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New Oligocene to Early Miocene Palynomorph Zonation of GZ-1 Well, Onshore Western Niger Delta, Nigeria

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ABSTRACT: Palynological studies was carried out on GZ-1 well from the onshore western Niger Delta in order to recognized a new detected developments in the varieties of key pollen and spore taxa that have shorter and more distinguished interval zones to advance stratigraphical delineation. Palynological analysis was carried out using the conventional maceration technique for recovering acid insoluble organic-walled microfossils from sediments. The result yielded rich and diversified palynomorphs. The main assemblage were dominated by angiosperm pollen grain (dominant global flora from Late Cretaceous onwards) followed by pteridophytes/bryophyte spore. Dinoflagellate cysts, on the contrast, were less diverse while the Gymnosperm pollen were scarce. The identified palynomorph were used to establish seven main zones - AF1 *Psilatricolporites crassus* zone, AF2 *Verrucatosporites usmensis* zone, AF3 *Triplochiton scleroxylon* zone, AF4 *Crassoretitriletes vanraadshooveni* zone, AF5 *Acrostichum aureum* zone, AF6 *Gemmatriporites ogwashiensis* zone and AF7 *Retitricolporites irregularis* zone in this study. Established on quantitative events, the zones were also divided into seven subzones with some having finer subdivisions into (a) and (b) ranging in age from Early Oligocene to Early Miocene. Previous unfiled event trends of important indicator taxa of spores and pollen accredited to Pelliceria, Caesalapinoideae, Stenochlaena palustris, Polypodiaceae, Lygodium microphyllum, Polypodiaceae, Adiantaceae and Amanoa (Euphorbiaceae) have assisted improvement of formerly used palynological zonation schemes in the Niger Delta. It is anticipated that this quantitative zonation scheme erected, will help with imminent palynostratigraphical studies in the onshore Niger delta area.

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The Cenozoic Niger Delta Basin is one of the Southern Nigeria sedimentary basins. Geographically, as indicated by Reijers *et al.,* (1997), it is situated between Latitudes 3º and 6ºN and Longitudes 5º and 8ºE. Many researchers had worked on the provincial significance of palynological relationship in the region. Germeraad *et al.,* (1968), carried out the most comprehensive palynological research to date on some of the Tertiary sediment from the world's tropical areas - South America, Asia and West Africa. They heartened the improvement of palynological research in Venezuela and later in the Niger Delta. Consequently, Evamy *et al.,* (1978), adopted a formal palynological zonation scheme for the Niger delta using alpha numeric nomenclature - P200, P300, P400, P500, P600, P700, P800 and P900 zones and subzones. However, facts about the individual marker pollen types are not made to the public and remains in the developed company for proprietary reasons. Legoux (1978), also established independent, but then a corresponding palynological zonation schemes. He employed specific marker taxa and their relative abundances, with the description of numerous new pollen types. Similarly, Poumot (1989), utilized palynoecological groups to infer 'palynocycles' and 'mega-palynocycles' for Late Miocene to Pliocene sections of the Niger Delta. The study is valuable primarily for understanding of depositional environments, changes in succession and the presence of sequence, but has insignificant utilization for age dating and stratigraphical correlation. Morley (1996a, 1996b), was the first to recommend sequence stratigraphical observations based on palynology, vegetation and climate, which was later advanced by Adebayo and Ojo (2014). Among the palynological zonation schemes for the Niger Delta, the schemes of Germeraad *et al.,* (1968); Evamy *et al.,* (1978) and Legoux (1978) are centered largely on qualitative occurrences, while the schemes of Morley (2000), take account of palaeoclimatic controls and are quantitatively useful in diverse parts and age intervals in the Niger Delta. The scheme of Evamy *et al.,* (1978) can be useful transversely in the whole of Niger Delta region, even though the zones and sub-zones are too

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large to capture understated palynological events. The zonation of Morley (2000), offers additional improvements, with quantitative events, but then is less consistent in the western part of the Niger Delta. Adeonipekun *et al.,* (2015), worked on Late Miocene to Early Pleistocene three exploration wells from the western delta region of the Niger Delta to find an acceptable solution that will aid the recognition of shorter interval zones, understated subtle events and advance the palynostratigraphical resolution of the region. They discovered new palynological features that assisted them to defined five main palynological assemblage zones from their study. New events and features were recognized and the varieties and occurrence developments of the palynomorphs used have been verified in over 100 exploration wells from across the offshore Niger Delta. With these, missing sections were identified and enhanced stratigraphical modelling through the use of sequence stratigraphical procedures. /This study is on new palynomorphs zonation in the Early Oligocene to Early Miocene sediments of GZ-1 well, onshore western Niger Delta. Fig. 1 shows the location of GZ-1 well.

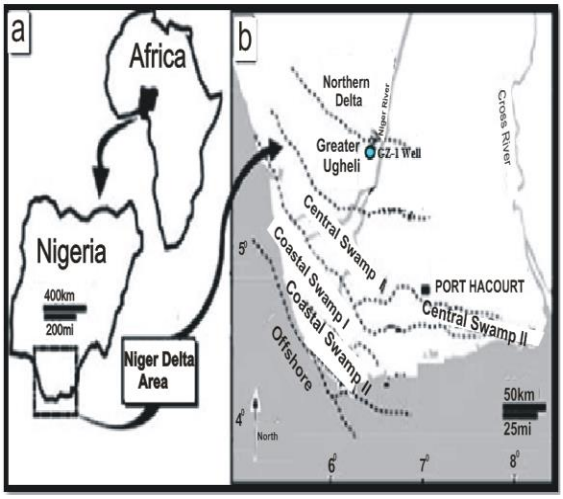

Fig. 1: Map of the Niger Delta basin showing the different depositional belts (depobelts). (After Doust and Omatsola 1990). The dot indicates the location of the study well.

