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Lithofacies, Palynostratigraphy and Paleoecology of the Outcropping Rock Succession at Ogbunike Old Toll Gate, Niger Delta Basin, Nigeria

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Authors' contributions

Authors worked together and approved the submission of the manuscript.

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ABSTRACT

Aim: Sedimentary succession exposed at Ogbunike old toll gate is part of the outcropping sediments of the Niger Delta Basin and its age is controversial. The outcrop was studied for the purpose of age determination, lithostratigraphic placement and interpretation of paleoecology, paleoclimatology and depositional environment.

Methodology: Lithofacies and biofacies analyses were integrated in the study.

Results: Thirteen lithofacies identified include; bioturbated sandstone, ripple laminated sandstone, ripple laminated claystone, dark shale, ferruginized sandstone, carbonaceous sandstone, greyish shale, very fine sandstone, mudstone, massive claystone, coarse sandstone, cross bedded sandstone and flaser bedded sandstone lithofacies. Four lithofacies associations consisting of lower shoreface to inner neritic, fluvial channel, lagoonal/mixed flat and subtidal sandwave associations were delineated. Middle Eocene age is assigned to the succession based on the high abundance of marker pollen such as *Margocolporites foveolatus, Ctenelophonidites costatus, Monocolpites marginatus, Retibrevitricolporites triangulatus, Proxapertites cursus, Bombacacidites* sp. and common occurrences of *Scrabratisporites simpliformis, Anacolosidites luteoides, Psilatricolporites crassus, Gabonisporis viaourouxii, Striatricolporites catatumbus* and *Retistephanocolporites williamsi.* These co-occur with *Cordosphaeridium cantharellus*. Palynofloral

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group recovered are dominated by mangrove and palm pollen. Pteridophyte spores are also abundant whereas the hinterland pollen group is very low. Benthic foraminiferal assemblages of T*extularia*, *Miliammina,Ammobaculites Haplophragmoides, Fursenkoina*, *Heterolepa, Reophax, Nodosaria, Florilus, Uvigerina, Cibicides* and *Bolivina* recovered from the dark shale suggest deposition in an inner neritic setting. Trace fossil suite of *Skolithos- Cruziana* ichnofacies is an attribute of the sedimentary units.

Conclusion: The sedimentary succession is part of the Ameki Group (Nanka Formation) deposited under varied environmental setting. Paleoclimate is tropical.

Keywords: Palynomorph; foraminifera; dinoflagellates; depositional environment; Ameki group; sandstone.

1. INTRODUCTION

The Ameki Group which comprises the Ameki, Nanka and Nsugbe formations [1] have been described as the outcropping lithostratigraphic units of the Niger Delta Basin. The Agbada Formation has also been identified as the subsurface equivalent of the mentioned group [2-3]. The Ogwashi Asaba and the Benin formations conformably and successively overlie the Ameki Group (Table 1).

The Ameki Group has been dated as Early to Mid Eocene on the basis of the diverse gastropod and pelecypod fauna [4-8]. Wright et al [3] dated the group as Eocene to Oligocene. The overlying Ogwashi Asaba Formation has been dated also as Mid to Late Eocene on the basis of palynomorphs [9], Oligocene to Miocene [3,10] and Upper Eocene to Miocene [11]. The environment of deposition has also been variously interpreted as estuarine [12], barrier-ridge- lagoon complex to intertidal and subtidal [13], and shallow marine [14].

There is a controversy in age and stratigraphic placement of the sedimentary succession at Ogbunike old tollgate.On the basis of palynomorphs, the exposure was dated Upper Eocene to Miocene and was stratigraphically assigned to the Ogwashi Asaba Formation [11]. Nwajide [1] grouped the exposure as part of the underlying Ameki Group (Nanka Formation). Chiaghanam et al [15] dated the same outcrop as Mid Eocene and also stratigraphically assigned it to underlying Nanka Formation (Ameki Group). Stratigraphic placement of a particular sedimentary succession into two different lithostratigraphic units within a basin is improper and thus, a confusion especially to the academic community as to where to place the said outcrop within the Niger Delta stratigraphic framework. This confusion calls for re- evaluation of the shales and mudstone facies of the outcrop for age determination and lithostratigraphic placement of the exposure within the stratigraphic framework of the Niger Delta Basin.

