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PALYNOSTRATIGRAPHIC ANALYSIS OF THE AGBADA FORMATION (NEP-1 WELL) OFFSHORE, EASTERN NIGER-DELTA BASIN, NIGERIA

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ABSTRACT: *Palynological analyses were carried out using thirty six composite ditch cutting samples from NEP -1 well, off-shore eastern Niger Delta Nigeria. The interval studied is 1750 meters thick, belonging to the Agbada Formation; lithologically, the section varies from shaly-sand to sandy-shale to shale. Three zonal assemblage schemes have been erected; zone boundaries were placed where significant changes occurred in the abundance of the species, the proposed palynological zones are: Echiperiporites cf. estelae, Psilatricolpites okeizeis and Foeveotricolpites sp. zones; these are correlatable with the pantropical zones. The investigated samples from the section are assigned a late Miocene to early Pliocene age based on the palynological evidences at this site.*

Keywords: Stratigraphy, Palynostratigraphy, Palynomorph, Agbada Formation, Niger Delta

INTRODUCTION

The Tertiary Niger delta basin is situated along part of the Gulf of Guinea on the west coast of Africa. It lies between latitudes 4^0 and 6^0 N and longitudes 5^0 and 8.5^0 E (Fig. 1). It is a large arcuate delta of destructive wave-dominted type (Weber and Daukoru, 1975; Evamy et al., 1978). Niger delta basin is one of the sedimentary basins formed by the rift faulting of the Nigeria Precambriam rock (Evamy et al., 1978).

Niger delta is important because of its hydrocarbon resources, the delta started to evolve in Eocene period, due to the interplay between sediment supply and subsidence. Presently, deposition of sediments is going in the offshore terrain. Niger Delta is a matured basin based on the exploration and exploitation of crude oil that have taken place there, a prolific oil province within the West Africa subcontinent. Since the first discovery of crude oil in 1956, many geological researches have been undertaken, especially by oil companies.

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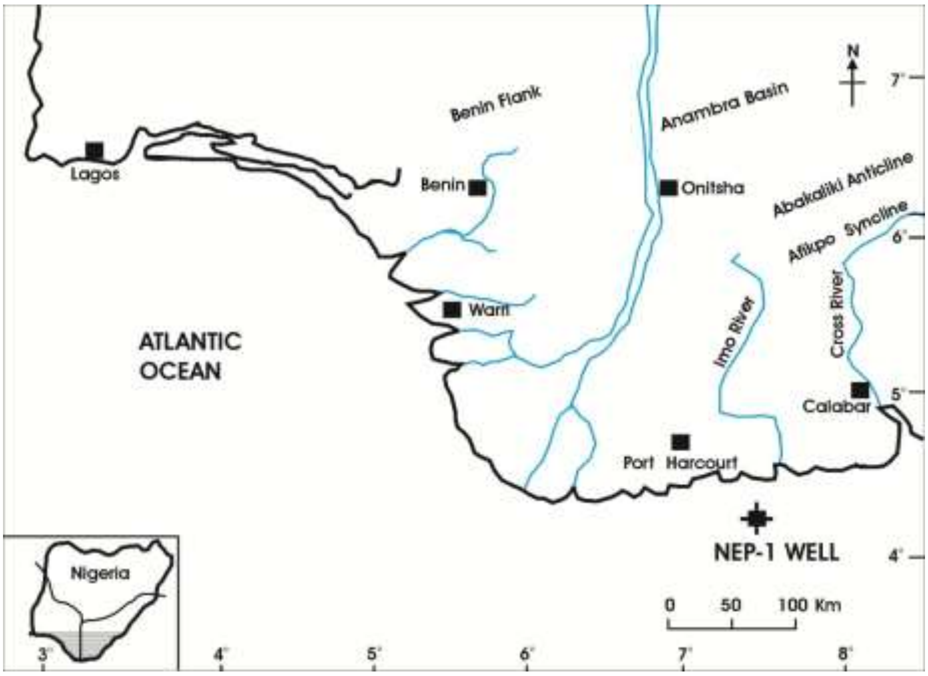

Figure 1: Map showing the location of NEP-1 well, offshore Niger Delta. Inset is the map of Nigeria, showing the location Niger Delta (Aturamu and Ojo, 2015)

LITERATURE/THEORETICAL UNDERPINNING

Published results of these works include those on sedimentology (Short and Stauble 1967; Weber, 1971; Weber and Daukoru, 1975; Ejedawe, 1981, 1982; Stacher 1994), palynology of Tertiary sediments from tropical areas (Gemeraad et al., 1968), the palynomorphs in the paleoenvironments of some eastern Niger delta sediments (Mebradu, 2000). Avbovbo (1978) studied the lithostratigraphy of the Niger Delta, while Ojo and Salami (1992) worked on the biostratigraphy of the basin; Ojo and Adebayo (2001) studied the miospore biostratigraphy of Agbada Formation, eastern Niger Delta basin, while Adebayo et al. (2012) worked on palynology of Bog-1 Well, Southeastern Niger Delta Basin. A detailed description of the stratigraphy and lithology of the formations in the basin, including the type sections (interval in this study belongs to the Agbada Formation), has been presented by Short and Stauble (1967) and Avbovbo (1978).

