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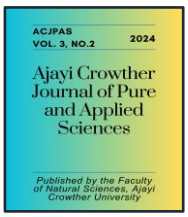

Article

Palynostratigraphic And Paleoenvironmental Investigation of FUNCH-1 Well, Western Niger Delta Basin, Nigeria

[1]*Moyosoluwa Odunayo Adeyemi and Oluwafunmibi Omojiade Ayorinde

[1] Department of Geology and Mineral Sciences, Crawford University, Ogun State, Nigeria; moyo_adeyemi@yahoo.com (M.O.A.); therealfunmibii@gmail.com (O.O.A.)

* Correspondence: Adeyemi M.O.; moyo_adeyemi@yahoo.com.

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Abstract

An exploratory well (Funch-1) from the western Niger Delta was subjected to palynological analysis in order to deduce and delineate the different palynozones in the well together with their paleoenvironment and respective ages. Thirty (30) ditch cutting samples collected at intervals of 60ft from 9,390ft to 11,190ft in the well were subjected to palynological analysis. Sample preparation involved the removal of carbonate and siliceous materials. A total of forty-one (41) palynomorph species were identified, out of which *Acrostichum aureum*, *Psilastephanocolporites sapotaceae*, *Gemmamonoporites sp*, *Psilatricolporites crassus, Verrutricolporites rotundiporus and Verrucatosporites sp.* were identified as marker species. Biozonation was carried out using standard zonation scheme and one zone of pollens and spores i.e., P700 and two (2) subzones P770 and P780 were identified on the bases of the Top) and Base of the marker species. Based on the identified palynozones, the age of the interval of the well investigated is late to middle Miocene. Paleoenvironmental studies on indicate that the majority of pollen and spores are found in brackish marshes.

Keywords: Paleoenvironment, Biozonation, Palynomorphs, Miocene, Marker species.

1. Introduction

Palynology is the study of micro-organic materials such as pollen grains and other spores (collectively called palynomorphs) found in both living and fossil forms [1]. They are important groups of microfossils and in general are important tools for the petroleum industry. Pollen and spores are produced by plants as part of their propagation. Spores are produced by bryophytes such as ferns while Pollens are produced by higher plants such as conifers and angiosperms. They are produced in large numbers and as they are microscopic can travel far by wind and in water, before the eventually settle in water bodies such as lakes, ponds, rivers, and oceans. Palynology is an interdisciplinary science because it involves Geology, biological science, and Botany. it studies fossil palynomorphs such as pollen, spores, acritarch's together with particulate organic matter and sediments palynology does not include diatoms.

Spores are produced by "lower plants" or cryptogams and they are the most studied within pteridophytic vascular plants and bryophytes [2]. Classification of free sporing plants such as Bryophyta (mosses and liverworts) and Pteridophytes (seedless vascular plants), relies on morphology, wall structure, and wall sculpture [3, 4]. Homospory in the fossil record involves four-fold division in spore production, resulting in trilete spores with a tetrahedral shape or monolete spores with a tetragonal shape. Trilete and monolete marks represent the points of contact between spore tetrads [5]. Spore types are categorized based on the arrangement of spore tetrads. Tetrahedral tetrads have a

trilete or Y-shaped mark, while tetragonal tetrads have a rectilinear scar and bean-shaped outline.Laesurae, apertures in the exine, can be commissures or margos. Spores can be monolete (single laesura), alete (without laesura), or trilete (three laesurae) [3]. Pollen of Mesozoic and younger non-marine deposits, has an intine (cellulose wall) and an exine (tough, inert layer) [4]. Gymnosperms appeared in the late Devonian, while angiosperms emerged in the early Cretaceous [6]. Pollen morphology can be described based on polarity, symmetry (radial or bilateral), shape (prolate, oblate, spheroidal), and aperture types (inaperturate, monoporate, diporate, tricolpate, monosulcate) [3].

