30%) pollen, (38%) spore (8%) fungal spore, (16%) dinoflagellate and (8%) diatom. These indicate a terrestrial depositional environment. The presence of fungal spores probably indicates a swamp environment with very little marine indicator and sparse flora content (Adesalu and Nwankwo, 2005).

Location 3

Sample 3 consists of (53%) pollen, (33%) spore (4%) fungal spore, (4%) dinoflagellate and (4%) diatom. This indicates a terrestrial depositional environment Dinoflagellates and Diatoms are not very abundant, which indicates that the environment is not favorable for their survival (Adesalu and Nwankwo, 2005).

Location 4

Sample 4 is rich in palynomorphs and is composed of (36%) pollen, (27%) spore, (10%) dinoflagellate, (18%) fungal spore and (10%) diatom. These indicate a terrestrial environment. The presence of few dinoflagellate cysts in a pollen and spore-dominated assemblage probably indicates infiltration of marine water (Oloto and Ihunda, 2013).

Location 5

Sample 5 is rich in palynomorphs and is composed of (66%) pollen, (118%) spore, (8%) fungal spore and (8%) diatom. The assemblage consists of a few diatoms, and is dominated by pollen and spores; in addition, the presence of leaf cuticles indicates a terrestrial depositional environment shown in Plates 1 and 2 (Li *et al.*, 2010).

Location 6

Sample 15 is devoid of dinoflagellate cyst but rich in palynomorphs and is composed of (38%) pollen, (46%) spore (7%) fungal spore and (15%) diatom. The presences of fungal spore probably indicate transportation from a swamp to the estuarine environment. The presence of Diatoms indicates a marine environment but judging by the high percentage of present pollen and spore, it indicates a terrestrial environment.

Location 7

Sample 7 is a rich dinoflagellate cyst which is composed of (14%) dinoflagellate cyst with an increase in (46%) pollen, (26%) spore, (7%) fungal spore and (7%) diatom. The presence of fungal spores suggests a swamp depositional environment (Ohimain *et al.,* 2010).

Locations 8

Sample 8 is rich in palynomorphs and is composed of (40%) pollen, (32%) spore (8%) fungal spore, (8%) dinoflagellate and (8%) diatom. Pollen and spore show relative dominance over fungal spore dinoflagellate and diatom. These indicate a terrestrial depositional environment. Dinoflagellate and diatom are low in number probably indicating that the environment of deposition was not favourable (Nwankwo *et al.*, 1997).

Location 9

Sample 9 is rich in palynomorphs and is composed of (44%) pollen, (50%) spore and (6%) fungal spore. Pollen