The present study documents the recovered palynomorphs within the studied intervals, establishes informal palynological zones and correlates same with the pantropical zones of Gemeraad et al. (1968), and Legoux (1978).

GEOLOGIC SETTING AND STRATIGRAPHY

The Niger delta is a prograding depositional complex found within the Cenozoic Formation of the Southern Nigeria, bounded in the west by the Benin flank; the subsurface continuation of the West Africa shield, in the east by Calabar flank; the subsurface continuation of the Oban massif, to the North by Abakaliki and the post-Abakaliki (Anambra basin); the Atlantic Ocean is to the south (Murat, 1972). Due to subsidence and deposition, a succession of transgressive

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and regressive sequence (circa 250 km) advance in the south west of the Niger delta (Oomkens, 1974). This resulted in the accumulated deposition of between 9,000m to 12,000m thick transgressive/regressive sequences, which according to Curtis (1970) is similar to the Gulf Coast Tertiary section in the United State of America.

Lithostratigraphy

Short and Staubles (1967) classified the subsurface Niger delta into three stratigraphic units; Benin Formation being the youngest, Agbada Formation and the oldest is Akata Formation. The Agbada Formation is the hydrocarbon - prospective sequence, a paralic clastic sequence which lies below the Benin Formation (continental sand) in the Niger delta. The shallowest part of this sequence is composed almost entirely of non-marine sand (Doust and Omatsola, 1990). The Agbada Formation consists of predominantly sandy units with minor shale intercalations and thick shale units at the base (which is an alternation of paralic sandstone, shale and clay). This sequence is over 4,000 m thick, but thicker at the central part showing that the depocentre is located in the central Niger delta (Evamy et al. 1978).

The alternation of fine and coarse clastics sediments or clastic particles provides multiple reservoirs-seal couplets, the paralic sequence is present in all depobelts, and the age ranges from Eocene to Pleistocene. A fluviatile origin is noted by the coarseness of the sand grains and its poor sorting (Fig. 2)

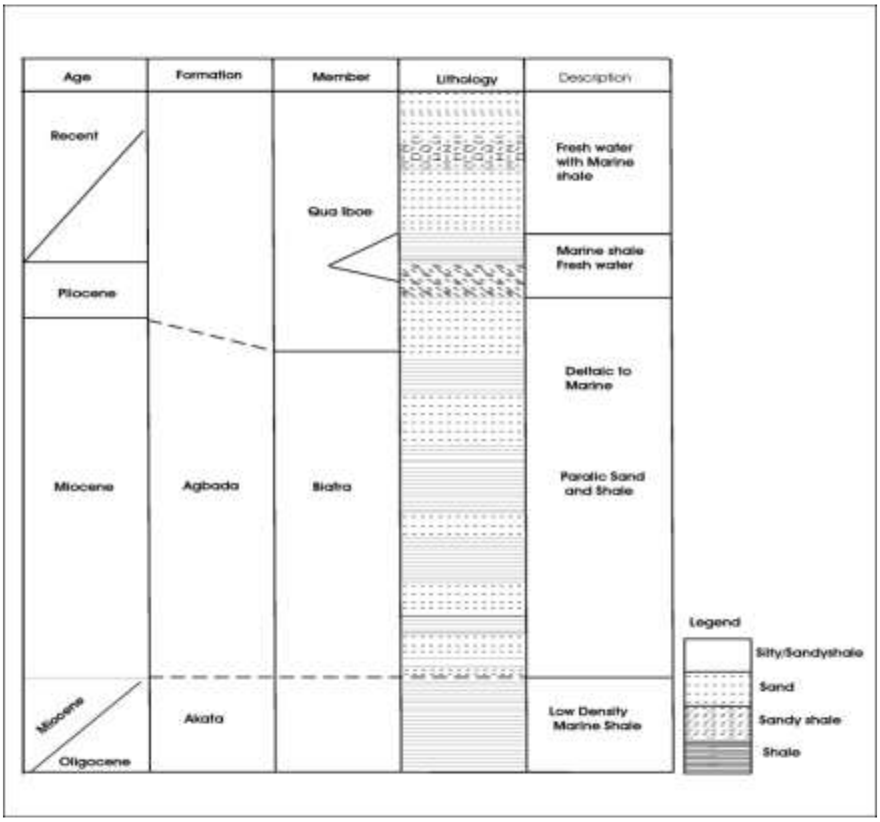

Figure 2: Generalized Stratigraphy of Eastern Niger Delta (Evamy *et al*. 1978)

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MATERIALS AND METHODS

A total of 36 composite samples were selected from 102 ditch cutting samples covering a total interval of 1750 m (i.e the shallowest, at ~1400 m; the deepest, at ~3150 m) from NEP -1 well, located deep offshore, eastern Niger Delta. Samples were numbered sequentially according to increasing depth, ditch-cuttings samples were selected at interval of between 2.0 and 4.0 m in the well-laminated black shales. The samples are mainly dark gray to black fissile shale and sandstone; these were dried and used for palynological analyses.

