Palynozonation and Lithofacies Cycles of Paleogene to Neogene Age Sediments in PML-1 Well, Northern Niger Delta Basin.

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ABSTRACT

Results of quantitative palynomorph species analysis from a depth range of 318 - 2073 m of well PML-1 in the northern Niger Delta depo belt were synthesized with lithofacies results to erect a lithostratigraphic sequence for the well area. Quantitative palynomorph analysis within the well PML-1 enabled the erection of two palynozones (*Ephedra claricristata and Auricupollenites echinatus* Range zones) of Oligocene (Late Rupelian and Chattian stage) and three palynozones (*Verrutricolporites laevigatus / Verrutricolporites scabratus* Range zone and *Verrutricolporites rotundiporus and Margocolporites* sp. Abundance zones) of Early - Late Miocene.

The *Ephedra claricristata and Auricupollenites echinatus* Range zones occupy depth ranges of 2054 – 2073 m and 1999 – 2036 m respectively, and correlate with the Ameki Formation. The *Verrutricolporites laevigatus/Verrutricolporites scabratus* Range zone and *Verrutricolporites rotundiporus and Margocolporites* sp. Abundance zones occur within depth ranges of 1780 – 1945 m, 1725 – 1743 m and 1195 – 1707 m respectively and are within the Agbada Formation.

A synthesis of gross sedimentologic characteristic revealed a cyclic association of twelve lithofacies types. Analysis of lithofacies characteristic and association in the lower section of the studied interval correlated the section with the Ameki Formation and overlain by the Agbada and Benin Formations at higher stratigraphic horizons in this part of the north-western Niger Delta Basin.

(Keywords: palynozones, lithofacies, Niger Delta, Oligocene, Miocene, Ameki Formation)

INTRODUCTION

Earlier works on the establishment of the Niger Delta stratigraphy achieved in no small measure the division of the sedimentary package of the Delta into three formational units: the basal marine Akata Shale, middle Agbada sand and shale and the top Benin sand and sandstone Formation (Short and Stauble, 1967), although largely based on lithostratigraphy. These formations have been correlated updip with stratigraphic units in the flank areas of the delta and in the southern edge of the Cretaceous Anambra Basin, formed during the Cretaceous-Tertiary sedimentary times.

The definition of the actual lithostratigraphic sequence of the northern Niger Delta of which this study is a part, could pose some challenges when working with well samples. The complication that normally arises is attributed to cyclic sedimentation occasioned by sea level changes through time in the course of deposition of the Delta sedimentary pile. The cyclic occurrence of facies could be easily misleading in trying to assign well sections to formational units.

The lithostratigraphic pile of the Niger Delta Basin can only be correctly ascertained when lithologic characteristics are used with age and depositional data in assigning a particular section/interval to a specific formational unit. This is seen in the work of Murat (1972) on the stratigraphy of the flank area of the Niger Delta, who concluded based on lithostratigraphic data, that the Oligocene Ogwashi-Asaba Formation was missing from the stratigraphy of the Benin Flank, and that the Niger Delta Benin Formation rest unconformably on the Eocene Ameki Formation. In the northern Niger Delta, we believe the sequence of event can only be correctly established if age data set is closely used with lithofacies data. Age determination and stratigraphic division of the sedimentary sequence in the petroliferous Niger Delta Basin is important in the correlation of intervals of interest both at the field and basin-wide scales.

Biozonation as a stratigraphic technique as used in this study has been employed in correlation of geologic sequences based on the appearance, extinction, occurrence and co-occurrence, abundance, absence, etc. of fossil species in sediments. The use of palynological components in sediment for zonation of sedimentary piles and applied in basin analysis has become increasingly important in recent times (Chow, 1995; Helenes et al. 1998; Morley, 2000; Sowunmi, 2004; Barreda et al. 2009).

Palynological research form a strong component of applied research in the petroleum industry aimed at resolving challenges associated with stratigraphic and facies complexities. The choice of fossil species in this study is because palynomorphs has a pivotal advantage over other microfossil groups by being both autochthonous and allochthonous in nature, abundant and commonly preserved in both continental and marine deposits. The abundance of these forms in the fossil record enables statistical treatment to reveal correlatable biosignals in both onshore and offshore deposits, thereby placing event in a biochronological order.

Biochronological correlation of sedimentary packages is directed towards the realization of obtaining a clear picture of sedimentation and ancillary geologic events in time and space, thus giving a clear insight into the configuration of subsurface geologic elements such as reservoirs, seals and fairways. Correlation based on rock fossil content has an unusual advantage of elucidating the paleodepositional settings under which the sediments were laid down.

There has been substantial improvement in stratigraphic resolution through the application of palynological methods aimed at identifying events which reflect paleoclimatic, tectonic, orographic and sea level changes but without resulting in widespread extinction of plant taxa (Morley, 1991). The potential of palynological studies is gradually been realized in the Niger Delta Basin, although much still needs to be done. The work of Gemeraad et al. (1968) on the Palynology of Tropical Areas, remain the most comprehensive work to date.