Adebayo [7] carried out palynological studies on ditch cuttings retrieved from south eastern Niger Delta and identified mangrove species *Zonocostites ramonae* (Rhizophora) and *Fovetricolporites crassiexinus* (Avicennia) as the predominant palynomorphs. The study revealed the dominance of high sea level and wet climatic conditions during the deposition of the studies sediments. Aturamu et al [8] carried out palynostratigraphic analysis 36 ditch cutting samplesfrom Agbada Formation and three zonal assemblage schemes were identified: *Echiperiporite cf. estelae*, *Foeveotricolpite sp. Psilatricolpites okeizeis* and their ages were assigned a late Miocene to early Pliocene age. Ikegwuonu [9] carried out palynostratigraphic studies on Imo Formation, Ameki Formation and Ogwashi Formation established different palynomorph assemblage zones with their corresponding ages. The recovered spores and pollen grains were used to establish six informal palynomorph assemblage zones labeled zone A-F based on the first and last occurrence of two or more species.

Ogbahon [10] using ditch cuttings from a well offshore western Niger Delta basin, determined the age of the sediments and reconstructed the paleoclimate and depositional paleoenvironment. Retrieved pollen grains include *Zonocostites ramonae*, *Retitricolporites irregularis*. He inferred the paleoenvironment to include brackish lagoons and open saltwater swamps etc. Bankole *et al.* [11] using 407 ditch cutting samples from 3 wells in the Agbada Formation identified assemblages that are predominantly of terrestrial origin especially the pteridophytic and bryophytic spores, gymnosperms, and angiosperm the pollens. The ecologically significant taxa were categorized into five main phytoecological groups which include; mangrove, freshwater, coastal swamp, savanna, montane and tropical rain forest groups. Adebayo [12] used 40 ditch cutting samples gotten from the Agbada Formation in Niger delta basin to obtain pollen and spores with paucity of dinoflagellate cysts. The stratigraphic ranges of *Zonocostites ramonae*, *Retitricolporites irregularis*, *Fovetricolporites crassiexinus* and some other marker species were used to demarcate five informal palynological zones in the study area. Chukwma-Orji *et al*. [13] using 50 ditch cutting samples gotten from Ida-4 well in Niger Delta established palynostratigraphic zones, relative age and paleoenvironment of deposition. Marker species such as *Zonocostites ramonae* and *Multiareolite formosus* were used to establish three zones. Thomas and Osung [14], used ditch cutting samples to identify six climatic cycles as well as deduce the depositional regimes which indicate the recurrent palynological sequences and vegetation variations based on sea level change. Adeonipekun and Kudejo [15] using samples taken from three different locations ABC, GH, DEF from the coast recovered palynomorph species that include *Elaeis guineensis*, *Acrostichum aureum* and *Pteris spp*. These species indicate terrestrial origins of the sediments.

Oloto [16] using 127 samples (55 sidewall and 72 ditch cuttings) gotten from Igbomotu-1 well in central coastal Niger delta divided the study area into four zones. Zone 1 (*Spiniferites pseudofurcalus*), Zone 2 (*Multispinula quanta*), Zone 3(*Chytrioelsplaeridum sp.*), Zone 4 (*Sumatradinium hispidium*). Boundaries are marked by unconformities recognized by presence of gravel horizons in a predominantly silty shale sequence. Oloto [17] carried out a study on the dinoflagellate cysts retrieved from the Maastrichtian section (Nkporo shale) represented in the a well from the coastal flank of Niger Delta. He identified 16 genera and 37 species of Dino cysts as well as 6 genera and species of pollen and spores. He recognized six dinoflagellate zones and four pollen/spore zones which he used for paleoenvironmental and paleoclimatic study.

1.1 Geology and Stratigraphy of the Niger Delta

The Niger Delta Basin is situated in the coastal and offshore region of the Benue Trough, a substantial and long-established geological formation (Figure 1). The Benue Trough, characterized by folding and rift basin features oriented in a northeast-southwest direction, extends across Nigeria. Its formation

coincided with the initiation of the Gulf of Guinea and the Equatorial Atlantic during the Aptian-Albian period when the equatorial regions of Africa and South America commenced their separation [18]. The initiation of the Benue Trough was triggered by taphrogenic subsidence, which occurred along fundamental transform faults that penetrated the lithosphere. These faults represent the onshore extensions of the Chain and Charcot oceanic fracture zones [19, 20]. Subsequently, the main axis of subsidence for the Niger Delta was influenced and determined by these faults.