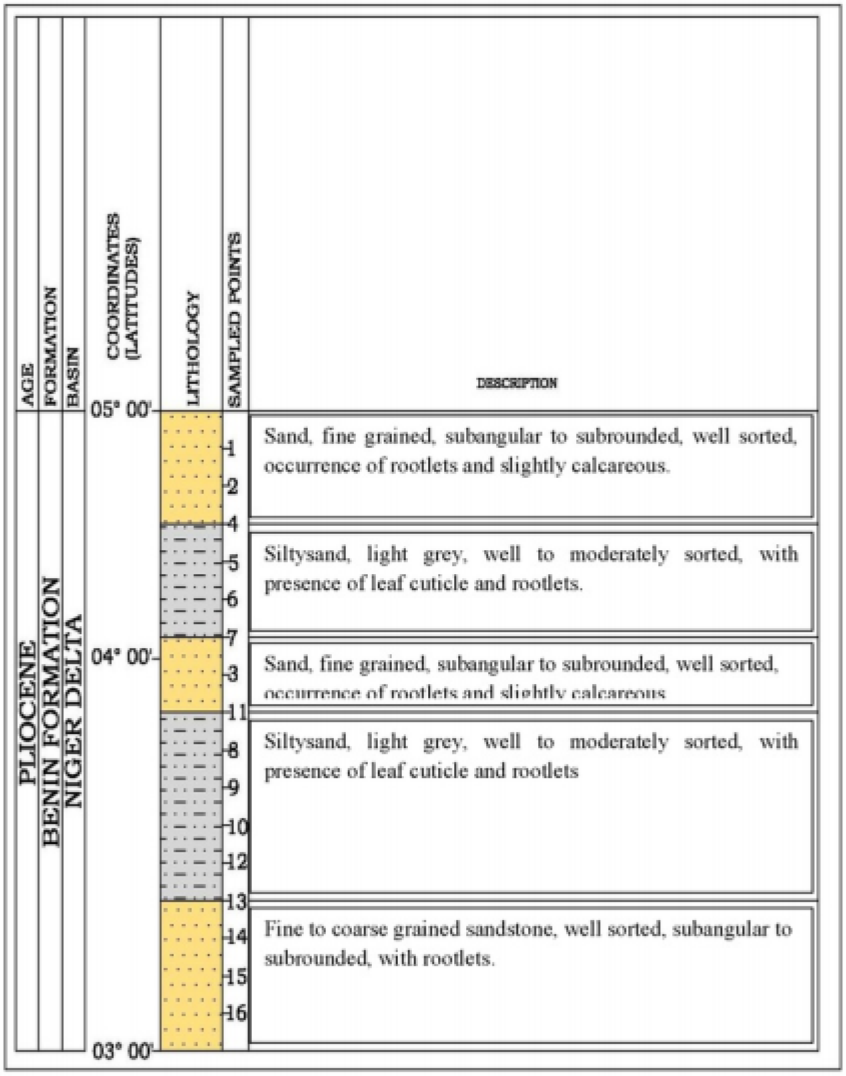

Fig 4.1: Lithology of the study area.

and pores show a relative abundance than other forms like (*Zonocostites ramonae* and *Monoporites annulatus*). These indicate a terrestrial depositional environment (Sowunmi, 1999).

Location 10

Sample 10 is composed of (36%) pollen, (36%) spores, (9%) dinoflagellate, and (9%) diatoms but is rich in pollen and spores. This indicates a terrestrial depositional environment; the presence of fungal spores suggests a swamp depositional environment (Rochon *et al*., 1999).

Location 11

Sample 11 is devoid of dinoflagellate cysts and composed of (62%) pollen, (28%) spores, and (10%) fungal spores. The abundant pollen and spores indicate a terrestrial depositional environment; this indicates a near-shore marine environment, and the presence of plant debris indicates a more terrestrial depositional environment (Adesalu *et al*., 2011).

Location 12

Sample 12 is composed of (36%) pollen (36%) spore, (9%) fungal spore, (9%) dinoflagellate and (9%) diatom. Pollen and spores show relative dominance over fungal spores; these indicate a terrestrial depositional environment. The presence of fungi suggests a swamp depositional environment (Adesalu *et al.*, 2011).