This study aims at interpreting the age of the outcrops at the Ogbunike old toll gate using both palynomorphs and foraminiferal data for stratigraphic placement. It also attempts to interpret the environments of deposition. The paleoecological and paleoclimatic conditions under which the sediments were deposited will also be interpreted. Fig. 1 is the geologic map of the study area.

1.1 Regional Tectonics and Stratigraphic Setting

The origin of the Niger Delta Basin is related to the evolution of the Benue Trough as a failed arm of the West and Central African Rift System during the Jurassic. The development of the Benue Trough is associated with the break- up of Gondwana Supercontinent and subsequent opening of the Southern Atlantic Ocean during the Lower Cretaceous. The trough represents a major tectonic phase in the Nigerian sedimentation history [16-20]. Deposition commenced in the trough during the Aptian to Early Albian when the sediments of Awi and Mamfe Formations were laid down as the basal units in the southern part of the trough. The filling in of the trough with the sediments of the Abakaliki Formation and Mfamosing Limestone (Albian); the Ezeaku Group (Cenomanian-Turonian) and the Awgu Formation (Coniacian) was controlled by two cycles of marine transgressions and regressions. The sediments in the trough were folded and uplifted during the Santonian epeirogenic tectonics which resulted into the formation of the Abakaliki- Benue Anticlinorium and a simultaneous subsidence of the Anambra Basin and the Afikpo Sub- Basin to the northwest and southeast of the folded axis respectively [21-23]. The Anambra Basin and the