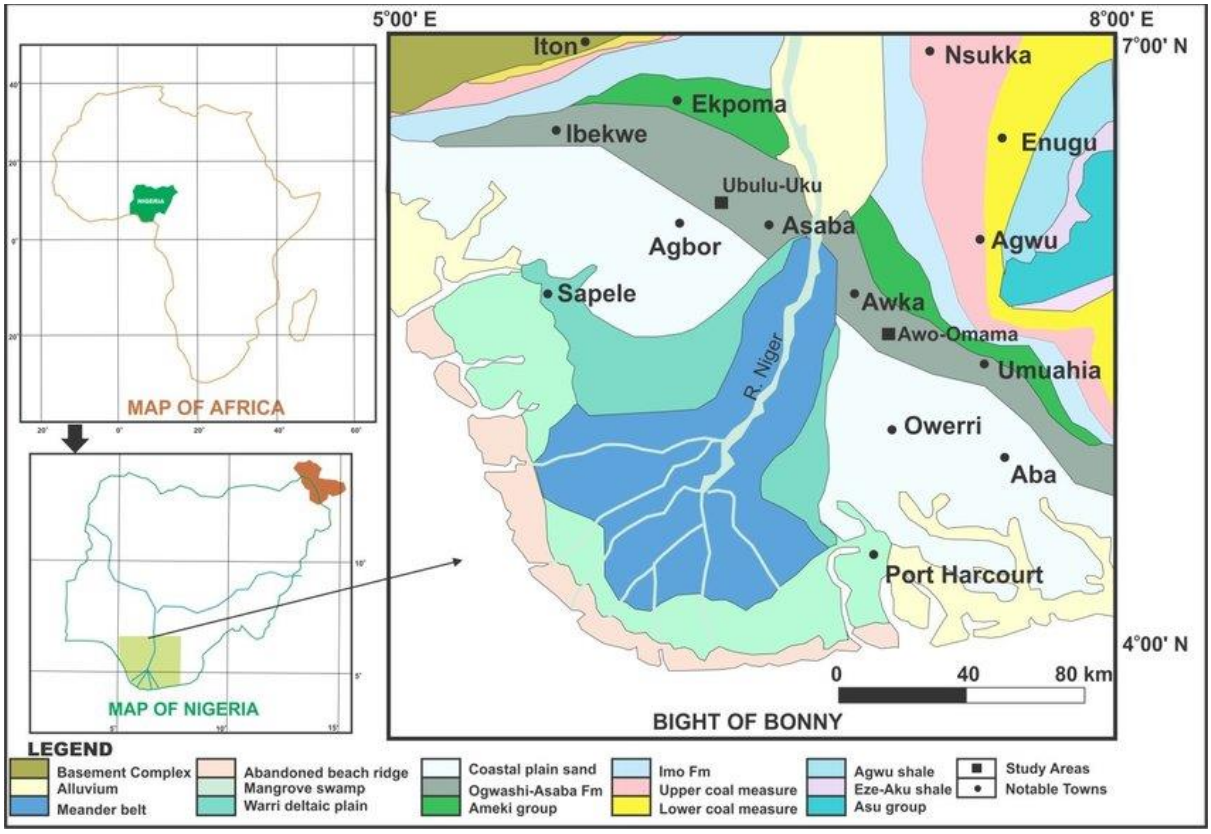

Figure 1: Geological map of the Niger Delta

The sedimentary deposits in the Benue Trough are located within Cretaceous subbasins, namely the Gongola, Yola, Abakaliki, Anambra, and Afikpo subbasins. Among these, the Niger Delta stands out as the most recently formed subbasin within the Benue Trough. The evolution of the region's stratigraphy and paleogeography has been influenced by various factors, including the movement of deltaic depocenters towards the south [18, 22], the displacement of depocenters in a westward direction after deformation, and the occurrence of marine transgressions moving northward [23]. These processes have played a significant role in shaping the stratigraphic and paleogeographic development of the Benue Trough and its subbasins.

The depositional history of the Niger Delta dates back to the Early Cretaceous period. During this time, the filling of the Southern Nigeria sedimentary basins was influenced by three major tectonic phases and epeirogenic movements, which led to significant transgressive-regressive cycles [24]. These tectonic events caused the displacement of the main basin and the formation of three smaller basins: the Abakaliki trough (Albian to Lower Santonian), the Anambra basin (Upper Santonian to Lower Eocene), and the Niger Delta (Lower Eocene to the present) [25]. Our understanding of the Cretaceous lithology in the Niger Delta Basin is primarily based on the exposed Cretaceous section in the neighbouring Anambra Basin to the northeast. This allows us to gain insights into the stratigraphy of the region. However, information regarding the lithology of the Niger Delta Basin above the Cretaceous is primarily derived from drilling and coring activities conducted within the basin [26].