Location 13

Sample 13 is rich in fungal spore which is composed of

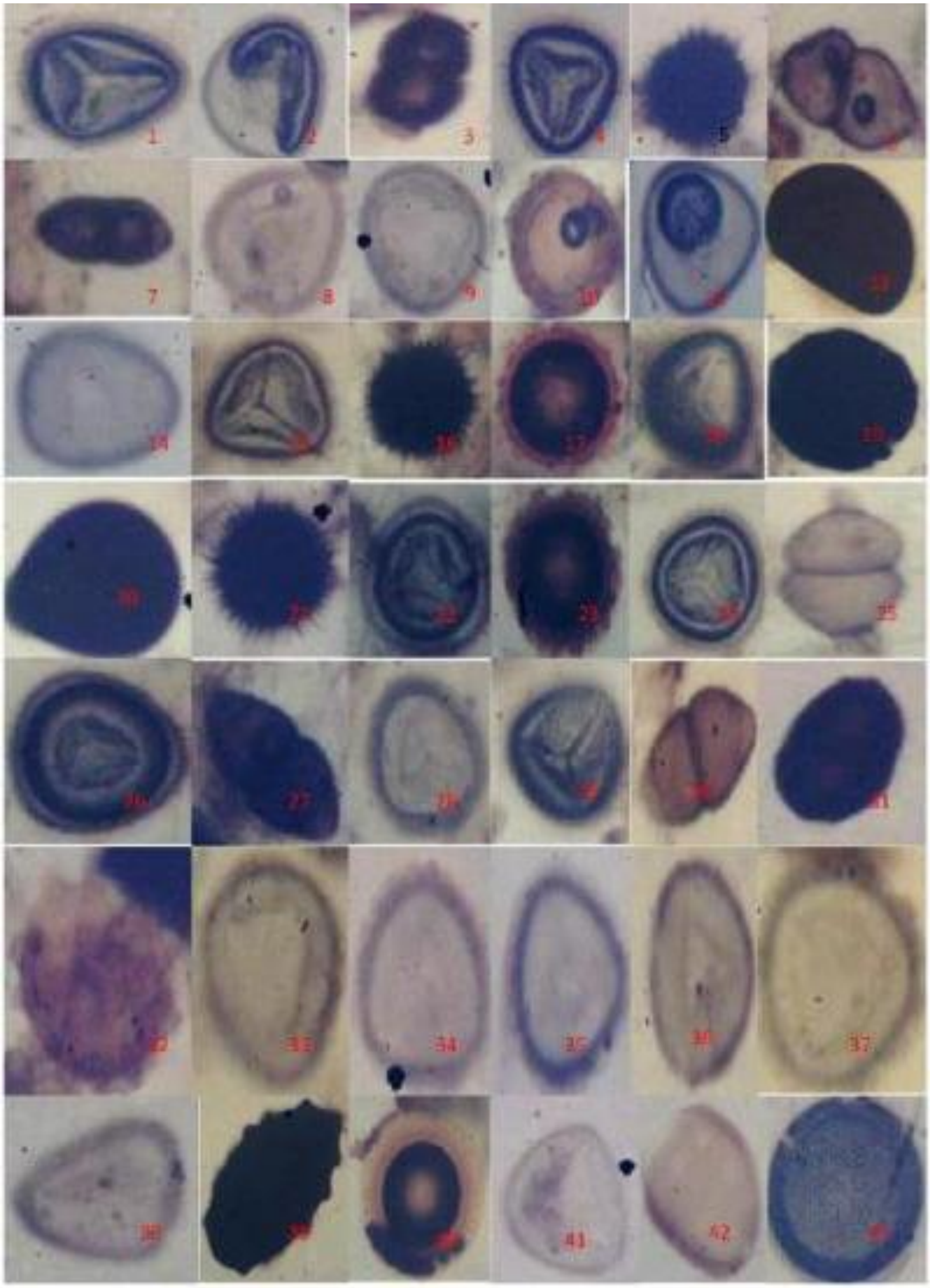

Plate 1. Explanation to plate 1 are as follows:
Samples 1, 2, 4, 15, 22, 24, 26 and 29: Trilete spore.
Samples 3, 5, 6, 7, 13, 16, 20, 25, 27, 30 and 39: Fungal spore.
Samples 8, 9, 33, 34, 35, 36, and 37: *Proteacidites sp.*
Samples 10, 17 and 23: *Echitriporites sp.*
Sample 40: *Echitricolporites spinosu.*
Sample 43: Daitom.

(100%) fungal spore. The presence of fungal spores suggests a swamp depositional environment (Oloto and Ihunda, 2013).

Location 14

Sample 14 consists of (70%) pollen, (15%) spore, (5%) fungal spore, (5%) dinoflagellate cysts and (5%) diatom. Pollen shows relative dominance spore, these indicate a terrestrial depositional environment. The presence of fungal spores suggests a swamp depositional environment. Dinoflagellate cysts (10%) and diatom (5%) are few; the low number indicates that the environment of deposition was not favourable. Moreover, the presence of *Monoporities annulatus* coincided with a reduction of forest species and freshwater swamp forests, thus, indicating a slight climate change, probably to a brief dry period shown in Plates 1 and 2 (Rochon *et al*., 1999).

Location 15

Sample 15 consists of (64%) pollen, (18%) spore, (6%) fungal spore, (6%) dinoflagellate cyst and (6%) Diatom. The presence of a few dinoflagellate cysts in a pollen and spore-dominated assemblage probably indicates infiltration of marine water. Diatoms are low in number these probably indicate that the depositional environment is moving from terrestrial to marine (Adesalu *et al*., 2011).

Location 16

Sample 16 is rich in pollen and spores and is composed of (28%) pollen, (56%) of spore, (5%) fungal spore, (5%) dinoflagellate and (5%) diatom. The spore encountered in this location shows a relative abundance than the pollen. These indicate a terrestrial environment. The presence of fungal spores probably further confirms a swamp depositional environment (Adesalu *et al*., 2011).

Biozonation

Zone 1

Poor in palynomrophs assemblages: from the top it showed the species first occurring with the presence of *Classpollis sp*, *Echitriporites sp*, *Praedapollis africanus* showed a slight increase in abundance. Species last occurring at the base marked zone *Retidiportess sp*, *Proteacidites sp*, *cyathdites sp*.

Note: Although some of the genera which produce this pollen type have a pan-tropical distribution (Figure 4). The occurrences in the Neogene appear to be restricted to the Caribbean area and Nigeria. It is possible that the extension of the range to the Indo-Malesian area took place relatively in the Pliocene.

The paleoenvironment of deposition showed a significant of tidal and freshwater swamp previously recognized pollen and spores in relation to present vegetation, the paleoecological zone with the presence of *Retitricolporites sp, Psilatricolporites sp* and *Echiperiporites sp* sparsely represents a freshwater swamp vegetation these indicate a relative presence of pollen (Plates 1 and 2).

Zone II

The top is defined by the first observed quantitative increase of *Auriculiidites* with a high increase of pteridophyte spore while the base shows an increase in palynomorph species first appearing at the bottom- *Auriculiidites*, *Zonocostites ramonae*, *Nynpheapollis clarus*. The base was marked by a slight increase in pteridophytespore, palcoenvironment of deposition showed a significant of tidal flat, from recognized pollen and spore in relation to present vegetation: therefore the paleoecocolgical zone with the present of *Zonocostites ramonae* (Plates 1 and 2), indicates freshwater forest vegetation (Riparian).