About 25gm of each sample was soaked in hydrofluoric acid (HF) to remove silicates, and dilute hydrochloric acid (HCl) to remove any carbonates present. Sieving process was carried out over a 5µm mesh; the retrieved debris of the samples was mildly oxidized, followed by heavy mineral liquid separation of the macerals using Zinc bromide (ZnBr2) at 2.1g/cc. Residue was mounted on glass slides with DPX mountant. This standard method of preparation was in accordance with Traverse (1988); Faegri and Iversen (1989), Wood et al. (1996) and Adebayo et al., (2015). Photomicrographs of diagnostic species were taken with Nikon Koolpix P6000 digital camera; abundance of pollen, spores, dinoflagellates, fungal spores, and other stratigraphically significant forms present were determined for each sample using a semi-quantitative approach. These were further interpreted by comparison with established works (Germeraad et al., 1968 and Legoux, 1978).

RESULTS/FINDINGS

The analysed well log sediments are dominated by shales and sandy shale beds (Fig. 3); these are generally fissile, dark grey in colour, with few ferruginous materials and clay nodules.

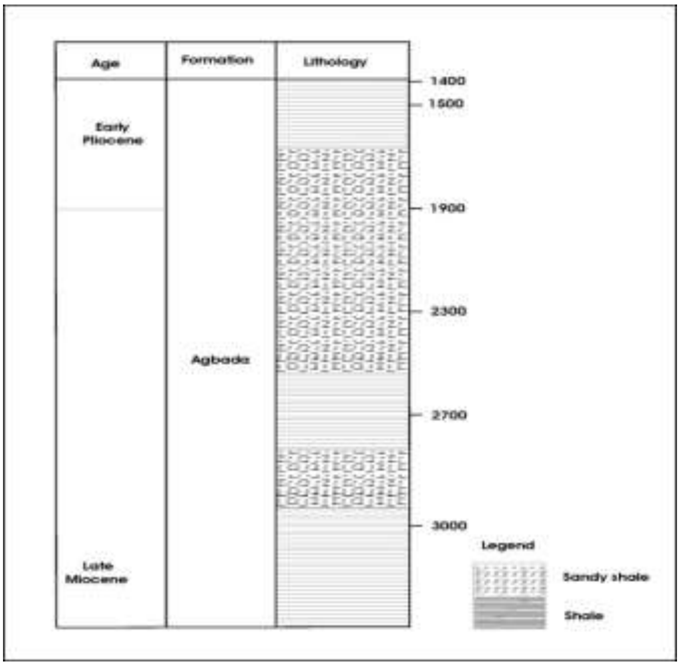

Figure 3: Simplified composite Lithology of NEP-1 well, Eastern Niger delta (Aturamu and Ojo, 2015)

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1. A lower unit B, consists of uniform shales with very few thin bed of sandy shale. This is the lower sedimentary unit within the analysed interval of the well; shale here is generally dark grey to light grey. It is sandy to silty in some places. Also few small-sized mica flakes are found in the lower part of the well.

2. An upper unit A, consists of an alternation of sand and shale. The shaly units are generally thinner in the upper part of the sequence.

Generally, the sandy-shale units are slightly coarse to fine grained, unconsolidated, and poorly sorted, but the sorting becomes relatively good most especially where there are increase in shaly content, this forms the typical paralic facies portion of Niger delta which concurs with the observation of Braide (1983). However, there are significant differences in the sandy unit and the shaly units; this is not unusual in this type of depositional environment (Braide, 1983). Generally, the recovered palynological assemblage consists mainly of pollen and spores (i.e fungal spores). Palynomorphs were well preserved (see plate) and typically diverse. The pollens are made up of species of Monocolporites, Tricolporites, and Triporites. Other materials recovered include foraminifera (both planktics and benthics), cuticles and some palynodebris.

A total of 988 palynomorphs were encountered out of which 531 were identified, this comprises of 21 species (see plates). The diversity and abundance of these microfossil assemblages varies throughout the interval studied (Fig. 4). The highest number of palynomorphs counted was 44 at 1900 ft while the lowest was 17 at 3050 ft. The recovered palynomorphs enabled the delineation of three zones: *Foveotricolporites* sp. zone, *Psilatricolpites okeizei* zone and *Echiperiporites* cf. *estelae* zone. Palynological zones discussed are range zones; this is used to establish an informal palynostratigraphy within this sequence.