Specific lithofacies characterize different depositional environments. These facies are formed in association with like facies. Facies generators include both auto and allocyclic factors operative within depositional settings. Each of these settings produce a set of facies association that characterize individual formation and thus acts as a basis for differentiating and distinguishing formational units. In complex settings as exemplified by the Niger Delta, the sole application of lithofacies association may prove substantially inadequate.

In this study, we attempt a characterization of lithofacies and age-date the sediments using recovered palynomorph assemblage; evaluate their first and last appearance datum (FAD and LADs), occurrence and co-occurrence and/or absence from the well section of well PML-1 for the purpose of zoning the sediments into age-correlatable units that fits into formational units. Results obtained in this study is hoped to be useful in correlation studies in other parts of the Niger Delta and adjoining basins.

GEOLOGIC SETTING

The Niger Delta lies between longitudes 5° and 8.4°E and latitudes 3° and 6°N (Figure 1) within the coastal area of the Gulf of Guinea. It covers an area of about 75,000km^2 with an overall regressive fill of about 12,000m (Doust and Omatsola, 1990; Reijers, 1996).

The Niger Delta Basin is considered to have been built out over a crustal tract on the trailing edge of the African continent, and can be classified as a marginal sag basin based on Kingston et al. (1983) basin classification model. The Niger Delta Basin is bounded to the north by the Cretaceous Anambra Basin, to the east by the Calabar Flank and Abakaliki Anticlinorium and to the west by the Benin Flank, while the Atlantic Ocean forms its southern limit. It is building out into the Atlantic

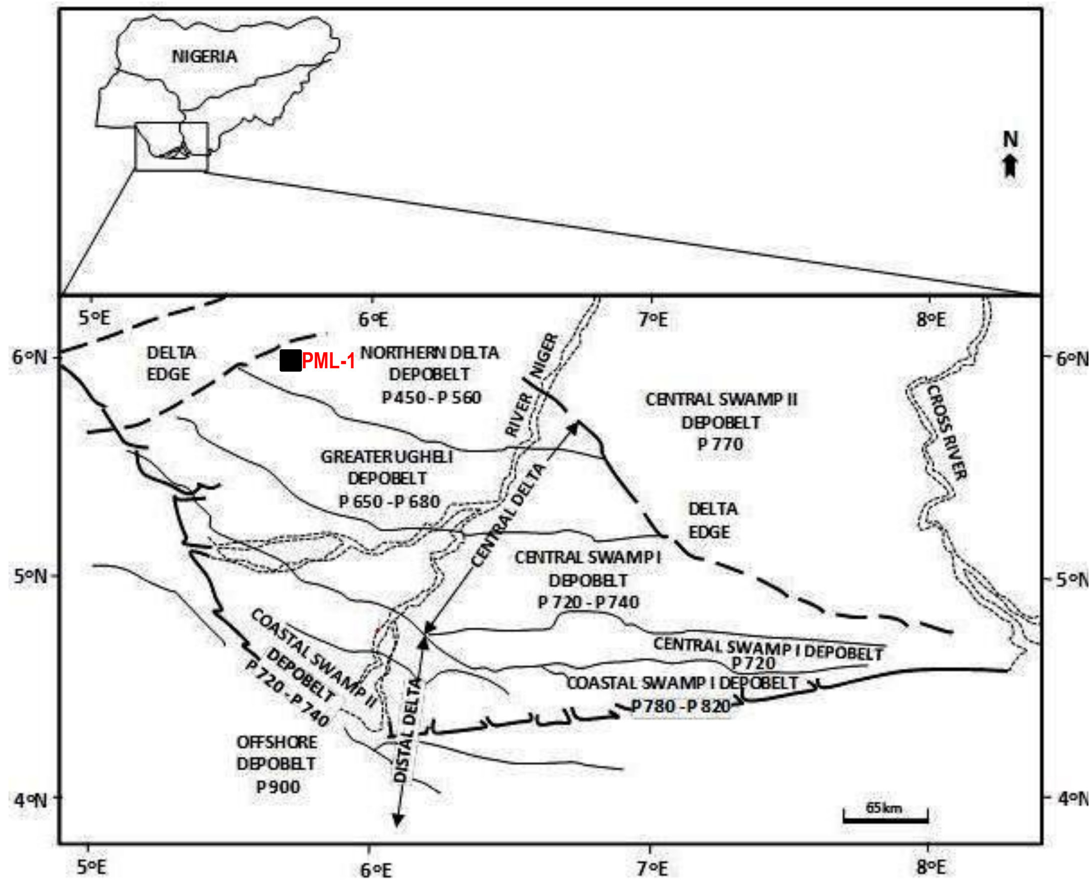

Figure 1: Map of Niger Delta Basin Showing the Locations and Depobelts in which PML-1 Well is Located (Modified after Doust and Omatsola 1990).