Zone III

The top showed a slight increase in palynomorphs. Species first appearing at the top; *Echitriporites sp, zonocostites ramonae, Nympheapollis clarus*. Species last occurring at the base market the zone. The base showed an increase in pteridophyte spore; *Lavigatosporites ovatus*, *Cingulatisporites ovatus*, *Verrucatosporites sp*, *Triletes sp* and some pollen like *Echritricolporites ovatus, Verrucatosporites sp, Triletes sp* and some pollen like *Echritricolporites spinosus, Elaeis guineensis, Retitricolporite sp, Proxaporities operculatus* (Plates 1 and 2), and the base marks a quantitative increase in *Elaeis guineensis* (Figure 4). The paleoenvironment of deposition showed a significant of tidal flat. Previously recognized pollen and spore in relation to present vegetation, the paleoecological zone with the presence of *Elaeis guineensis* is palm vegetation which is characterized by a decrease in pollen with a percentage of (48%).

Zone IV

The top is marked with a distinct increase in palynomorph assemblages showing the presence of *Echitriporites sp, Zonocostites ramonea, Nympheapollis clarus*, but with pollen in association with *Psilatriporites sp* and common *Fenestries spinosa*. Reduction of pteridophyte spore towards the base species first appearing at the bottom

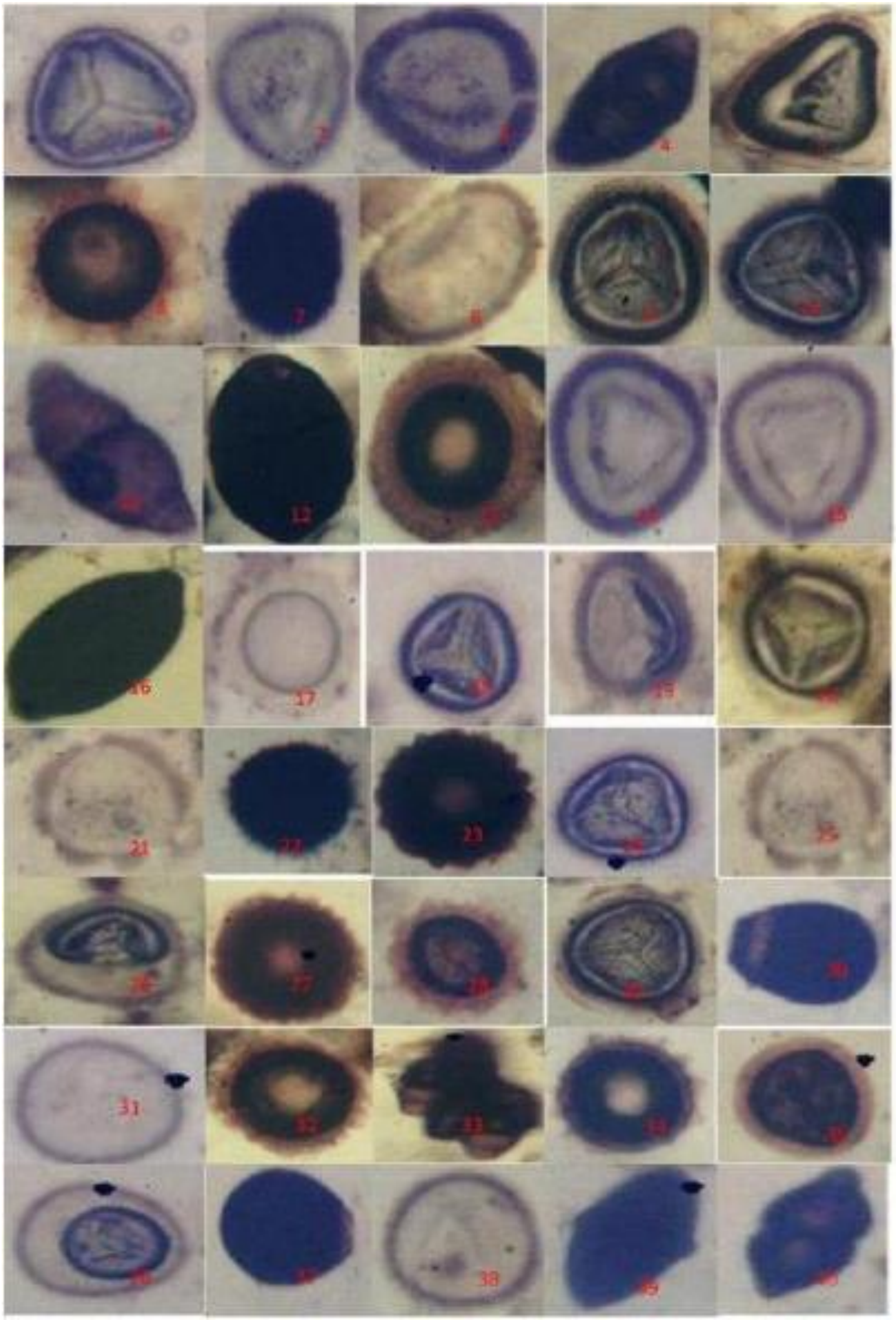

Plate 2. Explanation to plate 2 are as follows:
Samples 1, 5, 9, 10, 18, 19, 20, 24, 26 and 29: Trilete spore.
Samples 4, 7, 11, 12, 16, 22, 30, 33, 37, 39 and 40: Fungal spore.
Samples 2, 3, 14, 15, 31 and 36: *Retitricolporites sp*.
Samples 6, 27, 32, 34 and 35: *Echitricolporites spinosus*.
Samples 17, 21, 25, 35 and 38: *Echitripites sp*.