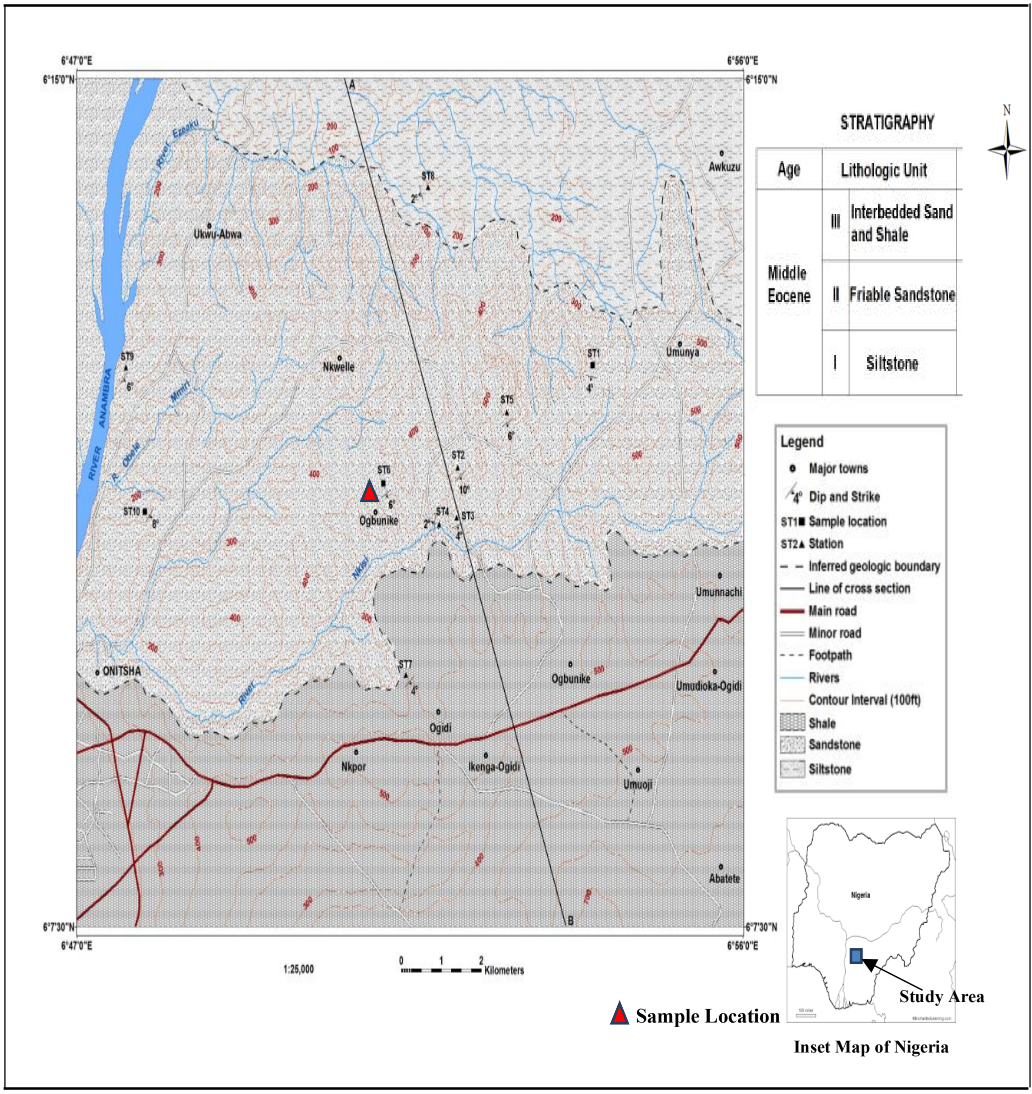

Fig. 1. Geologic map of the study area

Afikpo Sub- Basin were filled from Late Campanian to Danian. Further subsidence after the filling up and compaction of the sediments of the Anambra Basin induced the major marine transgression of the Early Paleocene as well as initiation of the sedimentation and subsidence of the Niger Delta Basin (Table 1).

The oldest sediment in the outcropping part of the Niger Delta Basin is the Imo Formation deposited during the Late Paleocene marine transgression. This was successively overlain by the Ameki Group (Ameki, Nanka and Nsugbe formations) and Ogwashi Asaba Formation respectively which were laid down under regressive conditions [2-3,1].

2. MATERIALS AND METHODS

The methods adopted in this study include outcrop logging and laboratory analyses.

The outcrop at Ogbunike old toll gate was logged from base to the top and the litholog of the outcrop was produced (Fig. 2). Lithofacies were identified based on lithology, grain size and sedimentary structures. Vertically stacked and conformably overlying lithofacies that reflect a model for any particular depositional environment was interpreted as facies association of that environment [25-26].

Eight (8) samples of shale and carbonaceous mudstone were collected from the exposure for biostratigraphic analyses.

Table 1. Stratigraphic succession in the southern Benue Trough, Anambra and Niger Delta Basins [7,24,2,21,8]

TIME SCALE			SEDIMENTARY UNITS	
Cenozoic	Pliocene		Niger Delta	Benin Formation
	Miocene			
	Oligocene			Ogwashi-Asaba Formation
	Eocene			Nanka Formation / Ameki Formation
	Paleocene	Thanetian		Imo Formation
		Danian		
Late Cretaceous	Maastrichtian		Anambra Basin	Nsukka Formation
				Ajali Sandstone
				Mamu Formation
	Campanian			Nkporo Fm / Enugu Fm / Owelli Sst / Afikpo Sst
	Santonian		Southern Benue Trough	Unconformity
	Coniacian			Awgu Formation
	Turonian			Ezeaku Group
	Cenomanian			Mfamosing Limestone
Early Cretaceous	Albian			Abakaliki Formation
	Aptian			Awi Formation
Precambrian				Basement Complex