Ocean at the mouth of the Niger-Benue and Cross River drainage systems and extends more than 300km from the proximal to distal ends (Reijers, 1996). It has prograded from the Eocene to Recent southwards (Reijers, 1996; 2011), forming successive depobelts that represent the most active portion of the delta at each stage of its development. Although the sedimentary wedge is dominated by prograded material, it contains major transgressive marine sequences that contribute to making its geology complex.

The tectono-stratigraphic history of the Niger Delta Basin reveals that the basin represents the third cycle in the evolution of the southern Nigerian sedimentary basinal element (Murat, 1972; Weber and Daukoru, 1975). The Niger Delta Basin has evolved through time, controlled by pre- and synsedimentary tectonics (Evamy et al. 1978; Ejedawe, 1981; Knox and Omatsola, 1987; Stacher, 1995), climatic variations and the proximity and nature of sediment source area (Reijers, 2011)

Based on the dominant sedimentologic characteristics influenced by depositional conditions, the sedimentary pile is divided into three main age-diachronous lithostratigraphic formational units, the Akata, Agbada and Benin Formations (Short and Stauble, 1967). The sedimentologic complexity presented by these formations has informed recent proposals of the upgrade of the formations to the status of groups (Reijers, 2011).

MATERIALS AND METHODS

Lithological and textural analysis was carried out on ninety two (92) non-composited ditch cutting samples within a depth range of 318 – 2073 m from well PML-1 located in the northern Niger Delta depobelt (Figure 1). Samples were described under a stereo microscope for whole rock characteristics which included grain morphology, sorting, dominant grain population, and presence of accessory minerals and carbonaceous material. Twenty five (25) of these non-composited samples (Fig. 2) were selected for palynological sample processing based on the following criteria: facies, resolution, interval of interest, and confirmation of sedimentological results. Sampling intervals varied for different sections of the well due to depth occurrence of suitable lithologies for biostratigraphic purpose.

Thus sampling for the lower section of the well which occupies a depth range of 1999 – 2073 m, range from 18 – 19 m (sampling interval mean = 18.5 m). The mid section with a depth range of 1469 – 1945 m, had a sampling range of 9 – 73 m, with mean sampling interval value of 43.3 m, while the upper section of the well which range in depth from 318 – 699, with more sandy lithologies, had a sampling range of 18 – 239 m, with a mean sampling interval value of 135 m. Samples were processed by standard method described by Traverse (1988).

These samples were subjected to various stages of acid treatment followed by sieving, density separation and concentration of organic matter through centrifuging, staining with appropriate dye (Safranin O), mounting on slides with mounting medium (Norland) and then covering with cover slips. Prepared slides were studied under x40 and x100 objectives using an Olympus CH30 camera-attached microscope. Species were identified with reference to published literatures, and photomicrographs of index taxa taken. All dinocysts, pollen and spores encountered were included in the total palynomorph count, on which the percentage composition of individual pollen, spore and dinocyst species at respective depths was based.

In age-dating the sediments of the well section, zonal division based on the distribution of pollen species in the well was carried out. The zones (Figure 2) were delineated by the first and last occurrence, and presence and/or abundance of two or more species.

The ages of the delineated zones were determined by comparison with established zones, used and correlated with the Geological Time Scale (e.g., Germeraad et al. 1968; Legoux, 1978; Evamy et al. 1978; Frederiksen, 1980a; Salard-Cheboldaeff, 1990; Salami, 1990; Shaw, 1998, 1999; Oloto, 1994, 2009; Guerstein et al. 2004; Graham et al. 2000; Brown and Loucks, 2009; Lucas and Ishiekwene, 2010; Dickey and Yancey, 2010; van Geel et al. 2011, etc.). The determined ages were thus used in conjunction with results derived from lithofacies analyses above to established and draw up the lithostratigraphy for the well area.

RESULTS AND DISCUSSION

Sedimentological/Lithofacies Analysis

A synthesis of gross lithologic and grain attributes derived from grain microscopy enabled the definition of facies types for the well section. Two lithotypes (sand and shale) and twelve lithofacies (medium-grained sand, shaly medium-grained sand, coarse-grained sand, shaly coarse-grained sand, shaly very coarse-grained sand, very coarse-grained sand, shaly pebbly sand and pebbly sand, sandy silty shale, sandy shale, calcareous shale, fissile dark grey glauconitic shale), are defined as shown in Table 1 and Figure 2.

The distribution of the various facies identified in the well section revealed a prominent cyclic pattern probably generated by the inter play of auto and allogenic constraints. Three formational units have been distinguished in this study. These include the Ameki, Agbada and Benin Formations.