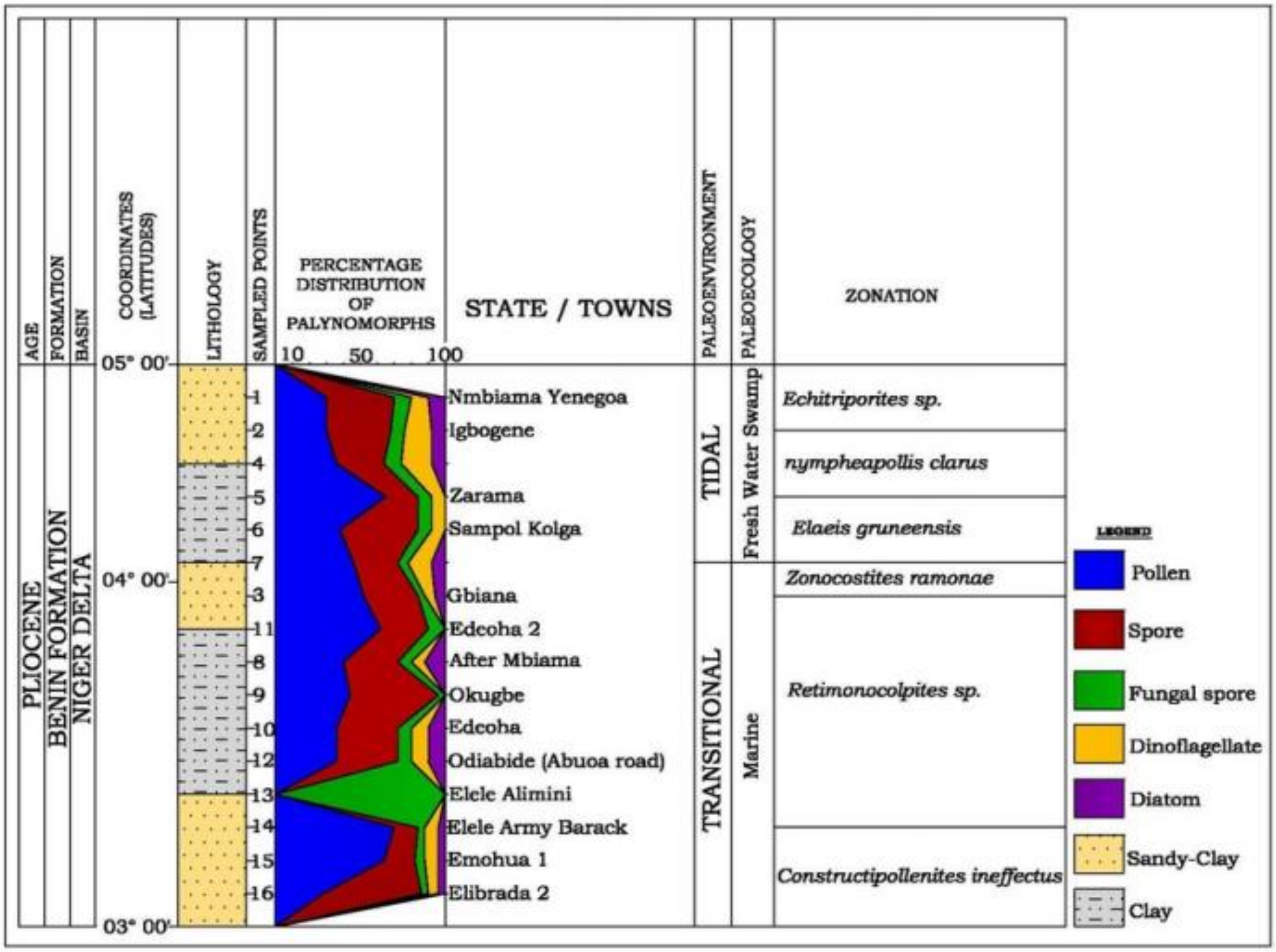

Figure 3. Percentage distribution of palynomorphs from north to south latitude.

Table 1. Biozonation of the study area.

Locations	*Zone 1*	Family	Taxon	Subzone
Location 12		*Asteraceae (compositae)*	*Echitricolporites sp*	Pliocene
Location 2-4	*Zone II*	*Arecaceae*	*Nympheapollis clarus*	Pliocene
Location 5-7	*Zone III*	*Arecaceae*	*Elaeis Sinensis*	Pliocene
Location 7-8	*Zone IV*	*Rhizophoraceae*	*Zonocostites ramonae*	Pliocene
Location 8-14	*Zone V*	*Ctenolophonaceae*	*Retimonocolpites sp*	Pliocene
Location 14-16	*Zone VI*	*Microphylium*	*Constructipollenites ineffectus*	Pliocene

shows an increase in abundance of palynomorph: *Polyadopollenites sp, Monocolpites sp*; with high pollen grains of *Longapertitis sp*. (Table 1).