Geological setting: The geology of the Niger delta has been described and defined by Short and Stauble (1967). Reijers (2011), submitted that the formation of the Niger Delta began in the Eocene, with the first deltaic sediments deposited to the south and east of the former Cretaceous coastline in the 'northern delta depo-belt'. Several transgressive and regressive events have successively taken place (Short and Stauble 1967; Evamy *et al.,* 1978) and according to Reijers (2011), these processes have given rise to the delta complex being deposited farther and farther offshore to the south. The lithofacies of the Cenozoic Niger Delta is mainly assembled into continental, transitional and marine leading to three Formations, viz., in ascending order: the Akata, Agbada and the Benin Formations. Fig. 2. The Akata Formation (marine sediments) is from Paleocene to Recent. Short and Stauble (1967); Reijers *et al.,* (1997); Doust and Omatsola (1990). The Imo shale is the outcrop equivalent categorized by continuous, uniform shale and turbidites sand deposition in marine environment. The shales of this Formation are largely under compacted. Akpoyovbike (1978). On top of the marine sequence is the Eocene to Recent Agbada Formation. Avbovbo (1978). The Agbada Formation consists of repeated coarsening-upward regressive sequences composed of shales, siltstones, and sandstones deposited in dalta front and lower delta plain settings. Weber (1971). It's establishes the actual deltaic portion of the sequence. Lambert-Aikhionbare and Ibe (1984), opined that the Agbada Formation is composed of the petroleum bearing reservoir rocks while the Akata Formation bears the source rocks. Ekweozor and Okoye (1980). Topping the sequence is generally the continental Benin Formation, which consist of a succession of Eocene to Holocene massive poorly indurated sandstones, thin shales, coals, and gravels of continental to upper delta plain origin. Okosun *et al.,* (2016). The Benin Formation is superimposed by diverse types of Quaternary deposits, Boboye and Fawora (2007), deposited on littoral and deltaic plain environments. Weber and Daukoru (1975). Fig. 2 shows the schematic representation of diachronous nature of major lithofacies units and stratigraphic relationships of clay-filled channels on the Delta Flanks.

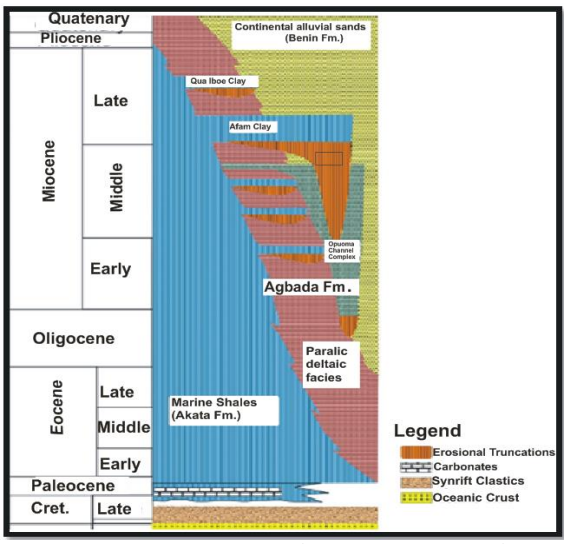

Fig 2: Schematic Representation of Diachronous Nature of Major Lithofacies Units and Stratigraphic Relationships of Clay-filled Channels on the Delta Flanks (Modified after Doust and Omatsola, 1990 and Lawrence *et al*., 2002).

MATERIALS AND METHODS

Twenty grams from each of the ditch cutting samples provided by NPDC were used for the palynological study, following the technique of Wood *et al.,* (1996). The sediment were digested for 30 minutes in 40 % hydrochloric acid to remove carbonates, then 72 hours in 48 % hydrofluoric acid for the removal of silicates. This was followed by complete neutralization with distilled water. Removal of the fluoride gel (formed during the HF treatment) was done using hot concentrated HCl acid and wet sieving the residue using a 10-µm polypropylene Estal Mono sieve. The residues were oxidized for 30 minutes in 70 % HNO_3 to render the fossils translucent for transmitted light microscopy; rinsed in 2 % K OH solution to neutralize the acid, swirled and stained with Safranin-O to increase the contrast for identification and photography. Heavy-liquid separation with $ZnBr_2$ (2.2 s.g) and separating of the remains with a 20 µm sieve. The residues were spotted with pipette on cover slip, left to dry and were then mounted on glass slides using Canada basalm as adhesive mounting medium. Palynomorph residue were then studied with a transmitted light binocular microscope to identify the different palynomorphs (pollen, spores and dinoflagellate cysts). Where possible, about 200 - 300 grains including (fern spores and pollen) were counted from each slide for quantitative palynological analysis. Photomicrographs of well-preserved palynomorphs were taken with the aid of Sony digital camera (14.1 mega pixels). Identification of Palynomorphs (pollen, spores and dinoflagellate cysts) was undertaken by matching with palynological work of relevant publications and web-based albums. The statistical data (palynological count) obtained was computerized using the StrataBug 2.0 software with depth on the y-axis and the identified taxa on the x-axis. The works of Germeraad *et al*., (1968), Evamy *et al.,* (1978) and Legoux (1978) were primarily used for the palynological zonation. Consequently, a new zonation scheme identified in this study was established and defined in this paper. Importance was placed on the First Downhole Occurrence (FDO)/Last Appearance Datum (LAP) than on the First Appearance Datum (FAP)/Last Downhole Occurrence (LDO) of chronostratigraphically significant taxa when defining palynozones to prevent the caving of microfossils associated with ditch cutting samples. Seven main zones and subzones were demarcated and two of the subzones were further subdivided into two each. Qualitative and quantitative events of both the single taxa and the whole assemblage composition establishes the sub-zones. Thus, they are subject to biological evolution/extinction in addition to palaeoclimatic and ecological factors.