Palynomorph Taxa and Zonation

The sediments yielded rich and well preserved pollen and spores, from which forty one species was recovered. The microfloral assemblage is dominated by land derived forms. Few dinocysts were recovered from the entire well section. The spore species present in the samples were noted to be dominated by long-ranging species, hence not suitable for the needed resolution required in this study. The pollen assemblage was thus solely relied upon as they presented a better appearance and disappearance signatures in the well section. Three Range and two Abundance zones were defined in the well section, ranging from Early Oligocene to Late Miocene (Table 2, Figure 3). Two zones were defined for the Oligocene, while three zones were defined for the Miocene.

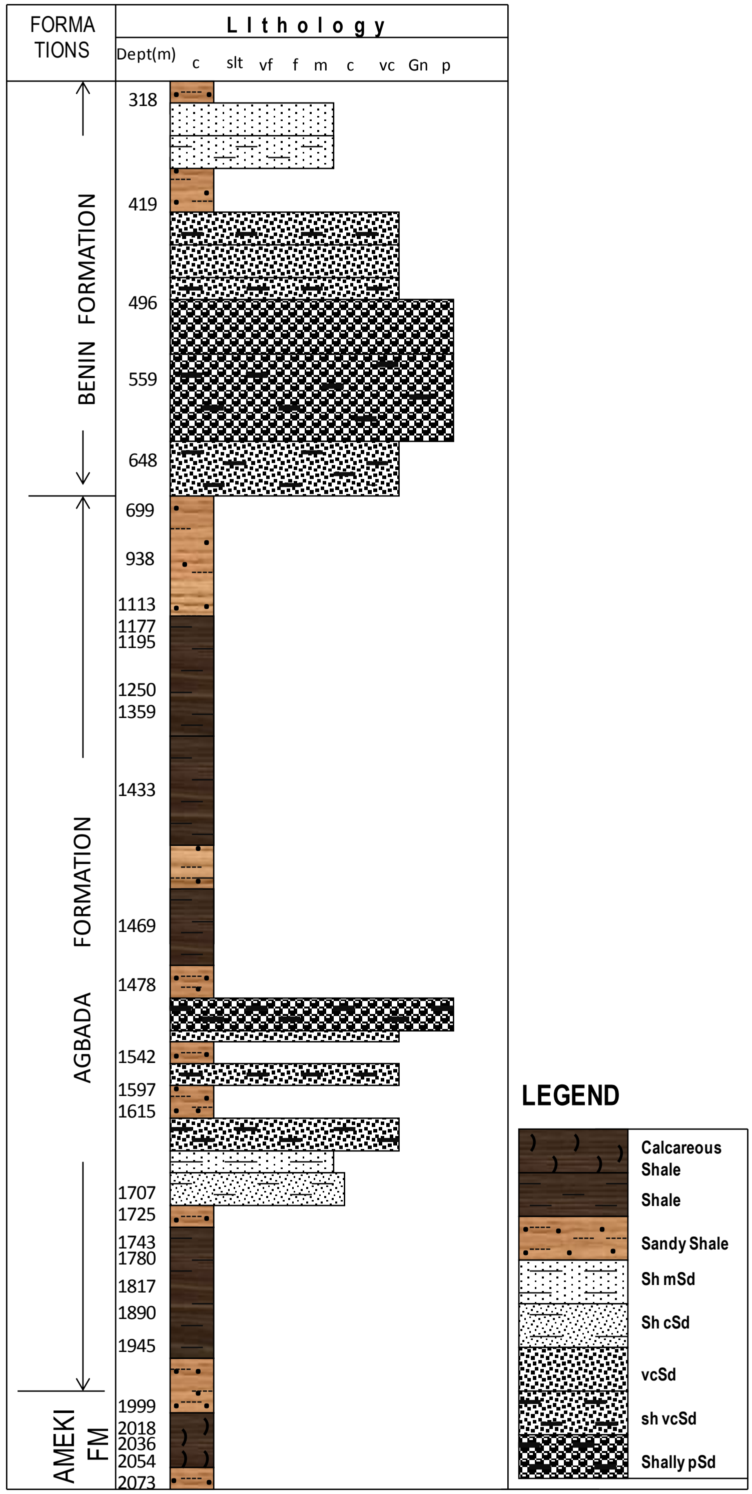

Figure 2: Lithologic Log of Well PML-1 Showing the Different Lithotypes and Lithofacies Described in the Well Section (Depth Values Show Sampling Points).

Table 1: Lithotypes and Lithofacies Recognized in Well PML-1 Section.