Paleoenivrionment of deposition showed a significant of alluvial plain, previously recognized pollen and spores in relation to present vegetation; the paleoecological zone with the presence of *Longapertitis* indicate a freshwater swamp/rain forest vegetation with a high percentage of pollen (65%).

Zone V

The top is rich in palynomorphs. Species first appearing from the top with increase in pollen grain-*Echitriporites sp, Zonocostites ramonae, Nympheapollis clarus, Psilatriportites sp*, and and an increase in pteridophyte spore minimum. Species first appearing at the bottom: - *Aletepollenites sp*, *Fenestries sp*, *Monoporites annulatus, psilatricolporites sp, psilamonocolpites sp* and *syncolpites*

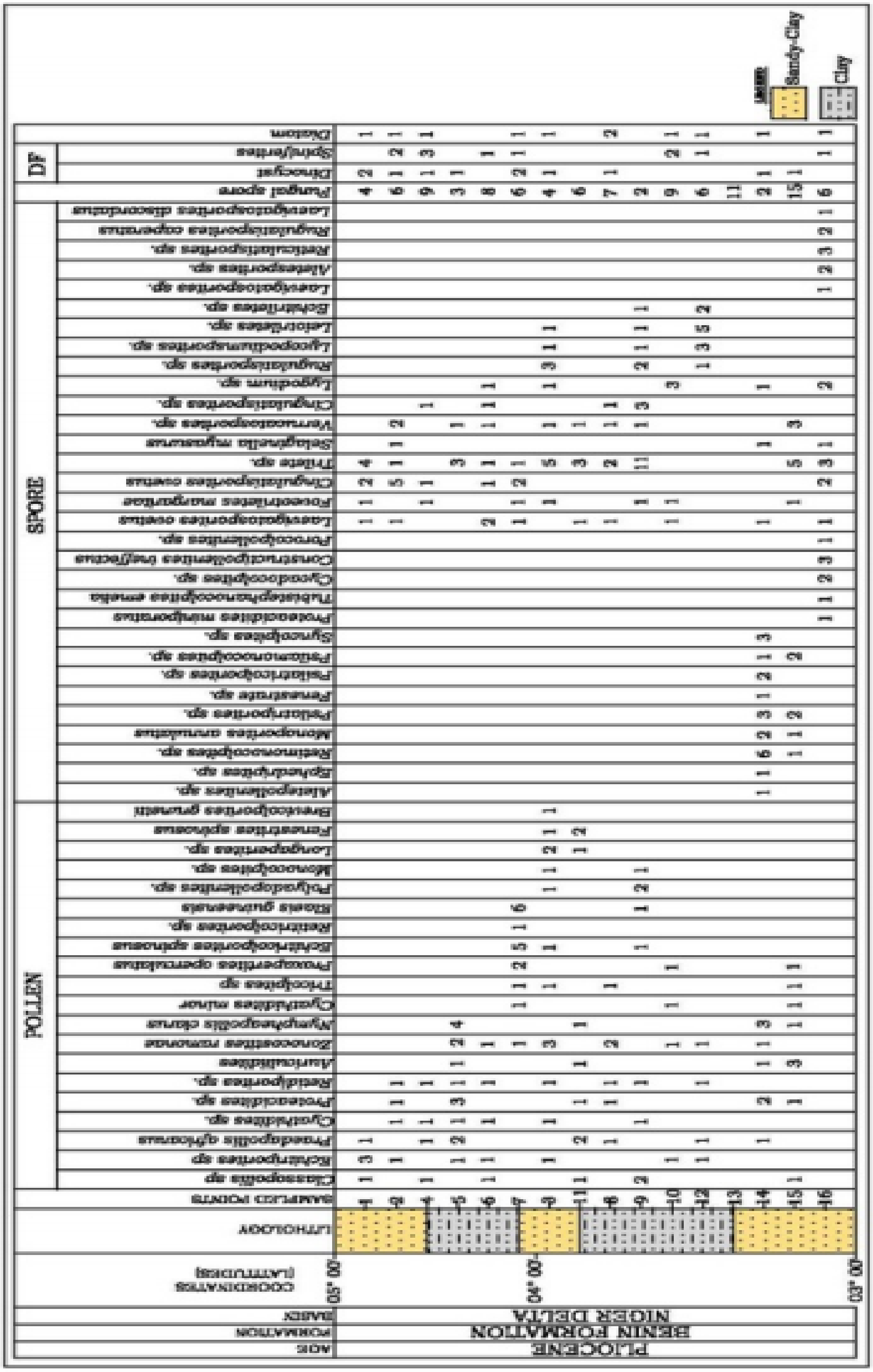

Figure 4. Paleogeographical distribution of palynomorphs within the study area.

sp, Paleoenvironment of deposition showed a significant of alluvial plain shown in plate 1 and plate 2 (Figures 3 and 4). The paleoecolgical zone with the present *Monoporites annulatus* indicate freshwater swamp rain forest.