Shale samples for palynological studies were processed using the conventional acid maceration, alkali treatment and staining methods. These helped to concentrate and recover the acid insoluble organic microfossils present in the shale. About 10g of each sample was crushed and treated with 35% of hydrochlororic acid (HCl) to remove the carbonates that might be present in the sample. The samples were allowed to stay in the fume cupboard for 48 hours before the acid was decanted. Distilled water was used three consecutive times at six hours intervals to neutralize the acid and to thoroughly wash the samples. The silicates in the samples were removed (dissolution) by treatment with 40% hydrofluoric (HF) acid. The samples were stirred at regular intervals with a nickel rod and were then allowed to stand for 24 hours in a fume cupboard before the acid was carefully decanted. The process of neutralization of the acid using distilled water was again repeated in order to ensure that the samples were thoroughly washed. A 10 micron sieve was used to wash the samples for the recovery of the palynomorphs. During the first round of washing the samples were oxidized with about 40% of 60% trioxonitrate (v) (HNO_3) acid. The oxidation lasted for about 20 minutes and the normal process of neutralization was repeated. To further neutralize the effect of the oxidation, 10ml of 5% potassium hydroxide (KOH) solution was added during the second round of washing and sieving. The residue was centrifuged with 1ml of Zinc Chloride (specific gravity of 2.2) in order to separate the palynomorphs from other organic debris. The recovered palynomorphs were mounted on glass slide using the Norland Gel as a mounting medium. Identification and counting were done using a Leitz light microscope.

The shale samples were also analyzed for foraminiferal contents. 20g each of the samples was treated with one teaspoonful of anhydrous sodium carbonate for thorough disintegration. Enough water was used to soak the sample and allowed to stay over- night. A 53µ mesh sieve was used to wash the samples. The washed samples were dried at a minimum temperature of 20°C and were sieved into coarse, medium and fine fractions. The microfossils were picked and identified using a binocular microscope.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Lithofacies description

Thirteen lithofacies were identified and are shown on Figs. 2- 6. These include;

1. Bioturbated sandstone lithofacies (F1): The sandstone is fine grained and pinkish in colour with a thickness of about 1.42 m (Fig. 2). Long tubes of *Thalassinoides* burrows are common (Fig. 3a). The lithofacies occurs at the basal part of the exposure.
2. Ripple laminated claystone lithofacies (F2): This consists of wave ripple laminated whitish claystone at the basal part of the exposure and are sandwiched in between bioturbated sandstone and ripple laminated sandstone lithofacies. Its thickness varies from 15.2 cm to 20 cm (Fig. 2).
3. Ripple laminated sandstone lithofacies (F3): The lithofacies consists of fine grained sandstone with very low amplitude wave ripple laminations (Figs. 2 and 3b). The thickness of the sandstone is about 1.45 m. Bioturbations also occur.
4. Dark shale lithofacies (F4): The facies overlies the wave ripple laminated fine grained sandstone lithofacies. It consists of dark, very fissile and pyritic shale (Figs. 2 and 3c) which yields a yellowish brown coloration on weathering. Long tubes of *Thalassinoides* burrows measuring up to 20 cm long and 2 – 3 cm in diameter is characteristic. The thickness is about 2.65 m.
5. Ferruginized sandstone lithofacies (F5): This consists of fine to medium grained ferruginized and massive sandstone with an erosional base exposed at the middle part of the outcrop. Thickness varies from 0.9 m to 1.19 m (Figs. 2 and 4a).
6. Greyish shale lithofacies (F6): This consists of non- pyritic, indurated shale that is greyish in colour and is about 0.79 m thick (Fig. 2).
7. Mudstone lithofacies (F7): The lithofacies consists of greyish mudstone with thickness that varies from 0.6 m to 1.15 m. It has some thin laminations and lenses of very fine grained, whitish sandstone (Figs. 2, 4b & 5a).
8. Very fine grained sandstone lithofacies (F8): The lithofacies consists of very thin bed (17 cm thick) of very fine grained whitish, clayey sandstone which overlies the carbonaceous mudstone lithofacies (Fig. 2).
9. Flaser bedded sandstone lithofacies (F9): This consists of fine to medium grained sandstone with whitish claystone flasers (Figs. 2, 5b and 6). Thickness varies from 5 cm to 0.55 m. *Ophiomorpha*burrows occur.
10. Coarse grained sandstone lithofacies (F10): The lithofacies consists of coarse grained sandstone of about 0.3 m thick which is generally massive and clay free (Fig. 2).
11. Carbonaceous sandstone lithofacies (F11): It consists of medium grained, greyish sandstone of about 10 cm thick (Fig. 2)
12. Massive claystone lithofacies (F12): The thickness varies from 10 cm to 0.73 m. It consists of whitish claystone that is devoid of physical sedimentary structures (Fig. 2).
13. Cross bedded sandstone lithofacies (F13): This consists of cross bedded fine to medium grained sandstone of about 0.34 m to 0.62 m thick which constitute the upper part of the exposure (Figs. 2 and 6). Cross beds are of planar type in which the foresets are draped by whitish claystone. Reactivation surfaces, tidal bundles, herringbone structures and *Ophiomorpha* burrows are characteristics.