Within the Tertiary period, the Niger Delta has experienced long-term progradation onto the passive margin of the Atlantic Ocean, resulting in the formation of three significant lithostratigraphic units.

These units, namely the Akata, Agbada, and Benin Formations, represent large-scale lithostratigraphic divisions within the subsurface of the Niger Delta. As we move basinward, these formations decrease in age, indicating an overall regression of depositional environments within the clastic wedge of the Niger Delta. Corresponding units to these formations can be observed in exposed areas of southern Nigeria [27]. These formations are distinguished from one another based on their respective ratios of sand to shale. They collectively demonstrate a coarsening-upward pattern of progradation within the clastic wedge, deposited in various environments such as marine, deltaic, and fluvial settings.

Evamy et al. [28] conducted maturation studies and analyzed macrofaunal assemblages, concluding that the Akata Formation serves as the primary source rock in the Eastern Niger Delta. On the other hand, the Agbada Formation, characterized by a mixture of sand and shale (paralic sequence), was deposited in a transitional or mixed marginal environment. This formation exhibits an upward increase in sorting and sand content. In contrast, the Benin Formation has experienced significant syndepositional deformational structures within the Niger Delta and displays a rich microfaunal assemblage at its base.

Ajaegwu et al. [29] conducted sedimentological and palynological analyses on ditch cutting samples obtained from a well drilled in the Eastern Niger Delta. Their findings confirmed that the analyzed section belongs to the Agbada Formation. Consequently, they assigned a late Miocene to early Pliocene age to this formation. The present study aims to investigate the palynomorphs, palynozones, age of formation, and the depositional environment encountered by the FUNCH-1 well, which was drilled in the western Niger Delta.

2. Methodology

Thirty (30) ditch cutting samples from Well FUNCH-1 collected from depth between 9,390 and 11,190ft at intervals of 60ft were subjected to standard palynological processing in order to determine the palynological content, interpret the age and reconstruct paleoenvironment of deposition.

Twenty-five (25) grams of air-dried samples were subjected to standard chemical treatment described by Brasier [30]. Each sample was later pulverized in a porcelain mortar with a pestle to approximately 2-5mm sized particles in order to enhance maximum recovery of the palynomorphs. The pulverized samples were introduced into a container filled with concentrated hydrochloric acid (36%) and kept overnight. The supernatant solution was decanted and the residue was rinsed three times with distilled water. This procedure was carried out to digest the carbonate component and prevent the formation of insoluble calcium fluoride in the next stage of the processing. Afterwards, the residue was soaked in hydrofluoric acid (60%) inside a fume cupboard, the mixture was stirred with plastic rod (non-silica material) for as long as the silica and silicates components were digested and left overnight in the fume cupboard. The mixture was then transferred into the centrifuge tube. The hydrofluoric acid was decanted and the samples were rinsed once again with distilled water and centrifuged three times for 5 minutes each at 2000 rpm. Hydrofluoric acid treatment was carried out to remove silica and silicates from the residue.

Warm 36% HCl was added to the residue and centrifuged for five minutes at 2000 rpm. The supernatant solution was later decanted. Also, cold 36% HCl was added. This was filled up with distilled water and centrifuged and washed three times. This second hydrochloric acid treatment is required for the removal of the hydrofluoric acid effects and fluoride(s) formed from the HF treatment. HCl (0.5%) was added to the sample in centrifuge tubes and stirred. This was then centrifuged for five minutes at 2000 rpm. The supernatant was then decanted. Zinc bromide, with a specific gravity of 2.2, was added to the mixture and thoroughly stirred using a glass rod. The mixture was then subjected to centrifugation at 1600 rpm for a duration of 10 minutes. As a result, the top portion of the mixture, which contained the organic material, floated to the surface. Carefully and gently, this floating layer was poured off into a newly labeled tube. This decantation process was repeated twice to ensure the maximum collection of organic material. The test was done to remove undigested silica, silicates, and heavier organic materials. 10% HCl was then added to remove the bromine effects and bromine formed. This was later washed with distilled water.