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Palynomorphs in NEP-1 well (Eastern Niger Delta)

Depth (m)	Lithology	Chronostratigraphy	Diversity	Abundance	*Fungal Spore 1*	*Syncolporites marginatus*	*Zonocostites ramonae*	*Verrucatosporites usmensis*	*Fungal Spore 2*	*Leotrillete spore*	*Psilatricolpites okeizei*	*Laevigatosporites* sp.	*Psiltricolpites operculatus*	*Monoporities* sp.	*Foveticolporites* sp.	*Monocolporites* sp.	*Echiperoporities* cf *estae*	*Psilatricolporites major*	*Longaperities varendendurg*	*Syncolporites* sp.	*Dinogymnium* sp.	*Striotoilis catatumbus*	*Psilatricolporities annullporites*	*Senegallium bicavatum*	*Psilamonocolporites* sp.	ZONE
1400	Shale	Early Pliocene	11	23	1	1	3	3	1	2	1	1	1	1			8									*Echiperioporites cf estelae*
	Shale	Early Pliocene	11	31	1		3	2	2	3	1		2	1	2	2	12									*Echiperioporites cf estelae*
1500	Shale	Early Pliocene	6	19	1		1	1		1			1				14									*Echiperioporites cf estelae*
	Shale	Early Pliocene	8	20	1			1	1	1		1		1	4		10									*Echiperioporites cf estelae*
1600	Shale	Early Pliocene	9	19	1	1	1	1			2	1	1	1			10									*Echiperioporites cf estelae*
	Shale	Early Pliocene	15	38	1	2	3	3	4		2	1	1	2	3		11	2	1	1	1					*Echiperioporites cf estelae*
1700	Shale	Early Pliocene	15	43	1	2	3	3	3	1	4	4	1	3		1	14	1		1	1					*Echiperioporites cf estelae*
	Sandy-shale	Early Pliocene	17	41	1	2	3	3	4	2	1	1	1	3			12	1	2		1	2	1	1		*Echiperioporites cf estelae*
1800	Sandy-shale	Early Pliocene	10	29	2	2	3	1			2			1			14			1	2	1				*Echiperioporites cf estelae*
	Sandy-shale	Early Pliocene	9	25	1	2	1	2			2						13		1	2	1					*Echiperioporites cf estelae*
1900	Sandy-shale	Early Pliocene	13	44		3	2	2	3	1		1	1	2			21		2	1	2	2		1		*Echiperioporites cf estelae*
	Sandy-shale	Early Pliocene	11	24			1	1	1	1		1	1	1	1		14		1			1				*Echiperioporites cf estelae*
2000	Sandy-shale	Late Miocene	13	39	1		3	3	3	3	14	2	1							3	1	2	1	2		*Psilatricolpites okeizei*
	Sandy-shale	Late Miocene	11	31	1		1	1	4	3	12				2					3		1	2	1		*Psilatricolpites okeizei*
2100	Sandy-shale	Late Miocene	15	39	1	1	1	2	4	4	12	2	1		2				4	1	2	1			1	*Psilatricolpites okeizei*
	Sandy-shale	Late Miocene	10	33	1		1	3	4	4	10		3		3								2		2	*Psilatricolpites okeizei*
2200	Sandy-shale	Late Miocene	8	21	1	1			1	1	9				4				2				2			*Psilatricolpites okeizei*
	Sandy-shale	Late Miocene	5	14		2	1	1			8		1								1					*Psilatricolpites okeizei*
2300	Sandy-shale	Late Miocene	10	21		1		1	3	1	8		2					1	1	1	2					*Psilatricolpites okeizei*
	Sandy-shale	Late Miocene	6	19		1	2	1	2		12		1													*Psilatricolpites okeizei*
2400	Sandy-shale	Late Miocene	10	24		1	1	1	2		12		3						1	2	1					*Psilatricolpites okeizei*
	Sandy-shale	Late Miocene	10	28	1		2	1		1			1		10	2	8						2			*Foveotricolporites* sp.
2500	Sandy-shale	Late Miocene	7	31	1		2		4	3			1		14		6									*Foveotricolporites* sp.
	Sandy-shale	Late Miocene	5	23	1	1			4				4		13											*Foveotricolporites* sp.
2600	Shale	Late Miocene	10	31		1	2	1	2				2		15	3		1					2		2	*Foveotricolporites* sp.
	Shale	Late Miocene	8	23	1	1	1	1	2				1		13									3		*Foveotricolporites* sp.
2700	Shale	Late Miocene	9	26	1		1	1	4	2			1		14				1					1		*Foveotricolporites* sp.
	Shale	Late Miocene	7	22	1		1	1		1			3		13		2									*Foveotricolporites* sp.
2800	Shale	Late Miocene	11	32	1		1	1	1	4		2	3		12				1					4	2	*Foveotricolporites* sp.
	Sandy-shale	Late Miocene	8	22	1			1		3			2		10				1					3	1	*Foveotricolporites* sp.
2900	Sandy-shale	Late Miocene	13	33		2	1	1	2	3			4		11	1				1	2	1	2	2		*Foveotricolporites* sp.
	Sandy-shale	Late Miocene	10	26		2	2	1	1	2		2	2		12									2		*Foveotricolporites* sp.
3000	Shale	Late Miocene	15	31	2	2		1		2		2	1		11		1	2	1	2	1		1	2		*Foveotricolporites* sp.
	Shale	Late Miocene	7	17	1			3		1			1		9									2		*Foveotricolporites* sp.
3100	Shale	Late Miocene	12	28	1			4		2					8		2	1	3	1		2	1	3		*Foveotricolporites* sp.
	Shale	Late Miocene	10	18		2		1	1				1		8				1	2	1			1		*Foveotricolporites* sp.
				988																						