These lithofacies were grouped into four facies associations as follow;

Lithofacies Association I (FA1): This association consists of vertically stacked succession of bioturbated sandstone, ripple laminated claystone, ripple laminated sandstone and dark shale lithofacies which conformably overlie each other (Figs. 2 and 3). Long tubes of *Thalassinoides* burrows are common on the bioturbated sandstone and dark shale lithofacies. *Thalassinoides* belong to *Cruziana* ichnofacies and are suggestive of low energy depositional setting. The depositional environment is interpreted as lower shoreface to inner neritic settings.

Lithofacies Association II (FA2): This consists of conformable succession of ferruginized sandstone, greyish shale, mudstone and very fine grained sandstone lithofacies (Fig. 2). The inferred depositional environment is fluvial channel.

Lithofacies Association III (FA3): The association consists of inter- bedded fine to

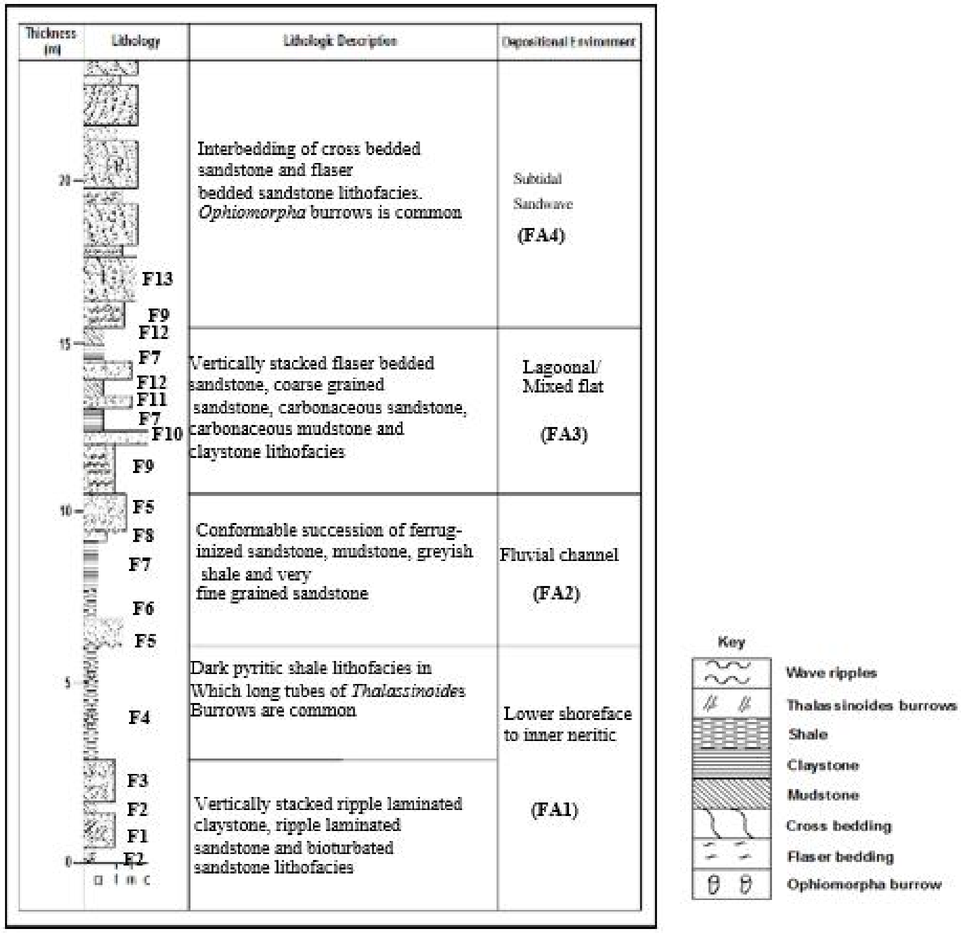

Fig. 2. Lithologic section of the Ameki Group exposed at Ogbunike old toll gate (N06°10´855, E06°51´953)