Test slides were made to determine the period of oxidation based on the degree of carbonization undergone by palynomorphs in the depositional environment. Oxidation time for samples varies depending on the depth of burial of the samples. Usually, a maximum of 10 minutes is required. To a clean glass slide, a drop each of the residue and glycerine in water (50% glycerol, 50% water) were added. These were spread evenly on the glass slide and a clean cover slip was gently lowered onto the slide with the aid of a picking needle and studied under a microscope.

Small quantity of concentrated nitric acid (70% HNO_3) was added to the residue in a centrifuge tube under the fume cupboard. The mixture was stirred, and a violent reaction occurred, more acid was added until a golden-brown colour was obtained. This was allowed to stand for few minutes to ensure that proper oxidation would have been affected. The sample was then centrifuged and washed three times or more with distilled water until a clear to liquid was obtained. Oxidation is sometimes required to lighten the exine of the palynomorphs to show greater detail and to remove unwanted organic materials. Caution was taken to avoid over oxidation of the preparation by neutralizing it with potassium hydroxide.

To the residue, a solution of potassium hydroxide (10%) was added, and the mixture was stirred. It was allowed to stand for a period of five minutes. After that, the mixture was rinsed three times with distilled water. This rinsing process was important to remove any remains of nitric acid or excess nitrates that may have been produced during the reaction of the nitric acid (HNO_3) with the organic matter. Subsequently, the mixture was centrifuged for five minutes at a speed of 2000 rpm to separate the solid residue from the liquid. This centrifugation step facilitated the removal of any remaining traces of nitric acid or excess nitrates from the sample.

Glacial acetic acid was added to the residue and stirred well with a dry stirrer. This was allowed to stand for 5 minutes and was then centrifuged and decanted. Acetolysis solution was prepared (nine parts of acetic anhydrite into graduated cylinder and one part of concentrated sulphuric acid was added. This acetolysis mixture was introduced to the residue and stirred. The tubes were put in a special stand and lowered into a glass beaker containing hot water at a temperature of 80-90C. This was left for 3-5 minutes while stirring cautiously. The tubes were then removed from the water and centrifuged for 5-10 minutes and decanted. The tubes were filled with water, stirred well, centrifuged, and decanted. The tubes were later filled with alcohol, centrifuged, and decanted. The residues were transferred to the phials.

An adequate number of glass slides were taken and wash-dried in alcohol and the depths were engraved on one end. To facilitate the spreading of Norland adhesive, one or two drops of the adhesive were carefully added to the center of the slide. The slide was then placed on a hot plate, allowing the adhesive to gradually spread and cover an area equivalent to the size of the coverslip. The residues were then spread on a clean cover slip, and these were allowed to dry. The coverslips and its contents were gently lowered onto the mountant containing glass slide with the aid of a picking pin to prevent the formation of air bubbles as much as possible. The glass slide was manipulated slightly to get rid of the trapped air bubbles. The slide was slightly warmed on a slide warmer to quicken its drying process and the boarders of the cover slip were carefully cleaned with razor blade and were then sealed with nail vanish. The remaining portion of the residue from which the permanent slides had been made were stored in phials.by adding glycerol-water mixture/glycerine and a drop of phenol to it. The glycerine-water mixture would help to lubricate the palynomorphs thereby preventing them from drying whilst the phenol would prevent fungal growth.

The aliquotus (a portion of the sample) was dispersed in polyvinyl alcohol. The dispersed sample, containing palynomorphs, was then examined for its morphological characteristics. These characteristics were compared to the descriptions, monographs, and diagrams provided in available publications [31, 32, 33]. This comparative analysis aided in the identification and classification of the palynomorphs present in the samples.

3. Results and Discussion

In the study, a total of 41 palynomorphs were identified and documented. Figure 2 displays photomicrographs showcasing some of these palynomorphs. The establishment of a palynological zonation for the well was accomplished by examining the palynofloral assemblage of the recorded index species and correlating their stratigraphic distribution with the zonation scheme proposed by Evamy *et al.* [34]. The analyzed section of the well has been broadly assigned to the P700 palynological zones as defined by Evamy *et al.* [34].