Legend.
Shale (dark shading)
Sandy-shale (light shading)

Figure 4: Stratigraphic distributions of Palynomorphs in NEP-1 well, eastern Niger Delta, Nigeria.

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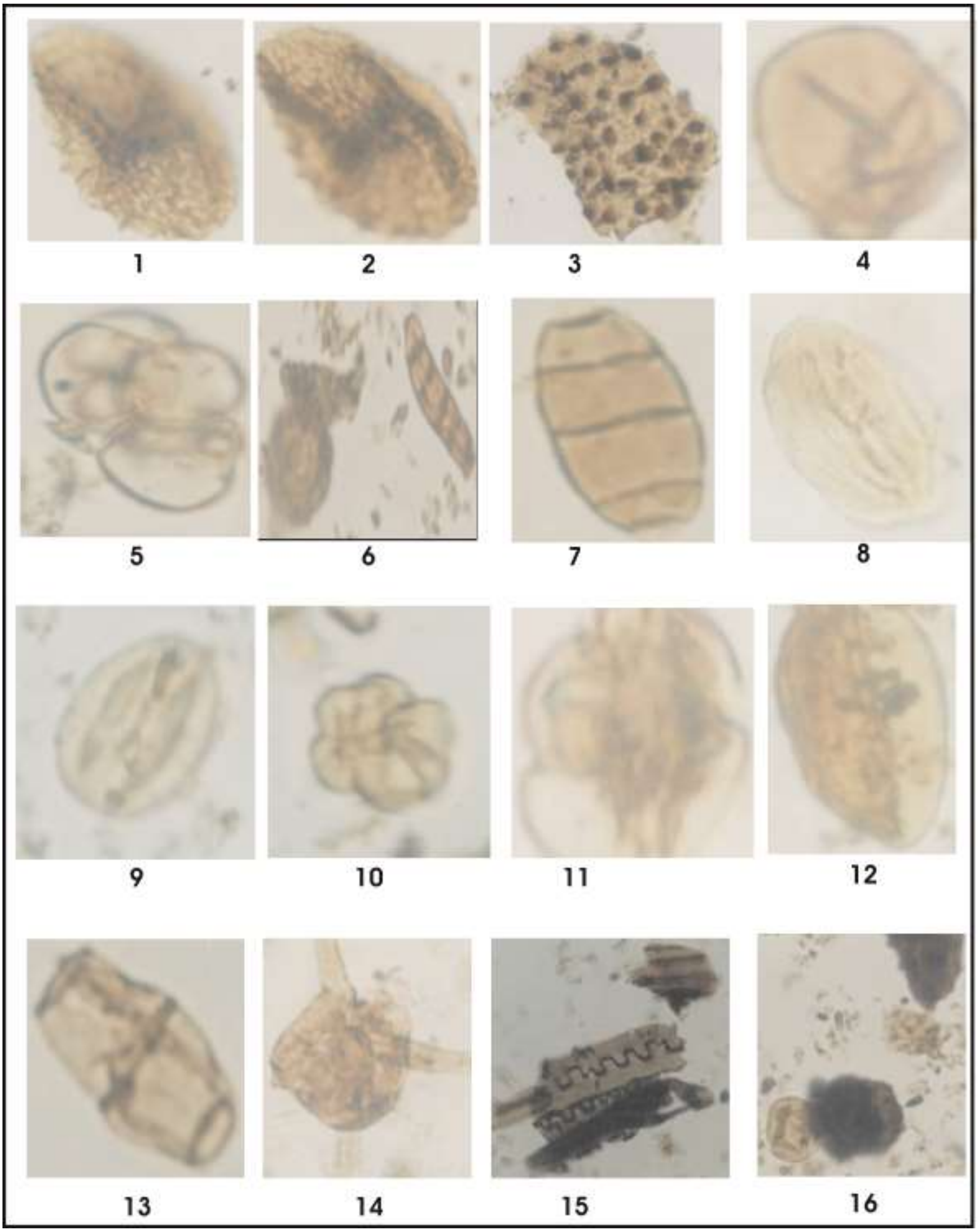
Plates