Zone VI

The first appearing species from the top are the following *Proteacidites miniprolatus, psiletricolpites sp,* *Tubustephanocolpirites emella, Cycadocolpites sp*. Subzone species namely *Monoporites annulatus, pailamonocolpites sp* and species last occurring at the bottom *psilaperiporites minimus, porocolpollenites sp*. Increase of *Laveigatospirites ovatus, Cingulatisporites ovatus, Lygodium sp*, Paleoenvironment of deposition showed a significant of transition; paleoecological zone with the present of *Monoporites annulatus* indicate mangrove forest (Rull *et al*., 1997).

Paleoenvironment and paleoecological interpretation

The depositional environments identified were based on recorded flora assemblages. From the top of the chart to the base (location 1-16), flora such as *Classpollis sp, Echitriporites sp, Praedapollis africanus* were recorded suggesting a tidal flat environment (Sowunmi 2004)**.** Invariably fungal spores are found in ponds and lakes which leads to the assumption that fungal spore is an indication of freshwater environment. A marine habitat for these green algae has been found in its abundance in the marine depositional environment (tidal flat) from location 1 to location 7 and fungal spores were probably transported from freshwater swamp where they once lived into marine water where they fossilized (Rull *et al*., 1997). The most likely environment of deposition is suggested based on the occurrence of *zonocostites ramonae, Monoporities annulatus, Laveigatospirites ovatus, Cingulatisporites ovatus and Lygodium sp*; therefore, it is inferred to be of an estuarine environment (Oloto, 1994). The presence of fungal spore in location 5, 6 and 7 also probably indicates transportation from a swamp to shallow marine environment (Figure 3). The percentage of pollen and spore is very relative because they were considered based on the few available sporomorph grains. This is as a result of the cumulative swampy effect of dominant dinoflagellate which was encountered again at location 1 to 6 followed by other forms such as the *Retidiporites sp, Proteacidites sp, Cyathdites sp*, of Coastal deltaic environment under the representation of the pollen and spore.. Moderate numbers of land-derived palynomorphs were recorded such as *Monoporites annulatus*, and the Pteridophyte spores with Dinoflagellate cysts recovered alongside. This agrees with the near shore marine environment interpretation based on the *spiniferites* association. The pollen and spore of location (8-16) is dominated by monoporate species which includes the Palmae group *Classpollis sp*; this implies that the prevailing climate was probably tropical (Sowunmi, 2004)**.** The pollen and spore assemblage is dominated by pteridophyta spore *Cyathidites minor* (28%) with other common species like the identified *verrucatosporites ovatus* (11%). The relative abundance of pollen/spore in marine environment is an indication of a closer proximity to the land environment. This assemblage suggests a tidal flat near shore environment (Figures 3 and 4). This transition from outer neritic to coastal deltaic environment suggests a period of transgression due to eustatic sea level rise. The change in the environment as revealed by the palynomorphs encountered progressed into transition which continues into an outer neritic environment (Oloto and Ihunda, 2013). The presence of *Zonocostites ramonae* and *Monoporites annulatus* (location 7 to 16) serves as an indication of mangroves ecological condition that prevailed at the time of deposition (Figure 4) while the presence of open marine elements mixed within this ecologic condition indicates contact with the sea (Ige, 2009). The dominance of *Longapertites sp*, *Zonocostites ramonae* and *Monoporites annulatus* in (Plates 1 and 2), indicate that they were derived from a restricted flora growing near the shore or even in the marine water, that is, a mangrove plant except for their typical impoverished state which suggests a more terrestrial condition of deposition while the active presence of dinoflagellate cyst indicates infiltration of marine water **(**Ige, 2009**).**

Conclusion

In conclusion, the close correspondence between the sporomorph and total palynomorph abundance curves shows that the Pliocene assemblages in the study area are composed almost entirely of land−plant sporomorphs, and that dinoflagellates and small diatom were frequent only in those samples containing few palynomorphs. The result of the acquired data on pollen-and-spore assemblage from the surface sediments when compared to the currently existing vegetation in the present day with close correspondence between the sporomorph abundance and percentage distribution chart is very relative because they are based on only a few sporomorph grains. The attribute of these works is to understand the events of the past, present and future behaviour of the earth system using palynological tools. Accordingly, the primary aspect of this paper is to infer the characteristic data of pollen and spore assemblages within the study area. The angiosperm palynofloral assemblage suggests a lowland vegetation of the Tertiary period during the deposition of the study sediments, in a transitional/tidal swampy mangrove. The studied area is palynologically divided into six zones, with the presence of *Nympheapollis clarus (40%*). *Fenestrites spinosus (20%)*, *Cyperaceapollis sp (30%)*, *Classpollis sp (10%*). *Echitriporites sp (20%)* and *Praedapollis Africanus* (40%) showing the lower zone being rich in pteridophtic spores and pollen of the family Arecaceae, while the other zones are dominated by pollen of the family Bombacaceae and dinoflagellates.