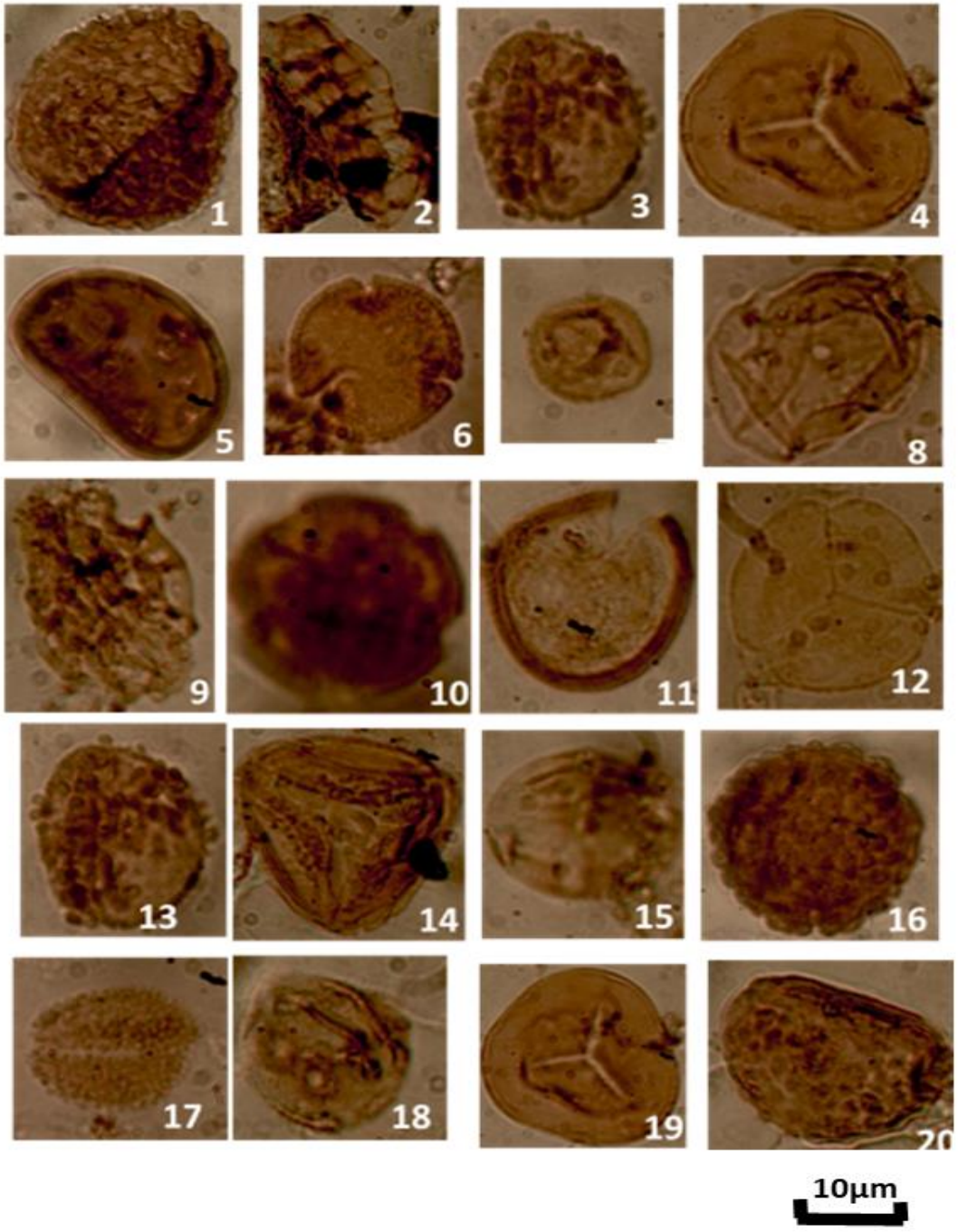

Figure 1: Photomicrographs of Palynomorphs.

(*1. Crassoretitriletes vanraadshooveni, 2. Fungal spore, 3. Gemmamonoporites sp, 4. Acrostichum aureum, 5. Laevigatosporites sp, 6. Brevicolporites guinetii 7. Cyperaceaepollis sp ,8. Monoporites annulatus, 9. Peregrinipollis nigericus 10. Pachydermites diederixi, 11. Nymphaeapollis clarus, 12. Stereisporites, 13. Gemmamonoporites sp, 14. Polypodiaceoisporites sp, 15. Psilastephanocolporites sapotacea,16. Psilatricolporites crassus, 17. Racemonocolpites hians, 18. Retibrevitricolporites obodoensis, 19. Acrostichum aureum, 20. Verrucatosporites sp*)

The analysis of palynological data from the wells revealed the identification of two palynological zones corresponding to the Late to Mid Eocene period. These zones were further divided into the P780 and P770 subzones. Considering the biozones identified, it can be interpreted that the studied section was deposited during the Late Miocene to Middle Miocene age. The palynological information provides valuable insights into the temporal framework of the studied section and helps establish its age within the geological timescale.