RESULTS AND DISCUSSION

Palynostratigraphy in GZ-1 well: The palynological analysis yielded rich and diversified palynomorphs of seventy one genera and one hundred and one (101) species. Seventy-four (74) pollen species, fourteen (14) spore species and thirteen (13) dinoflagellate cysts species - six (6) Peridinoid cysts with seven (7) Gonyaulacoid cysts were recovered. The main assemblage were dominated by angiosperm pollen grain (dominant global flora from Late Cretaceous onwards) followed by pteridophytes/bryophyte spore. Dinoflagellate cysts, on the contrast, were less diverse while the Gymnosperm pollen were scarce. In the palynomorph proportion, miospore make up about 86.7 %. The Angiosperm pollen (70 %), Gymnosperm pollen (2.9 %), monolete spore (4.9 %), trilete spore (8.9 %) whereas marine origin (dinoflagellates cysts) make up 12.8 %. The Gonyaulacoid (6.9 %) are more dominant than Peridinoid (5.9 %) in the recovered dinoflagellate cysts. Table 1.

Table 1: Shows the count and approximate percentage value of the different palynomorphs in GZ-1 well.

Types of palynomorph	Monolete spore	Trilete spore	Angiosperm pollen	Gymnosperm pollen	Gonyaulacoid dinocysts	Peridinoid dinocysts	Total
species and their count	5	9	71	3	7	6	101
Approx. Percentage value	5	9	70	3	7	6	100

The proportion of angiosperm pollen recovered are the highest in the studied well as shown in table 1. Fig. 3 shows the area plot of the percentage value of the different palynomorphs. The following species characterized the monolete spores: *Verrucatosporites* spp., *Verrucatosporites usmensis* and *Varirugosporites* spp. while the trilete spore were characterized by - *Acrostichum aureum, Cyathidites australis, Leiotriletes* spp., *Magnastriatites howardi, Polypodiaceoisporites* spp., *Elaeis guineensis* and *Foveotriletes margaritae* among others. The gymnosperm pollen are exemplified herein by two genera - *Ephedripites* and *Podocarpidites.* They were sparsely represented in the well. The following species: *Lingulodinium* spp., *Selenopemphix* spp., *Pheiodinium africanus, Lejeunecysta* spp.,

Cordosphaeridium inodes, Operculodinium spp. among others represents the dinoflagellate cysts. The commonest species are the *Lejeunecysta* spp. Also, foraminiferal test linings, freshwater algae and fungal spores were recognized.

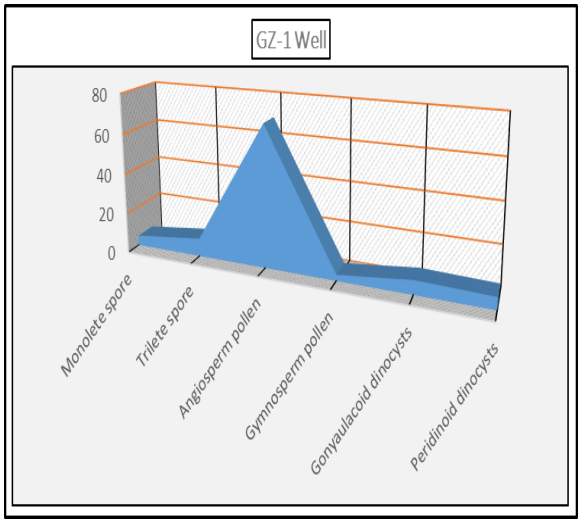

Fig. 3: Shows the area plot of the percentage value of the different palynomorphs in GZ-1 well.

Descriptions and characteristics of new zones and sub-zones in the study well: The corresponding zones compares with the zones of Germeraad *et al*., (1968); Evamy *et al.,* (1978) and Legoux (1978). Table 2 shows the abbreviations and definitions used in the zonation discussion.

Palynological zones demarcated in the studied well: Seven main zones have been documented, AF1 (*Psilatricolporites crassus* zone), AF2 (*Verrucatosporites usmensis* zone), AF3 (*Triplochiton scleroxylon* zone), AF4 (*Crassoretitriletes vanraadshooveni* zone), AF5 (*Acrostichum aureum* zone), AF6 (*Gemmatriporites ogwashiensis* zone) and AF7 (*Retitricolporites irregularis* zone). Also seven subzones were demarcated - AO1, AO2, AO3, AO4, AO5, AO6 and AO7.

Two of the subzones (AO2 and AO3) were further subdivided into (a and b). Within the Early Oligocene two sub-zones (AO1 and AO2) were established. One subzone each (AO3 and AO4) was demarcated within Early - Late Oligocene and Late Oligocene - Early Miocene.

Three subzones (AO5, AO6 and AO7) were defined within the Early Miocene. The assemblages of the new zones and sub-zones have more comprehensive explanations of their distributions and relative abundances of the component taxa present within them.

Table 4 reveals the new palynostratigraphical biozonation of the Early Oligocene - Early Miocene erected for GZ-1 well, based on pollen, spore, dinoflagellate cysts distributions and quantitative events.