	FACIES			
LITHOTYPES	***FT***	***Lithofacies Name***	**Short description**	**Dept (m) of occurrence**
Sand	1	Very coarse sand	Grain size ranged from medium – pebbly, angular – subr, poorly sorted sand grains. $CaCO_3$ cement and black carbonaceous material present	471.
	2	Shaly very coarse sand	Very coarse-grained sands composed of very fine-pebbly subangular-subrounded quartz grains, poorly sorted, contains up to 14% shale.	445, 496, 648 - 673, 1524, 1561, 1634 - 1652
	3	Shaly coarse-grained sand	Composed of very fine – pebbly sub< - subr quartz grain. Poorly sorted, contains about 12% shale	1689 - 1703
	4	Coarse-grained sand	Composed of very fine – pebbly sub< - subr quartz grain. Poorly sorted,	1689 - 1707
	5	Shaly medium-grained sand	Medium-grained sand composed of very fine – small pebbly sub< - subr grains, poorly sorted, grey colored	369, 1670
	6	Medium-grained sand	Composed of very fine – very coarse sub< - < sand grains, black coaly materials common, moderately well sorted	343
	7	Pebbly sand	Grain size ranged from medium – pebbly sub< – r medium – well sorted sand grains. Coaly material present. Light grey in colour.	509 - 534.
	8	Pebbly shaly sand	Predominantly pebbly, with very fine–pebbly sub<r- subr quartz grains, moderately well sorted	1487 - 1506, 559 - 622.
Shale	9	Fissile dark grey glauconitic shale	Fissile dark grey shale with altered glauconite, common black carbonaceous material	1286 - 1359, 1378 - 1433, 1743 - 1890
	10	Sandy silty shale	Shale composed of about 5% very fine (vf) subr-r sand grains	318, 394–419, 699 – 1113, 1369, 1451 – 1469, 1542, 1597 – 1615, 1725, 1963 - 1999, 2073,
	11	Sandy shale	Shale composed of about 20% very fine to very coarse sub< - subr sand grains. Present as intercalating beds between reservoir sand bodies	1369, 1451 - 1469, 1542, 1597 - 1615, 1725
	12	Calcareous shale	Contains whitish calcareous materials, light to dark grey	2018 – 2054

* Sub<: subangular, subr: subrounded, vf: very fine

***Ephedra claricristata* Range zone – A: Oligocene** (**Rupelian)**.

Reference section: 2073 – 2054 m.

Definition: The base of the zone is beyond the lower limit of the studied interval. It is defined by the occurrence and abundance of *Ephedra claricristata* (Table 2, Figure 3). Other species present in this zone include *Arecipites exilimuratus, A. crassimuratus, Sapotaceae pollenites, Polyadopollenites vancampori, Taxodaceaepollenites hiatipites, Brevicolpites guinetti, Triorites cf. africanus, Monocolpites marginatus* and *Ephedra exigua*.

***Auriculopollenites echinatus* Range zone – B: Oligocene (Chattian**).

Reference section: 2036 – 1999 m.

Definition: This zone has its base at the top of zone A and is marked by the first occurrence of *Auriculopollenites echinatus* and *Verrutricolporites* sp. (Figure 3). Other species present include *Ephedra exigua, Sapotaceae pollenites,* and *Arecipites exitimuratus.*

Table 2: Stratigraphic Distribution of Form Species in the PML-1 Well.

Depth (m) \ SPECIES	Racemonocolpites hians	Arecipites exilimuratus	Sapotaceae pollenits	Arecipites crassimuratus	Polyadopollenits vancampori	Taxodiaceaepollenits hiatipites	Brevicolpites guinetti	Triorites africanus	Ephedra claricristata	Monocolpites marginatus	Ephedra exigua	Auriculopollenites echinatus	Verrutricolporites sp.	Verrutricolporites scabratus
318														
419														
699														
938														
1177														
1195														
1250														
1359														
1469														
1478														
1542														
1597														
1615														
1707														
1725			1	1										
1743			2	2										
1780		1	1	1							1			5
1817		1	0	2							1		1	2
1890		2	1	2							1		1	5
1945		0	2	1							1		1	2
1999		3	2	1							1	7	1	
2018		2	1	2							1	3	1	
2036		1	1	3							1	2	1	
2054	1	1	0	1	1	2	1	1	7	2	1			
2073	1	2	1	1	2	1	1	2	4	2	3			

Depth (m) \ SPECIES	Verrutricolporits laevigatus	Verrutricolporites rotundiporus	Multiaerolites formosus	Grimdalea cf. baculatus	Retitricolporites sp.	Tricolporites sp.	Canthiumidites sp.	Striamonocolpites sp.	Malvacipollis sp.	Gematriporites sp.	Crototricolporites crotonoisculptus	Psilatricolporites sp.	Belskipollis elegans	Gematricolporites scabratus
318														
419		1											1	
699		1											3	
938		0											0	
1177		1											1	
1195		1										1	2	
1250		1										1	0	
1359		0										0	1	
1469		1										1	0	
1478		1										2	1	
1542		1										1	0	
1597		0										1	0	
1615		1									1	0	1	
1707		0									1	2	1	
1725		14									0	0	0	
1743		9									0	0	1	1
1780	4	1			2	1	1	2	2	1	1	1	2	
1817	4	2												
1890	2	1	1	1										
1945	3	0												
1999		1												
2018														
2036														
2054														
2073														