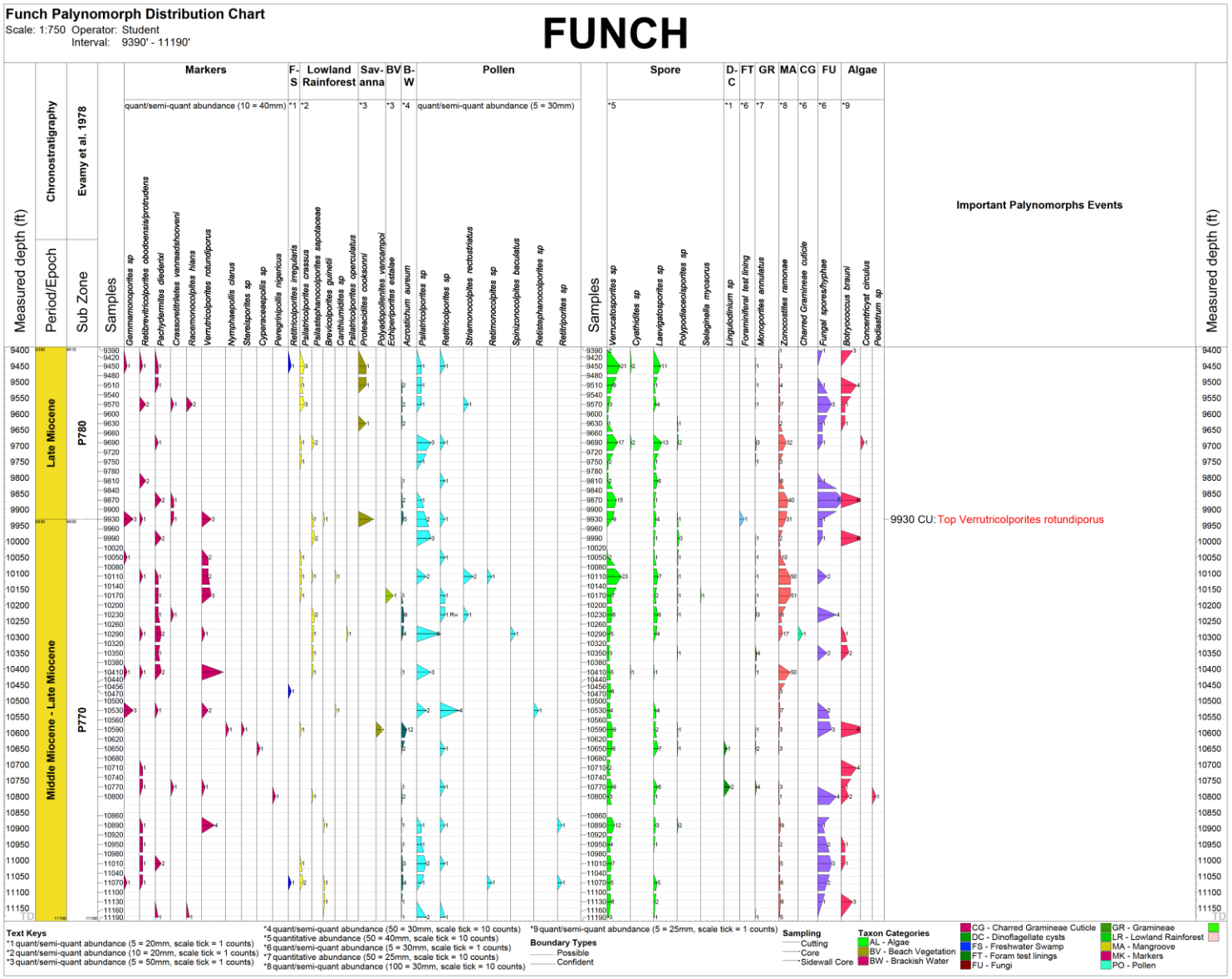

Figure 3: Biostratigraphic chart of FUNCH-1 Well

3.1 Descriptions of the identified palynological zones:

3.1.1 Late Miocene

Stratigraphic interval	:	9,390 – 9,930ft.
Zone	:	P700
Subzone	:	P780
Age	:	Late Miocene