ZONE AF1: (*Psilatricolporites crassus* zone) - Early Oligocene
Top of zone: QB *Striatricolpites catatumbus*
Base of zone: Not seen in the studied intervals.

Characteristics: General low/high frequencies number of palynomorph. Rare or absent of palynomorph at some depths. QT *Psilatricolporites crassus.* PO *Verrucatosporites* spp. and *Cicatricosisporites dorogensis.* DD *Pachydermites diederixi.* Complete absent of *Zonocostites ramonae*. QB *Laevigatosporites* cf. *discordatus, Retitricolporites irregularis, Praedopollis flexibilis, Racemonocolpites hians, Retibrevitricolporites obodoensis, Retitricolporites irregularis* and *Acrostichum aureum.* Rare *Ctenolophonidites costata.* RO *Protoperidiniaceae.* Presence of reworked palynomorph (*Psilatricolporites operculatus, Mauritiidites crassiexinus* and *Proxapertites cursus*). Equivalent zones**:** ?P520 -P540.

Table 2: Abbreviations used in the palynological zonation scheme for this study.

Abbreviation	Definition
FDO	First Downhole Occurrence (stratigraphic top or extinction event)
LDO	Last Downhole Occurrence (stratigraphic base or evolutionary appearance)
LAD	Last Appearance Datum
FAD	First Appearance Datum
OB	Quantitative base (a decrease in numerical abundance down-section)
QT	Quantitative top (an increase in numerical abundance down- section)
DD	Downhole decrease
PO	Peak occurrence
RO	Regular occurrence
DI	Downhole increase
TRO	Top Regular Occurrence
Spp.	Specie
Cf.	Compared with

Aff. Affinity

Table 3: Some of the recovered pollen and spore with their author references, botanical affinities and ecologies for the studied well.

Taxon, author	Botanical Affinity	Natural Habitat/Ecology
Acrostichum aureum, Kar (1992)	Polypodiaceae, Adiantaceae	Mangrove swamp
Cicatricosisporites dorogensis, Potonié and Gelletich (1933)	Schizaeaceae, Lygodiaceae, Dicksoniaceae	Mesophilous forest/Montane Forest
Crassoretitriletes vanraadshooveni, Germeraad *et al., (*1968)	Lygodium microphyllum	Humid marsh and coastal swamps
Elaies guineensis	Palmae	Rain forest
Laevigatosporites haardti, Thomson and Pflug (1953)	Polypodiacece	Mangrove swamp
Magnastriatites howardi, Germeraad *et al.,* (1968)	Parkeriaceae,Ceratopteris, Adiantaceae,	A tropical freshwater-fern
Verrucatosporites usmensis, Van Der Hammen (1956b)	Stenochlaena palustris, Polypodiaceae	Mesophilous forest/Lowland Rainforest
Ephedripites spp. Jardine and Magloire (1965)	Ephedraceae	Savanna
Podocarpus milanjianus, William *et al.,* (2013)	Podocarpaceae	Afromontane
Arecipites exilimuratus, Legoux (1978)	Arecaceae	Rain forest
Belskipollis elegans, Legoux (1978)	Acanthaceae	Montane Forest
Echiperiporites estelae, Germeraad *et al*., (1968)	Malvaceae, Thespesia populnea	Coastal swamp
Graminidites annulatus, Germeraad *et al.,* (1968)	Poaceae (Gramineae)	Savanna
Pachydermites diederixi, Salard- Cheboldaeff (1990)	Clusiaceae, Hyperiacaceae	Coastal swamp/Fresh Water Swamp
Peregrinipollis nigericus, Clarke (1966)	Caesalapinoideae	Riverine/Leguminous plants
Praedapollis flexibilis, Legoux (1978)	Fabaceae/Leguminosae?	Rain forest
Praedapollis africanus, Boltenhagen and Salard-Cheboldaeff (1973)	Fabaceae/Leguminosae?	Rain forest
Psilatricolporites crassus, Van der Hammen and Wymstra (1964)	Pelliceria, Caesalapinoideae	Mangrove swamp
Psilatricolporites operculatus, Van Der Hammen and Wymstra (1964)	Euphorbiaceae, Alchornea cordifolia	Riverine/Freshwater swamp
Racemonocolpites hians, Legoux (1978)	Palmae	Freshwater Swamp
Retibrevitricolporites obodoensis, Legoux (1978)	Euphorbiaceae/Rubiaceae	Freshwater swamp/Lowland Rain forest
Retibrevitricolporites protrudens, Legoux (1978)	Euphorbiaceae/Rubiaceae	Freshwater swamp
Retitrescolpites typicus, Sah (1967)	Oleaceae	Sub-tropical broad leaved ever green tree
Retitricolporites irregularis, Van der Hammen and Wymstra (1964)	Amanoa (Euphorbiaceae)	Freshwater swamp/Riverine
Spirosyncolpites brunii, Legoux (1978)	Loganiaceae**,** Fagraea sasakii	Rain forest
Verrutricolporites rotundiporis, Van Der Hammen and Wymstra (1964)	Crenea, Lythraceae	Mangrove/Coastal swamp
Zonocostites ramonae Germeraad, *et al.,* (1968)	Rhizophoraceae, Bruguiera, Ceriops and Caralia	Mangrove swamp