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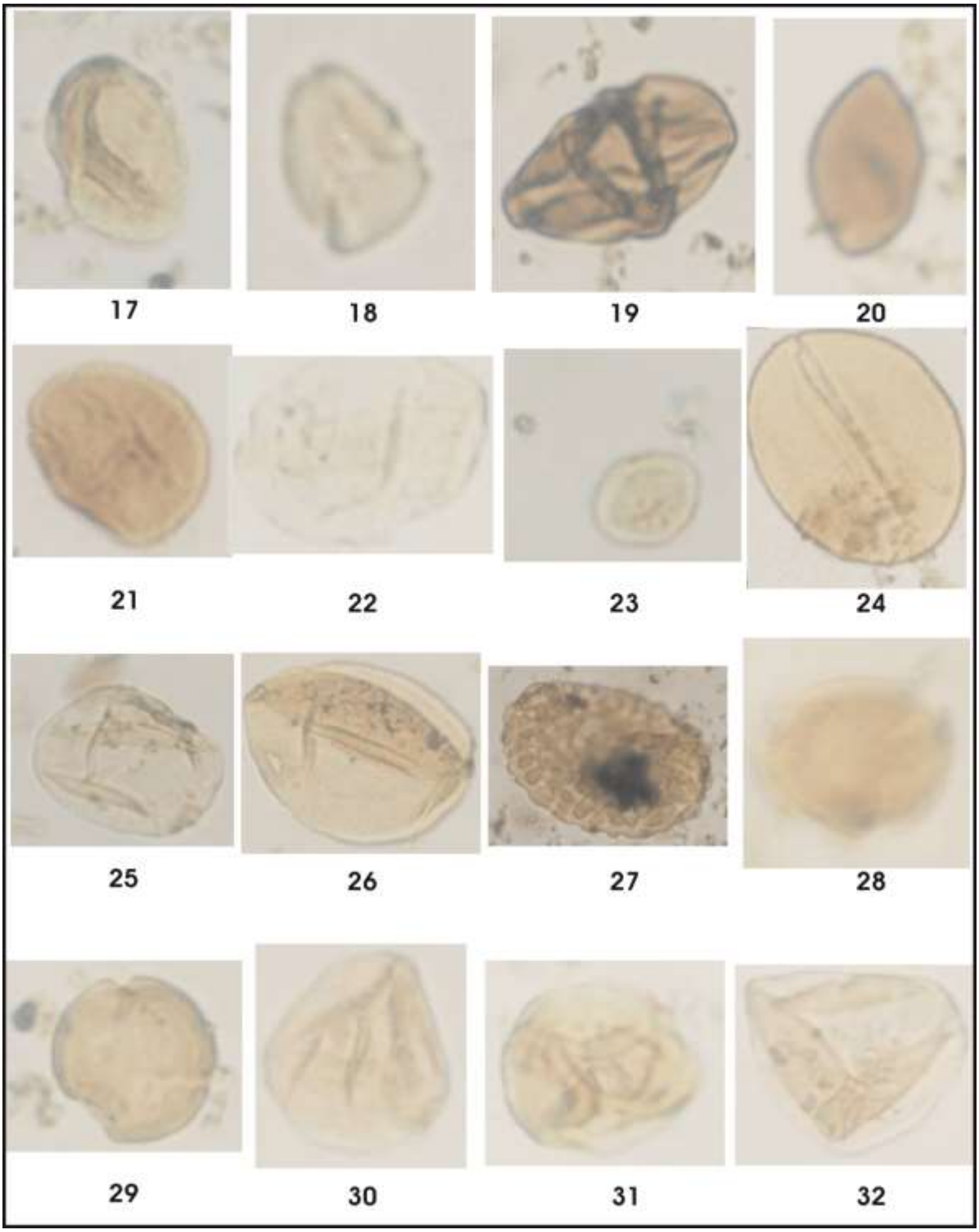

Scale = 30 µm

Plate explanations

Figs. 1, 2: *Echiperiporites* cf. *estalae*
Fig. 3: *Multicellasporities* sp.
Fig. 4: *Deltoidospora* sp.
Fig. 5: Globules
Fig. 6: *Multicellasporities* sp.
Fig. 7: Fungal spore

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Figs. 8, 9: *Striatopollis catatumbus*
Figs.10,11:*Psilastephanocolprites* globules
Fig. 12: *Longapertities vanendenburgi*
Fig. 13: *Dinogyminum* sp
Fig. 14: *Senegalium bicavatum*
Fig. 15: Palynodebris
Fig. 16: *Syncolporites marginatus*
Fig. 17: *Zonocostites ramonae*
Fig. 18: *Psilatricolpites okeizeis*
Fig. 19, 20: Fungal spore
Fig. 21: *Laevigatosporites* sp.
Fig. 22: *Monoporites annulatus*
Figs. 23, 24: *Monocolporites* sp.
Fig. 25: Fo*veotricolporites* sp.
Fig. 26: *Psilamonocolpites* sp.
Fig. 27: *Verrucatosporites* sp.
Fig. 28: *Psilatriporites* sp.
Fig. 29: *Psilatriporites operculatus*
Fig. 30: *Leotrilate* spore
Fig. 31: *Psilatriporites* sp.
Fig. 32: *Leotrilate* spore