Depth (m) \ SPECIES	Inaperturupollenites recticultus	Verrutricolporites microporus	Striamonocolpites rectostriatus	579, Lymingtomnnia cf. rhetor	Corsinipollenites jassiaensis	Malvacipollis tschudyi	Psilatricolporites costatus	Margocolporites sp.	Crototricolporites sp.	Retimonocolpites obaensis	Monocolpate pollen	Proteacidites cooksonni	Retitricolporites gulanensis
318													
419													1
699													
938													
1177										1		1	
1195		1	1				1	1		0			
1250		2	0				0	0		2			
1359		1	1				2	1		0			
1469		0	2				1	1		3	1		
1478		1	1				0	0		1			
1542		0	2				1	3		1			
1597		1	1				1	2		2			
1615		2	0				1	8		1			
1707		0	1				2	2	1	1			
1725		3	1	1	1	1	1						
1743	2	4	3										
1780													
1817													
1890													
1945													
1999													
2018													
2036													
2054													
2073													

***Verrutricolporites laevigatus/Verrutricolporites scabratus Range* zone – C: Early Miocene**.

Reference section: 1945 – 1780 m.

Definition: The base of this zone is at the top of zone B and is defined by the first occurrence of *Verrucatosporites scabratus, V. laevigatus* and *V. rotundiporus* (Fig. 3). Other species present within this zone include *Arecipites exilimuratus*, *A. crassimuratus, Verrutricolporites* sp. *Multiaerolites formosus, Grimsdalea cf. baculatus*, *Ephedra exgua,* and the last occurrence of *Retidiporites* sp*.* The top is defined by the last occurrence of *Verrutricolporites scabratus*, *V. laevigatus, Sapotacea pollenites,* and *Arecipites crassimuratus* (Table 2).

***Verrutricolporites rotundiporus Abundance* zone – D: Middle Miocene**.

Reference section: 1743 -1725 m.

Definition: The base of this zone is the top of zone C and is defined by the occurrence of *Verrutricolporites rotundiporus*, appeareance and abundance of *Verrutricolporites microporus* and *Striamonocolpites rectostriatus*, occurrence of *Gematricolporites scabratus* (Table 2)*.* The top of the zone is marked by an abundance of *Verrutricolporites rotundiporus* (Table 2), the occurrence of *Malvacipollis tschudyi* and *Corsinipollenites jassiaensis*. Other species present in this zone include *Crototricolpites crotonoisculptus* and *Belskipollis elegans* (Figure 3)*.*