ZONE AF2: (*Verrucatosporites usmensis* zone) - Early Oligocene
Top of zone: QT *Retitricolporites irregularis*
Base of zone: QB *Striatricolpites catatumbus*
Characteristics: Several barren depth were identified within the zone. QB *Verrucatosporites usmensis,* LDO *Bombacacidites annae* and *Magnastriatites howardi.* Consistent *Retibrevitricolporites protrudens,* DD *Podocarpus milanjianus.* Rare *Graminidites annulatus.* RO freshwater swamp species and marine palynomorph - *Polysphaeridium zoharyi* and *Lejeunecysta* spp., low in abundance of mangrove swamp. *Cordosphaeridium inodes* specie is restricted to this zone of the well. Presence of reworked pollen and spore (*Mauritiidites crassiexinus, Verrucatosporites usmensis* and *Psilatricolporites operculatus*).
Equivalent zone: P560

Sub-zone AO2a: (Early Oligocene)
Top of sub-zone: QB *Verrustephanocolporites complanatus*
Base of sub-zone: QB *Striatricolpites catatumbus*
Characteristics: Consistent *Zonocostites ramonae, Pachydermites diederixi, Praedopollis flexibilis, Racemonocolpites hians, Retitricolporites irregularis, Striatricolpites catatumbus, Peregrinipollis nigericus, Verrucatosporites usmensis* toward the base of the subzone. PO *Proteacidites cooksonii.* LDO *Bombacacidites annae* and *Magnastriatites howardi.*
Equivalent zone: P560 (upper part).

Table 4: New palynostratigraphical biozonation of the Early Oligocene - Late Miocene erected for GZ-1 well, Onshore Niger Delta, based on pollen, spore, dinoflagellate cysts distributions and quantitative events. The zones are comparable with zonation scheme of Evamy *et al*., (1978); Germeraad *et al*., (1968) and Legoux (1978).

Period/Epoch	Age	PALYNOLOGICAL ZONE/SUBZONE				Zone (this study)		Zonal markers and palynological events	Subzone (this study)		Subzonal markers and palynological events
		Germeraad *et al.*, (1978)	Legoux (1978)	Evamy *et al.*, (1978)							
Early Miocene	Burdigalain	*Crassoretitriletes varaadshooveni*	E2-1	P600	?P670	AF7	*Retitricolporites irregularis*	PO *Polypodiaceoisporites retirugatus* and *graminidites annulatus*. QT *Zonocostites ramonae RO Gemmatriporites ogwashiensis*	AO7		Rare/consistent /common/abundant of palynomorph recovery in the zone. QB *Gemmatriporites ogwashiensis, Psilatricolporites operculatus.* QT *Magnstriatites howardi* and *Acrostichum aureum*. RO *Graminidites annulatus, Zonocostites ramonae.* The presence of reworked sediments (*Psilatricolporites operculatus*). The zone is completely devoid of marine-derived fossils QT *Striatricolpites catatumbus*, QT *Gemmatriporites ogwashiensis*
					P650	AF6	*Gemmatriporites ogwashiensis*	Abundant *Zonocostites ramonae* and *Gemmatriporites ogwashiensis* QB *Acrostichum aureum*	AO6		Abundant pollen *Zonocostites ramonae* and *Psilatricolporites crassus*, freshwater swamp species - *Retitricolporites irregularis.* RO *Magnastriatites howardi* and *Psilatricolporites operculatus*, *Praedopollis flexibilis, Racemonocolpites hians, Striatricolpites catatumbus.* FDO *Brevitricolporites guinetii, Proteacidites cooksonii, Brevitricolporites molinae*. Consistent *Graminidites annulatus* as compared with the underlying zone. LDO *Retitriporites boltenhagenii*. Presence of reworked sediments (*Mauritiidites crassiexinus, Proteacidites sigalii, Proxapertites cursus*). FDO *Proxapertites cursus*
	Aqui – Burd.		C2 - D		P630	AF5	*Acrostichum aureum*	QB *Zonocostites ramonae* PO *Crassoretitriletes vanraadshooveni*	AO5		Rare/consistent mangrove pollen *Psilatricolporites crassus, Gemmatriporites ogwashiensis*, rain forest pollen *Praedapollis flexibillis.* FDO *Retimonoolpites irregularis,* *Echitriporites* spp., cf. *Psilatricolporites crassus*. Rare *Graminidites annulatus* and *Polysphaeridium zoharyi.* Reworked sediments (*Proteacidites sigalii* and *Psilatricolporites operculatus*). Acme event of *Zonocostites ramonae.* TRO *Verrucatosporites usmensis*
Late Oli.- Early Mio.	Cha. – Aqui.	*Magnastriatites howardi*	B3 - C1		P620	AF4	*Crassoretitriletes vanraadshooveni*	TRO *Verrucatosporites usmensis, Retimonocolpites irregularis*, abundant *Zonocostites ramonae*	AO4		General rare/consistent/common/abundant recovery of palynomorph in this zone. Rare *Bombacacidites annae, Marginipollis concinnis, Graminidites annulatus.* FDO *Cicatricosisporites dorogensis*, aff. *Retitricolpites bendeensis.* Acme event of *Acrostichum aureum.* Abundant occurrences of mangrove swamp pollen - *Zonocostites ramonae, Acrostichum aureum*, relative abundance of savanna pollen *Peregrinipollis nigericus*, fresh water swamp pollen - *Striatopollis catatumbus* and *Retitricolporites irregularis.* RO *Verrucatosporites usmensis* and *Lejeunecysta* spp. Event of *Crassoretitriletes vanraadshooveni*. TRO *Polypodiaceoisporites retirugatus*
E. - Late Oligo	Rup. - Chattian		B2-1	P500	P580	AF3	*Triplochiton scleroxylon*	TRO *Polypodiaceoisporites retirugatus.* FDO *Triplochiton scleroxylon*	AO3	b	Rare/consistent of most palynomorph comperative to the underlying subzone. Rare *Zonocostites ramonae*. TRO *Pachydermites diederixi, Racemonocolpites hians, Retitricolporites irregularis, Acrostichum aureum, Verrucatosporites* spp., *Praedopollis africanus* RO *Retimonocolpites irregularis*
										a	Consistent/common *Acrostichum aureum, Verrucatosporites* spp. PO *Triporotetradites* aff. *letouzeyi, Verrucatosporites usmensis.* Rare most of the palynomorph. LDO *Gemmatriletes clavatus, Anthocleista cf. vogeli, Psilatricolporites annuliporis.* QT *Retitricolporites irregularis*
Early Oligocene	Rupelian		A		P560	AF2	*Verrucatosporites usmensis*	QB *Verrucatosporites usmensis*, Consistent *Retibrevitricolporites protrudens*, DD *Podocarpus milanjianus* QT *Psilatricolporites crassus*	AO2	b	Rare/consistent/common of most palynomorph comperative to the underlying subzone. LDO *aff. Selaginella myosurus,* Event *Podocarpus milanjianus.* FDO *Leiotriletes* spp., *Magnomonoporites gemmatus* . RO marine palynomorph - *Polysphaeridium zoharyi* and *Lejeunecysta* spp. QB *Verrustephanocolporites complanatus*
										a	Consistent *Zonocostites ramonae, Pachydermites diederixi, Praedopollis flexibilis, Racemonocolpites hians, Retitricolporites irregularis, Striatricolpites catatumbus,* *Peregrinipollis nigericus, Verrucatosporites usmensis* toward the base of the subzone. PO *Proteacidites cooksonii*. LDO *Bombacacidites annae, Magnastriatites howardi.* QB *Striatricolpites catatumbus*
					?P540–P520	AF1	*Psilatricolporites crassus*	DD *Pachydermites diederixi*. QB *Acrostichum aureum*	AO1		General low/high frequencies number of palynomorph. QB *Laevigatosporites* cf. *discordatus, Retitricolporites irregularis, Praedopollis flexibilis, Racemonocolpites hians, Retibrevitricolporites obodoensis, Retitricolporites irregularis.* PO *Verrucatosporites* spp., *Cicatriocosissporites dorogensis.* Rare *Ctenolophonidites costata.* RO *Protoperidiniaceae.*