Palynological zones

Only the identified index palynomorphs were used in erecting a zonal scheme. Pollen and spores with short stratigraphical range and common to abundant occurrences have been found useful (Fig. 4). Species with long stratigraphic ranges, rare or possibly reworked are not used in this palynological interpretation interpretation (Adebayo *et al*., 2015). Three assemblage zones have been erected; zone boundaries were placed where significant changes occurred in the abundance of the species.

Foveotricolporites sp. zone (2400 m - 3150 m)

The abundance of *Foveotricolpites* sp. marked this zone. The top of the zone is marked with the relative abundance of *Psilatricolpites okeizei*. Most common species within the zone are *Senegalium bivicatum*, *Leotriletes* sp. and *Psilatricolpites operculatus*. The zone is assigned a late Miocene age based on the abundance of *Foveotricolpites* sp. and *Senegalium bivicatum* (Germeraad *et al*., 1968).

Psilatricolpites okeizei zone (2400 m - 2000 m)

This zone is based on the first down hole abundance occurrence of *Psilatricolpites okeizei at* 2400 m. Other taxa in the zone include *Laevigatosporites* sp., *Zonocostities ramonae*, *Verrucatosporites usmensis*, *Syncolporites operculatus*, *Leotrilete spore* and fungal spore. Occurrences of all these species terminated at the base of the well studied. Miocene age is inferred for this zone based on the abundance and extinction of *Psilatricolpites okeizei* (Germeraad *et al*., 1968 and Legoux, 1978).

Echiperiporites cf. estelae zone (1400 m- 1950 m)

The base of this zone is depicted by the extinction of *Monoporites* sp. at 1950 m; the top terminates within the well. The palynomorph assemblage in this zone comprises of *Zonocostites ramonae, Syncolporites maginatus, Verrucatosporite usmensis* and fungal spores. The age of this zone is inferred to be early Pliocene.

All these palynostratigraphical zones (Fig. 4) fall within the pantropical *Echitricolporites spinosus* zone of Germeraad *et al*. (1968) and J2 zone of Legoux (1978).

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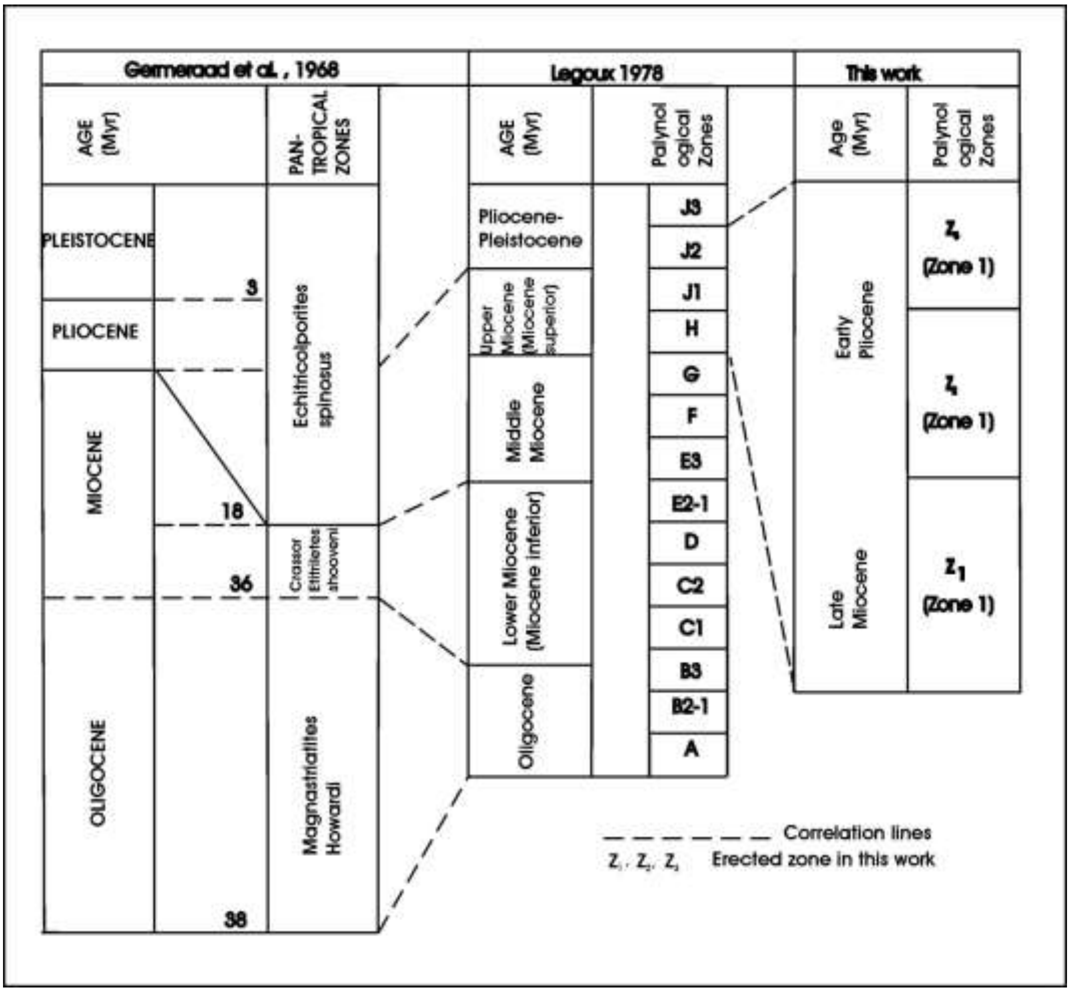