The upper boundary of the P780 subzone is typically determined by the top regular occurrence of *Racemonocolpites hians*. However, it is worth noting that this boundary might be shallower than the

depth of the first analyzed sample, which is at 9,390 feet. As a result, the upper boundary is tentatively placed at 9,390 feet. On the other hand, the lower boundary of the subzone is defined by the top occurrence of *Verrutricolporites rotundiporus*, which is observed at a depth of 9,930 feet. This subzone is characterized by abundance of *Verrucatosporites sp. Retibrevitricolporites obodoensis/protundens, Psilastephanocolporites sapotaceae, Psilatricolporites crassus* and *Acrostichum aureum* are moderately present. *Psilatricolporites sp., Laevigatosporites sp., Zonocostites ramonae,* Fungal spore and *Pachydermites diederixi* are also present in reasonable amounts. This zone recorded a reduction in the percentage of *Monoporites annulatus.*

3.1.2 Middle Miocene

Stratigraphic interval	:	9,930 – 11,190ft
Zone	:	P700
Subzone	:	P770
Age	:	Middle Miocene

The sub zonal top is defined by Top occurrence of *Verrutricolporites rotundiporus* at 9,930ft., while the base is tentatively placed at 11,190ft., the Terminal Depth. This subzone is characterized by regular occurrence of *Verrutricolporites rotundiporus. Retibrevitricolporites obodoensis/protundens, Pachydermites diederixi, Acrostichum aureum, Laevigatosporites sp., Verrucatosporites sp.* and Fungal spore are moderately present. This zone recorded a decrease in percentage of *Monoporites annulatus* and *Zonocostites ramonae.*

3.2 Paleoenvironmental reconstruction

Paleoenvironmental deductions were based on palynological evidence such as relative abundance and diversity of mio spores (Pollen and spores), marine (dinoflagellates) and freshwater indices (Pediastrum and Botryoccocus).

3.3 Paleoenvironmental synthesis

Interval 9,390 – 11,190ft, Pro deltaic to Open Shelf Environments

This unit is predominantly shaly with few thin sand/silt bodies occurring. The sand/shale ratio is approximately 10:90. The sands are predominantly milky white to glassy, fine, well-sorted, angular to sub-angular. The mudstones/shales are dark brownish, predominantly blocky and moderately hard. The interval is characterized by traces of mica flakes. The sand/shale ratio of 10/90 suggests a predominantly low-energy sedimentation for this unit. The index mineral suite of rare mica flakes supports a low-energy shallow marine, probably protected bay, environment for this unit.

Palynologically, this interval recorded reduction of palynomorphs. Brackish-water specie like *Acrostichum aureum* and *Zonocostites ramonae* are abundant while there is marked reduction in the record of pteridophyte spores like *Laevigatosporites* sp. and *Verrucatosporites sp*. This probably suggests deposition in pro deltaic to open shelf environments (Middle to Outer Neritics). A predominantly wet climate is also inferred for this interval due to the abundance of *Zonocostites ramonae* (Mangroove).

4. Conclusions

Thirty (30) ditch-cutting samples from the FUNCH-1 well drilled in the western Niger Delta from 9,390ft to 11,190ft at 60ft intervals were used in the study. After the samples were subjected to palynological analysis in the laboratory, forty-one (41) pollen and spore species were identified some of which include: *Verrutricolporites rotundiporus, Retibrevitricolporites obodoensis, Racemonocolpites hians* and *Zonocostites ramonae.* Based on the distribution and occurrence of marker species, the section of the Well analyzed was broadly assigned to the P700 palynological zones. The zones were further subdivided into the P780 (*Racemonocolpites hians*) and P770 subzones (*Verrutricolporites rotundiporus*). The distribution of species identified indicates that the highest diversity is observed in the brackish

water swamp. Based on this observation, it can be concluded that the studied zone corresponds to a Late Miocene to Middle Miocene age. The paleoenvironmental studies, which focused on the abundance of pollen and spores and their correlation with specific paleoenvironments, also revealed that the majority of these species are associated with brackish water swamps.

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