Sub-zone AO2b: (Early Oligocene)
Top of sub-zone: QT *Retitricolporites irregularis*
Base of sub-zone: QB *Verrustephanocolporites complanatus*
Characteristics: Rare/consistent/common of most palynomorph comparative to the underlying subzone. LDO aff. *Selaginella myosurus,* Event of *Podocarpus milanjianus.* FDO *Leiotriletes* spp. and *Magnomonoporites gemmatus.* RO marine palynomorph - *Polysphaeridium zoharyi* and *Lejeunecysta* spp.
Equivalent zone: P560 (lower part).

ZONE AF3: (*Triplochiton scleroxylon* zone) Early - Late Oligocene
Top of zone: TRO *Polypodiaceoisporites retirugatus*
Base of zone: QT *Retitricolporites irregularis*
Characteristics: Common freshwater swamp and lowland rainforest species. Rare *Graminidites annulatus.* Presence of reworked pollen and spore (*Psilatricolporites operculatus, Proteacidites sigalii* and *Verrucatosporites usmensis*). PO *Triporotetradites* aff. *Letouzeyi.* Abundant mangrove swamp pollen. FDO *Triplochiton scleroxylon*. QT *Polysphaeridium zoharyi* and QB *Lejeunecysta* spp. RO aff. *Retitricolpites bendeensis.*
Equivalent zone: P580.

Sub-zone AO3a: (Early - Late Oligocene)
Top of sub-zone: RO *Retimonocolpites irregularis*
Base of sub-zone: QT *Retitricolporites irregularis*
Characteristics: Consistent/common *Acrostichum aureum, Verrucatosporites* spp. PO *Triporotetradites* aff. *letouzeyi, Verrucatosporites usmensis.* Rare most of the palynomorph. LDO *Gemmatriletes clavatus, Anthocleista* cf. *vogeli, Psilatricolporites annuliporis.*
Equivalent zone: P580 (lower part).

Sub-zone AO3b: (Early - Late Oligocene).
Top of sub-zone: TRO *Polypodiaceoisporites retirugatus*
Base of sub-zone: RO *Retimonocolpites irregularis*
Characteristics: Rare/consistent of most palynomorph comparative to the underlying subzone. Rare *Zonocostites ramonae*. TRO *Pachydermites diederixi, Racemonocolpites hians, Retitricolporites irregularis, Acrostichum aureum, Verrucatosporites* spp. and *Praedopollis africanus.*
Equivalent zone: P580 (upper part).

ZONE AF4: (*Crassoretitriletes vanraadshooveni* zone) Late Oligocene - Early Miocene
Top of zone: TRO *Verrucatosporites usmensis*
Base of zone: TRO *Polypodiaceoisporites retirugatus*
Characteristics: General rare/consistent/common/abundant recovery of palynomorph in the zone. Rare *Bombacacidites annae, Marginipollis concinnis, Graminidites annulatus*. FDO *Cicatricosisporites dorogensis,* aff. *Retitricolpites bendeensis.* Acme event of *Acrostichum aureum.* Abundant occurrences of mangrove swamp pollen - *Zonocostites ramonae, Acrostichum aureum,* relative abundance of savanna pollen *Peregrinipollis nigericus,* fresh water swamp pollen - *Striatopollis catatumbus* and *Retitricolporites irregularis. T*RO *Verrucatosporites usmensis* and *Retimonocolpites irregularis.* RO *Lejeunecysta* spp. Event of *Crassoretitriletes vanraadshooveni* restricted to this zone of the well. The presence of reworked sediments (*Ephedripites* spp., *Verrucatosporites usmensis, Psilatricolporites operculatus*).
Equivalent zone: P620