Fig. 3. Lower shoreface to anoxic inner neritic facies association (a) Bioturbated fine grained sandstone lithofacies (b) Low amplitude wave ripple laminated fine grained sandstone (c) Dark shale lithofacies

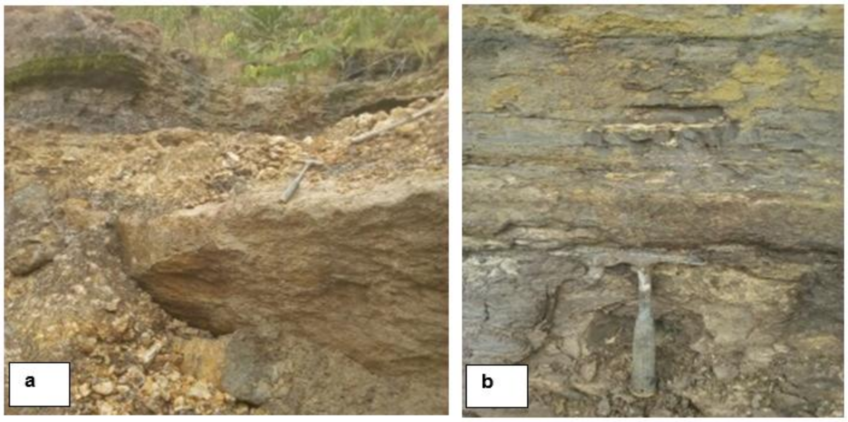

Fig. 4a & b. Fluvial channel facies association consisting of ferruginized fine to medium grained sandstone lithofacies which truncate one another and greyish shale, carbonaceous mudstone and very fine grained sandstone lithofacies. (b) The thin laminations and lenses of the whitish very fine grained sandstone lithofacies in the mudstone lithofacies are shown at the middle part of the figure above the ferruginized sandstone lithofacies

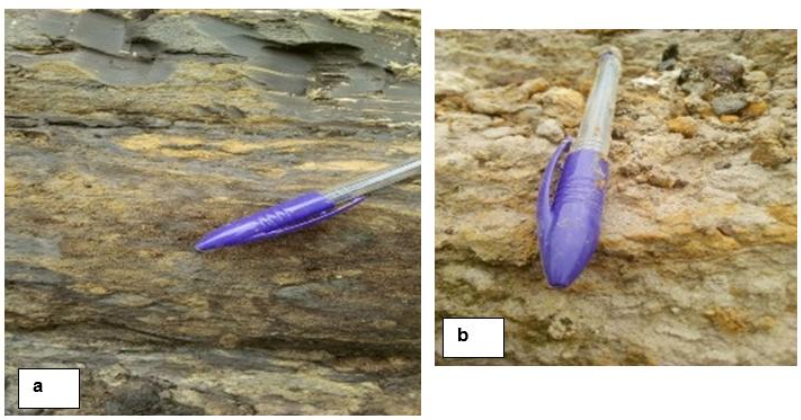

Fig. 5. Lagoonal/mixed flat facies association (a) Bioturbated carbonaceous mudstone. *Thalassinoides* burrows are common (b) Flaser bedded fine to medium grained sandstone lithofacies. Pen is pointing at *Ophiomorpha* burrow

Fig. 6. Subtidal sandwave facies association showing the flaser and cross bedded sandstone lithofacies

medium grained sandstone with clay flaser laminations, coarse grained sandstone, carbonaceous mudstone, massive claystone and carbonaceous sandstone lithofacies. Clay flasers are common on the basal sandstone (Fig. 2). *Ophiomorpha* and *Thalassinoides* burrows are common on the sandstone and mudstone respectively (Fig. 5). These ichnofossils belong to both *Skolithos* and *Cruziana* ichnofacies and can be interpreted to depict energy fluctuation from high to low respectively. The sandstone lithofacies were deposited under higher energy, the carbonaceous mudstone lithofacies under lower energy conditions whereas clay flasers formed on the sandstone under quiet water condition. Depositional environment is interpreted as lagoonal/mixed flat.