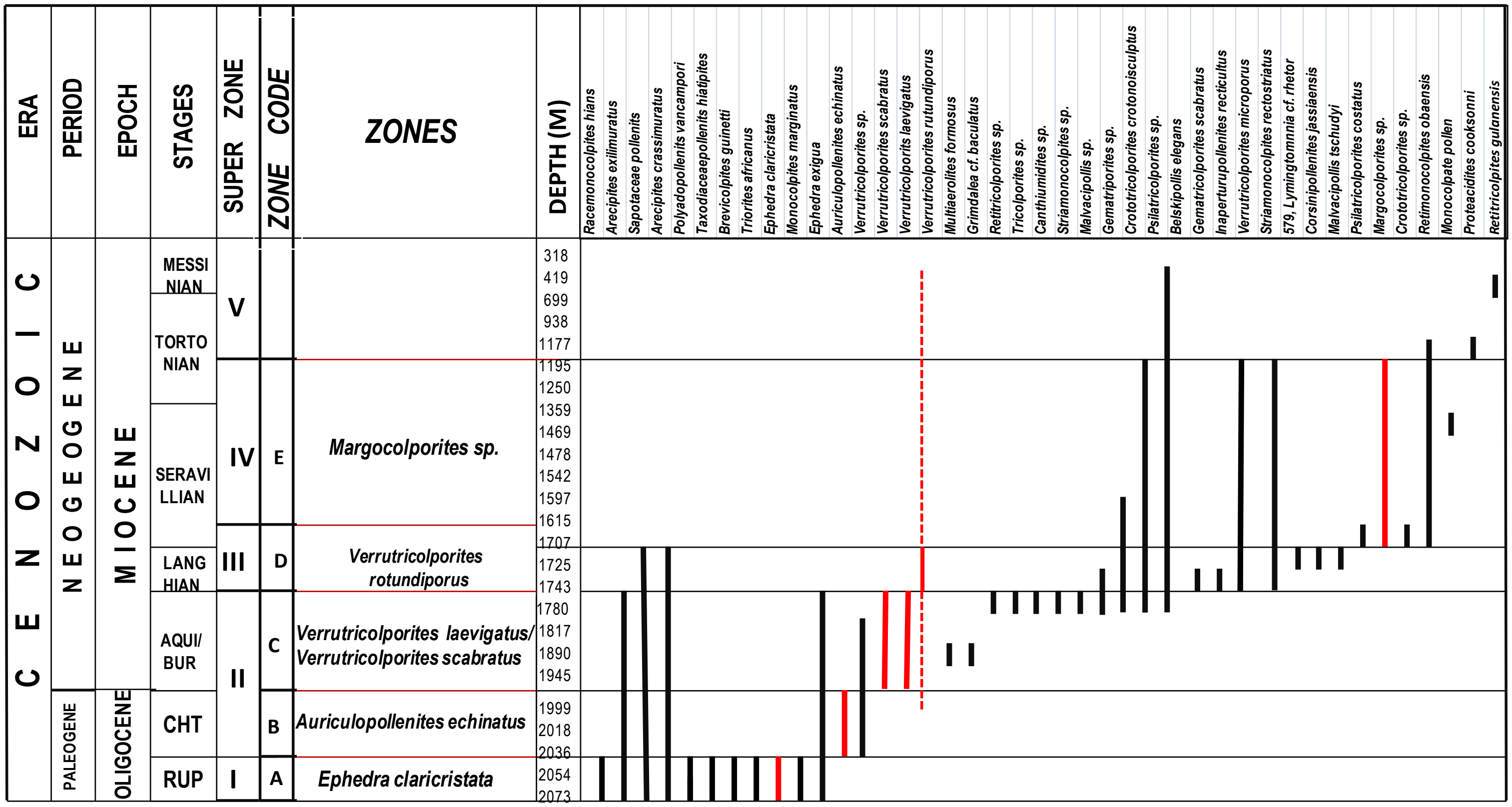

Figure 3: Stratigraphic Ranges of Key Pollen Species and Biozonation for Late Paleogene and Neogene in the Well PML-1, Niger Delta Basin.

***Margocolporites sp. Abundanc* zone – E: Late Miocene**.

Reference section: 1707 – 1195 m.

Definition: The base of this zone is at the top of zone D and is defined by the first occurrence of *Margocolporites* sp., *Retimonocolpites obaensis* and a *Crototricolpate* pollen sp (Figure 3). Other species present in this zone include *Verutricolporites rotundiporus, Belskipollis elegans, Crototricolporites crotonoisculptus* and *Monocolpate* pollen (Table 2). The top of the zone is defined by the last occurrence of *Striamonocolpites rectostriatus, Psilatricolporites costatus, Psilatricolporites* sp. and *Verrutricolporites microporus*.

DISCUSSION

Zone C is coeval with the upper part of the *Verrucatosporites usmensis* zone of Germeraad et al. (1968), the P620 to P680 zones of Evamy et al. (1978), and probably parts of the *Lygodiumsporites adriennis* and the *Pachydermites* zones of Oloto (1994), while it probably corresponds to the zone B-3 to E 2-1 of Legoux (1978).

Zone D is coeval to part of P680 and P720 and part of P740 zones of Evamy et al. (1978) (Fig. 4). These zones are equivalent to the *Ctenolophonidites lisamae* zone of Oloto (1994), and part of the *Magnastriatites howardi* zone of Germeraad et al. (1968).

Zone E is equivalent to the Evamy et al. (1978) P840 – P740 zones (Fig. 4) and to part of the *Magnastriatites howardi* zone of Germeraad et al. (1968).

The Lower - Upper Miocene in the studied section of PML-1 well correlates with the Agbada and Benin Formations of the Niger Delta Basin. Based on lithofacies and age characteristics (Table 1, Figure 2), the interval between 699 – 1999 m, is assigned to the Agbada Formation of the Niger Delta which displays marine shale, sand, sandy shale and shaly sand deposited in marine paleoenvironment, While the interval between 2018 – 2073 m, and is assigned to the Ameki Formation. Interval 318 – 673 m is characterized by dominantly very coarse and pebbly sand facies, characteristic of the Benin Formation in agreement with presentations made by Reyment (1965) and Dessauvagie (1974) and is thus assigned to the Benin Formation. This correlation is based on age, lithofacies characteristics and biosignals presented by shale units within the interval, which show an increased sporomorph and reduced pollen percentage with a complete absence of near-shore and marine palynomorphs species, and a corresponding occurrence of predominantly sandy lithofacies, characteristic of deltaic plain environment in which the Benin Formation is known to have been formed (Short and Stauble, 1967).

The Ogwashi-Asaba Formation has been shown to overlie the Ameki Formation. Murat (1972), show that the Ogwashi-Asaba Formation is absent in the Benin Flank area, but that the Ameki Formation is unconformably overlain by the Benin Formation. Lithofacies and age data sets from this study show that the Ogwashi-Asaba Formation is indeed absent in this area in accordance with data shown by Murat (1972), but rather the Ameki Formation is overlain by the Agbada Formation. The Agbada Formation is in turn unconformably overlain by the Benin Formation in contrast to Murat (1972) data of the Benin Formation resting unconformably on the Ameki Formation.