ZONE AF5: (*Acrostichum aureum* zone) - Early Miocene
Top of zone: FDO *Proxapertites cursus*
Base of zone: TRO *Verrucatosporites usmensis*
Characteristics: Rare/consistent mangrove pollen *Psilatricolporites crassus, Gemmatriporites ogwashiensis,* rain forest pollen - *Praedopollis flexibilis.* FDO *Retimonocolpites irregularis, Echitriporites* spp., cf. *Psilatricolporites crassus*. Rare *Graminidites annulatus* and *Polysphaeridium zoharyi.* The presence of reworked sediments (*Proteacidites sigalii* and *Psilatricolporites operculatus*). Acme event of *Zonocostites ramonae.*
Equivalent zone: P630

ZONE AF6: (*Gemmatriporites ogwashiensis* zone) - Early Miocene
Top of zone: QT *Striatricolpites catatumbus,* QT *Gemmatriporites ogwashiensis*
Base of zone: FDO *Proxapertites cursus*
Characteristics: Abundant occurrences of mangrove swamp vegetation pollen - *Zonocostites ramonae* and *Psilatricolporites crassus,* freshwater swamp species - *Retitricolporites irregularis.* Abundant *Gemmatriporites ogwashiensis.* RO *Magnastriatites howardi* and *Psilatricolporites operculatus, Praedopollis flexibilis, Racemonocolpites hians, Striatricolpites catatumbus.* FDO *Brevitricolporites guinetii, Proteacidites cooksonii, Brevitricolporites molinae.* Consistent *Graminidites annulatus* as compared with the underlying zone. LDO *Retitriporites boltenhagenii*. Presence of reworked sediments (*Mauritiidites crassiexinus, Proteacidites sigalii, Proxapertites cursus*).
Equivalent zone: P650

ZONE AF7: **(***Retitricolporites irregularis* zone) - Early Miocene
Top of zone: Not seen in studied sections.

Base of zone: QT *Striatricolpites catatumbus,* QT *Gemmatriporites ogwashiensis*
Characteristics: Rare/consistent /common/abundant of palynomorph recovery in the zone. QB *Gemmatriporites ogwashiensis, Psilatricolporites operculatus.* QT *Magnastriatites howardi* and *Acrostichum aureum*. RO *Graminidites annulatus* and *Zonocostites ramonae.* PO *Polypodiaceoisporites retirugatus*. The presence of reworked sediments (*Psilatricolporites operculatus*). The zone is completely devoid of marine-derived fossils.
Equivalent zone: **?**P670

Dating of the zonation scheme: The ages assigned to the zones and sub-zones are shown in table 4, that demonstrates relationships to the previous schemes of Germeraad *et al*., (1968), Evamy *et al.,* (1978) and Legoux (1978).

Early Oligocene: The upper part of the Early Oligocene age (P560) was delineated in GZ-1 well at 9447 ft. based on the increase of *Retibrevitricolporites obodoensis/protrudens.* Oboh *et al.,* (1997), used the presence of the specie *Retibrevitricolporites obodoensis* to define the Oligocene age. The specie *Loranthacites natalie* recovered in Oligocene sediment likewise agrees with the work of Salard-Chebodaeff (1990), who age dated the Oligocene to Eocene strata in Cameroun, Gabon and Congo using *Loranthacites natalie* specie. P540 was not delineated in the well due to the absence of *Arecipites exilimuratus*. The lower part of the Early Oligocene (P520) was demarcated at 10,172 ft. established based on the occurrence of *Racemonocolpites hians.* The marine dinoflagellate cysts encountered in the studied well generally come to an agreement with the sporomorph date mentioned above. Durugbo (2013), recorded *Lejeunecysta* and *Selenopemphix* spp. as developed during the Palaeocene and had their peak all through the Oligocene in the Niger Delta, Nigeria. Similarly, Bruno *et al.,* (2011), identified abundant and fairly well-preserved dinoflagellate cysts which enabled the recognition of Oligocene age using largely *Lejeunecysta* species signified by cf. *Lejeunecysta communis, Lejeunecysta lata, Lejeunecysta* spp. cf. *Lejeunecysta granosa,* cf. *Lejeunecysta globosa, Lejeunecysta beninensis* and additional dinoflagellate cysts such as *Pheiodinium magnificum, Pheiodinium africanum, Tuberculodinium vancampoae, Selenopemphix nephroides* and *Cordosphaeridium inodes.* The Oligocene age was delineated by Biffi and Grignani (1983), based on *Pheiodinium magnificum, Pheiodinium africanum* with various species of *Lejeunecysta* and *Selenopemphix* recovered from the Niger Delta sediments. *Pheiodinium africanum* was used in association with species of *Lejeunecysta* represented by *Lejeunecysta* spp. cf. *L granosa, Selenopemphix nephroides* and *Cordosphaeridium inodes* to support the sporomorphs marker species to establish the Oligocene age in the studied well.

Late Oligocene: The quantity base of *Peregrinipollis nigericus* define the base of the latest Oligocene age in the well. This is similar to the palynological zonal scheme (P580) of Evamy *et al.,* (1978) of the Niger Delta Basin, *Magnastriatites howardi* zone of Germeraad *et al.,* (1968) and latest Oligocene (Chattian) spores and pollens B2-1 zone of Legoux (1978). The late Oligocene age was demarcated at 6725 ft. based on the quantity base of *Peregrinipollis nigericus*. Essien *et al.,* (2016), Adeigbe and Ochigbo (2017), used similar palynomorph to age date Middle Miocene to Early Oligocene sediment. The late Oligocene interval is also categorized by significant reduction in percentage of occurrences of *Zonocostites ramonae* as recorded in the well.