Figure 5: Correlation of inferred palynological zones with the established zones of some other authors (Z_1, Z_2, Z_3 are erected zones)

Paleoecological deductions

Palynoassemblage of the studied interval is dominated by terrestrial miospores (see Fig. 4) and give evidence of continental proximity. But mangrove species (*Zonocostites ramonae* (*Rhizophora*) and *Foveotricolporites* sp. (*Avicennia*) and fungal spores also form significant components of the assemblage. The only marine phytoplankton recovered is *Dinogyminum* sp. Kohlmeyer and Kohlmeyer (1979) reported that less than 2% of all fungi are aquatic. Orinoco Delta fungal spores are most abundant (> $100g^{-1}$) in delta top facies, occur in lower abundances in the immediate pro-delta area and negligible on the outer shelf (Muller, 1959). A similar trend has been noted in the Niger Delta region (Melia, 1984).

Also, according to Oboh (1992) lagoonal facies are generally characterized by higher fungal spore content than adjacent marine shelf facies. Hence the concentration of fungal spores in sediments is proportional to the amount of terrestrial input, decreasing with distance from the source of land sediments. Much of fungal debris in coastal sediments probably represents allocthonous terrestrial material (cf Cooke and Reyner, 1984). The dominance occurrence of continental miospores, significant occurrence of mangrove species and the presence of *Dinogyminum* sp. suggests a deltaic - tidal swamp shoreline inhabited by mangroves (Adebayo *et al.*, 2012).

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DISCUSSIONS

Sharp quantitative (numerical) increase is noticed in the palynomorph assemblage between the zones erected (Fig. 4), this is inferred to be due to varying ecological factors. Aturamu and Ojo (2015), In earlier foraminiferal studies of this interval, correlated *Globigerinoides obliquus* partial range zone, dated late Miocene, to *Globorotalia Plesiotumida* of N-17 (Blow 1969). This is also equivalent to the benthic foraminifera zone, *Uvigerina peregrina/Quinqueloculina seminulum* (Aturamu and Ojo, 2015), which also lies within the late Miocene age. The palynological equivalence of these zones in this work is *Foveotricolpites* sp. and *Psilatricolpites okeizei zones.* This is equivalent to *Globorotalia conomiozea* of Poore and Berggren (1975). It is however similar to *Globorotalia sphaeroides* of Lamb and Beard (1972) and also *Globorotalia duterteri* of Blow (1970), and also comparable with the upper Miocene age of palynological zone (J_1 and J_2) erected in this work (Fig. 5).

Globigerinoides ruber abundance zone dated early Pliocene (Aturamu and Ojo, 2015) has its equivalent benthic foraminiferal partial zone in the study as the *Maginulina raphanus zone.* This is equivalent to *Globorotalia margaritae* of Blow (1970), also to the lower part of the *Globorotalia crassaformis* zone of Berggren (1977) and *Globigerina nepenthes* zone of Thunnel (1981); these are also equivalent to *Maginulina raphanus* benthic foraminiferal zone (Aturamu and Ojo, 2015). These foraminiferal zones are equivalents to *Echiperiporites* cf *estalae* palynological zone erected in this study.

CONCLUSIONS

This study reports on palynomorph assemblages from sediments penetrated by NEP-1 well in the eastern Niger delta basin. Three assemblage zones have been erected based on the abundance of the palynomorphs; zone boundaries were placed where significant changes occurred in the abundance of the species. The palynological assemblage zones identified are *Foveotricolporites* sp., *Psilatricolpites okezeis* and *Echiperiporites* cf. *estalae*. These zones fall within the broad pantropical *Echitricolporites spinosus* zones of Germeraad et al. (1968) and H-J_2 zones of Legoux (1978). A late Miocene to early Pliocene age has been assigned to the studied interval in the NEP-1 well while a deltaic - tidal swamp shoreline inhabited by mangroves paleoenvironment is inferred.

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