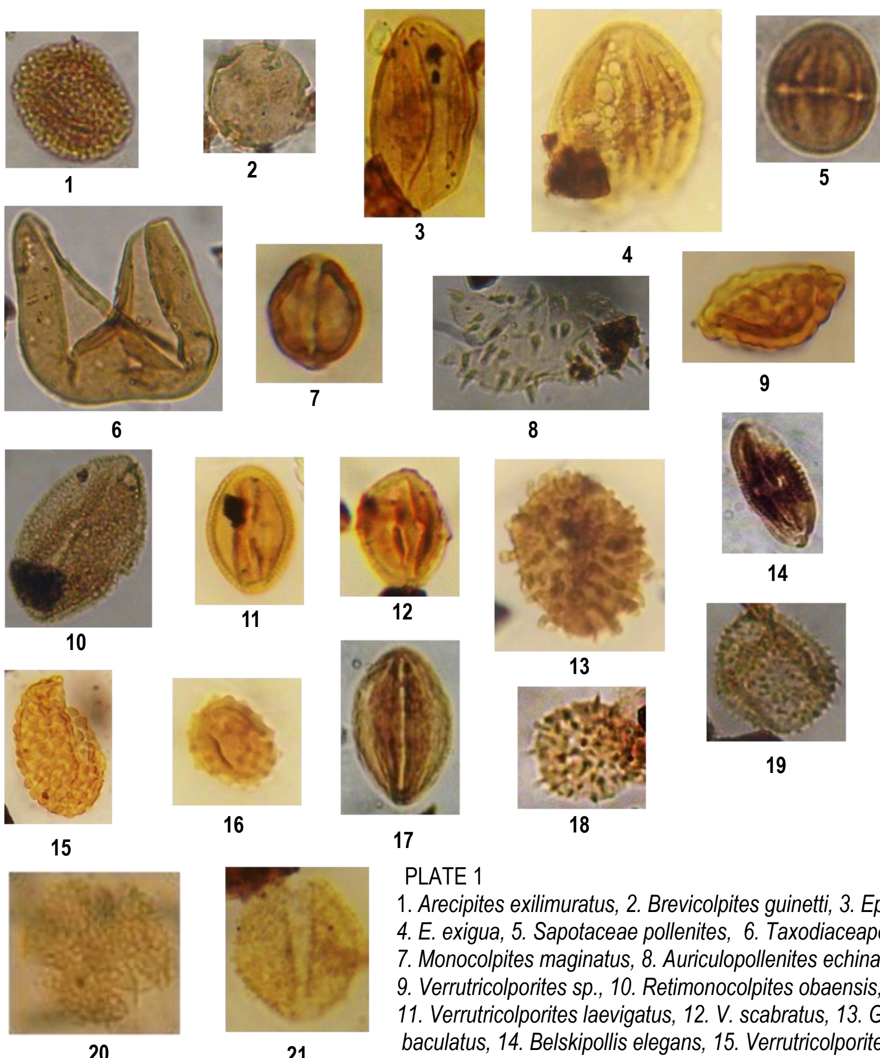

PLATE 1
1. *Arecipites exilimuratus*, 2. *Brevicolpites guinetti*, 3. *Ephedra claricristata*, 4. *E. exigua*, 5. *Sapotaceae pollenites*, 6. *Taxodiaceapollenites hiatipites*, 7. *Monocolpites maginatus*, 8. *Auriculopollenites echinatus*, 9. *Verrutricolporites* sp., 10. *Retimonocolpites obaensis*, 11. *Verrutricolporites laevigatus*, 12. *V. scabratus*, 13. *Grimsdalea* cf. *baculatus*, 14. *Belskipollis elegans*, 15. *Verrutricolporites rotundiporus*, 16. *V. microporus*, 17. *Striamonocolpites rectostriatus*, 18. *Echiperiporites* sp., 19. *Malvacipollis tschudyi*, 20. *Crototricolpites crotonoisculptus*, 21. *Racemonocolpites hians*.

CONCLUSION

In conclusion, the sediments studied in the well PML-1 show a large variety of palynomorph taxa occurring in different quantities associated with different lithofacies types. Although the stratigraphic association of various taxa may be a function of specific environmental controlling factors, their age ranges revealed that they can be applied to the delineation of stratigraphic sections into formation and field-wide correlatable units.

The lithofacies distribution indicates cyclic sedimentation occasioned by an inter play of sea level and climatic regime. The understanding of this enabled a modification of previously presented stratigraphy and thus a better understanding of the stratigraphic sequence in the area of study.

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