Oligocene/Miocene Boundary: The First Downhole Occurrence (FDO) of *Cicatricosisporites dorogensis* is generally used as an Oligocene/Miocene boundary marker specie in Nigeria. Germeraad *et al.,* (1968), Legoux (1978), had assigned the age range of the Agbada Formation between Oligocene and Early Miocene using the same marker specie. Essien *et al.,* (2016) and Artzner and Dorhofer (1978), delineated the Oligocene/Miocene boundary (O/M) boundary by the FDO of *Cicatricosisporites dorogensis* and the Last Downhole occurrence (LDO) of *Verrutricolporites laevigatus.* The FDO occurrence of *Cicatricosisporites dorogensis* identified at 5688 ft. was used to define Oligocene/Miocene boundary in the well.

Early Miocene: Early Miocene age (P620) was delineated in the present study based on the First Downhole Occurrence of *Praedapollis africanus* at 4962 ft. This agrees with the work of Legoux (1978), who used the marker specie to establish the early phase of Miocene and is also comparable to the submission of Evamy *et al.,* (1978) (P620) for the Niger Delta, Nigeria. Aquitanian to Burdigalian (P630) age was delineated at 4039 ft. based on the increase of *Praedapollis flexibillis*. Burdigalian (P650) age was delineated at 3186 ft. based on the quantity base of *Magnastriatites howardi* marker specie. Adeigbe and Ochigbo (2017), had delineated age range from Middle Miocene to Early Oligocene using *Magnastriatites howardi, Praedapollis flexibillis, Praedapollis africanus, Cicatricosisporites dorogensis, Peregrinipollis nigericus, Retibrevitricolporites obodoensis/protrudens, Arecipites exilimuratus* and *Racemonocolpites hians* species. Oloto (2014),

likewise used the occurrence of *Verrutricolporites rotundiporis* and *Praedapollis africanus* occurrence to support the existence of P620-P770 subzone (Early-Middle Miocene). According to Germeraad *et al.,* (1968), Rhizophora (*Zonocostites ramonae*) is absent from pre-Miocene sediments and start occurring abruptly in high percentages in the lowermost Miocene. From the record of this pollen in the well, it agrees with the report of Germeraad *et al.,* (1968).

Seven main zones have been documented, AF1, AF2, AF3, AF4, AF5, AF6 and AF7 in this study. Boundaries of the AF zones corresponds with the P500 and P600 zone and sub-zones P520, ?P540, P560, P580, P620, P630. P650 and ?P670 of Evamy *et al*., (1978) with more inclusive descriptions of the distributions and relative quantities of the constituent taxa obtained. The supreme important indicator taxa (zonal markers) are *Psilatricolporites crassus, Verrucatosporites usmensis, Triplochiton scleroxylon, Crassoretitriletes vanraadshooveni, Acrostichum aureum, Gemmatriporites ogwashiensis* and *Retitricolporites irregularis.* Zones AF1, AF2 and AF3 (P520 - ?P540, P560 and P580) were characterized by sporomorph marker species (*Racemonocolpites hians, Retibrevitricolporites obodoensis* and *Peregrinipollis nigericus)* in association with marine species of *Pheiodinium africanum Lejeunecysta* spp. cf. *L granosa, Selenopemphix nephroides* and *Cordosphaeridium inodes* in establishing the Oligocene age. Zones AF4, AF5 and AF6 (P620, P630 and P650) were defined by FDO of *Praedapollis africanus, increase of Praedapollis flexibillis* and base quantity of *Magnastriatites howardi.*

Some finer scale subdivisions were, conversely, recognized in the present study. All the zones have subzones (AO1, AO2, AO3, AO4, AO5 AO6 and AO7). Subzone AO2 and AO3 were further subdivided into a and b each. These sub-zones are based on qualitative and quantitative occurrences of individual taxa and general assemblage component, subject to biological development/extermination in addition to palaeoclimatic and ecological factors.

The new palynological zonation scheme of this study uses a combination of stratigraphical tops and bases as GZ-1 well quantitative changes. The several zones and subzones were demarcated with the assistance of the recovered pollen and spores botanical and ecological affinities. Mangrove in association with fresh water swamp and rainforest vegetation pollen and spore ascribed to Polypodiaceae, Parkeriaceae, Lygodiaceae, Euphorbiaceae, Clusiaceae, Pelliceria, Caesalapinoideae, Palmae and Rhizophoraceae families are the main palynomorphs recovered in all zones resulting from assemblages of plants that are currently prevalent in the Niger Delta. The *Podocarpus milanjianus* pollen, charred cuticle and possibly some Poaceae pollen could have been transported by air to the locations where they were deposited from areas within the inland savannah regions.

Conclusion: Palynological studies have recognized a new detected developments in the varieties of key pollen and spore taxa. Seven main zones have been documented, AF1, AF2, AF3, AF4, AF5, AF6 and AF7 which were further subdivided into seven subzones with some having finer subdivisions with age ranged from Early Oligocene to Early Miocene. Previous undocumented occurrence trends of important indicator taxa of spores and pollen have assisted improvement of formerly used palynological zonation schemes in the Niger Delta. It is anticipated that this quantitative zonation scheme erected, will help with imminent palynostratigraphical studies in the area.

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