COMPETING INTERESTS

The authors declare that they have no competing interests.

REFERENCES

Adesalu, T. A., & D.I. Nwankwo, 2005. Studies on the phytoplankton of Olero creek and parts of Benin River, Nigeria. *Ekolologia*, 3, 21-30.

Adesalu, T. A., & Olayokun, O. M. (2011). Water chemistry and phytoplankton composition of a polluted tidal creek, Lagos. *Journal of Science Research and Development*, *13*, 171-183.

Aigbedion, I., & Aigbedion, H. O. (2011). Hydrocarbon volumetric analysis using seismic and Borehole data over Umoru Field, Niger Delta-Nigeria. *International Journal of Geosciences*, *2*(2), 179-183.

Avbovbo, A. A. (1978). Tertiary lithostratigraphy of Niger Delta: GEOLOGIC NOTES". AAPG Bulletin.

Doust, H., & Omatsola, E. (1990). Niger Delta. In: Edwards, J. D. & Santograssi, P. A. (eds). *Divergent/Passive Margin Basins*. AAPG Memoir, *48*, 201-239.

Evamy, B. D., Haremboure, J., Kamerling, P., Knaap, W. A., Molloy, F. A., & Rowlands, P. H. (1978). Hydrocarbon habitat of Tertiary Niger delta. *AAPG bulletin*, *62*(1), 1-39.

Ige, O. E. (2009). A late tertiary pollen record from Niger Delta, Nigeria. *International Journal of Botany*, *5*(3), 203-215.

Ihunda, C. E, Adiela, U. P., & Ogbumgbada, I. F. (2017). Paleoenvironmental Analysis Outcrop In Akpoha Afikpo Basin South Eastern, Nigeria. *International Journal of Science and Invention Today*, *6*(2), 138-146.

Ivanov, D. A., Ashraf, A. R., & Mosbrugger, V. (2007). Late Oligocene and Miocene climate and vegetation in the Eastern Paratethys area (northeast Bulgaria), based on pollen data. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 255(3-4), 342-360.

Li, Y. M., Ferguson, D. K., Wang, Y. F., & Li, C. S. (2010). Paleoenvironmental inferences from diatom assemblages of the middle Miocene Shanwang Formation, Shandong, China. *Journal of Paleolimnology*, *43*, 799-814.

Nwankwo, D. I., & Kasumu-Iginla, K. (1997). Contribution to the diatom flora of Nigeria. 1. Pennate tube-dwelling diatoms from the Lagos mole. Nigerian Journal of Botany, *10*, 61-69.

Ohimain, E. I., Bamidele, J. F., & Omisore, O. O. (2010). The impacts of micro-topographic changes on mangroves in the lower reaches of the Benin River, Niger Delta. *Environmental Research Journal*, *4*(1), 167-172

Oloto, I. N. (1994). Nigerian Maastrichtian to Miocene dinoflagellate and miospore biozonation—A summary. *Journal of Mining and Geology*, *30*(1), 61-73.

Oloto, I. N., & Ihunda, C. E. (2013). Data acquisition for forensic and palylogical studies: A case study from Nigeria. *International Journal of Scientific and Technology Research*, *2*(6), 278-284.

Powell, J. H. (1989). *Stratigraphy and sedimentation of the Phanerozoic rocks in central and south Jordan* (p. 130). Hashemite Kingdom of Jordan. Geology Directorate. Geological Mapping Division, Bulletin. Retrieved from https://pascal-francis.inist.fr/vibad/index.php?action=get RecordDetail&idt=6402231

Rochon, A., Vernal, A. D., Turon, J. L., Matthiessen, J., & Head, M. J. (1999). Distribution of recent dinoflagellate cysts in surface sediments from the North Atlantic Ocean and adjacent seas in relation to sea-surface parameters. *American Association of Stratigraphic Palynologists Contribution Series*, *35*, 1-146.

Rull, V. (1997). Sequence analysis of western Venezuelan Cretaceous to Eocene sediments using palynology: Chronopaleo environmental and paleovegetational approaches. *Palynology*, *21*(1), 79-90.

Sowunmi, M. A. (1999). The significance of the oil palm (*Elaeis guineensis* Jacq.) in the late Holocene environments of west and west central Africa: a further consideration. *Vegetation History and Archaeobotany*, *8*, 199-210.

Sowunmi, M. A. (2004). Aspects of Nigerian coastal vegetation in the holocene: some recent insights. In: Battarbee, R. W., Grasse, F., & Stickley, C. E. (eds.). *Past climate variability through Europe and Africa*. Springer, Netherlands. Pp. 199-218.

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