Lithofacies Association IV (FA4): This consists of inter-bedded cross bedded and flaser bedded fine to medium grained sandstone lithofacies which constitute the upper part of the exposure. The base is flaser bedded (Figs. 2 and 6). *Ophiomorpha* burrows are common. Inferred depositional environment is subtidal sandwave.

3.1.2 Palynological analysis

The palynomorph recoveries from the carbonaceous mudstone, greyish shale and dark pyritic shale samples were fairly abundant and diverse. Diverse species of pollen, 5 species of spores, fungal hyphae, acritarch (*Leiosphaerdia)*, dinoflagellate (*Cordosphaeridium cantharellus)* and foraminiferal wall linings were recovered in this study. Marine species (dinoflagellates, acritarches and foraminiferal wall linings) were recovered from the dark shale lithofacies whereas the greyish shale and mudstone are barren of marine species. Table 2 shows the distribution chart of some of the palynomorphs.

A single count of *Cordosphaeridium cantharellus* together with few occurrences of *Leiosphaeridia* sp., foraminiferal wall linings and fungal spores and hyphae are attributes of the units.

The total palynomorph counts and percentages are shown in Table 3 whereas Fig. 7 shows the percentage distribution of the palynomorphs in the stratigraphic units sampled.

Results in Table 3 and Fig. 7 show pollen group to be of greater abundance and more diverse than other palynomorph groups. Distribution of palynomorphs in the stratigraphic unit, in the order of decreasing abundance is as follow; pollen (*Psilatricolporites* sp*, Longapertites marginatus, Psilastephanocolporites, Proxapertites operculatus* and *Retibrevitricolporites triangulatus)* and for spores *Laevigatosporites* sp. and *Leiotriletes* sp. dominated the group and were also abundant in all the samples analyzed. Some of the palynomorph groups recovered are shown as Fig. 8.

3.1.3 Micropaleontological analysis

The result of foraminiferal analysis is shown in Table 4. The mudstone and greyish shale lithofacies are barren of foraminiferal species. The assemblages in the dark shale lithofacies consist of low abundance of benthic species represented by both calcareous and agglutinated forms. Fig. 9 shows some of the forms recovered.

3.1.4 Paleoecological classes and paleoclimatic studies

The palynoflora recovered belong to five paleoecological classes namely; the mangrove/palm swamp, coastal plain/swamp, rainforest, freshwater swamp and marine groups (Fig. 10). Mangrove/ palm (e.g *Spinizonocolpites echinatus, Psilatricolporites* sp*, Longapertites marginatus and Proxapertites operculatus*) and fresh water pteridophytes (e.g *Laevigatosporites* sp *and Leiotriletes* sp) dominated the floral assemblage. Table 5 shows paleoecology and paleoclimatic conditions based on the palynomorphs recovered.

3.1.5 The Mangrove/palm group

Mangrove is grouped into nypa and pelliciera. nypa group recovered in this study consists of *spinizonocolpites echinatus* (Fig. 8b) which shows high abundance in the stratigraphic units. The pelliciera group is represented by *psilatricolporites crassus* (Fig. 8a). *psilatricolporites crassus* also show common occurrences and abundant.

3.1.6 Coastal plain/swamp and forest groups

The species of coastal plain/swamp recovered in this study show minor occurrences and are represented by *Monocolpites marginatus, Pachydermites diederixi, Retitricolporites irregularis, Retibrevitricolporites triangulatus, Polypodiaceoisporites* sp. among others.

The rainforest group is represented by *Psilastephanocolporites laevigatus* (Saptoceae) and *Bombacacidites* sp. which also show minor occurrences.

Table 2. Palynological distribution chart of the shale samples

Sample no	Pollen																														Spores					Others			
	Longapertites marginatus	*Psilatricolporites sp.*	*Psilatricolporites rotundus*	*Psilastephanocolporites laevigatus*	*Proxapertites operculatus*	*Psilatricolporites crassus*	*Scabratisporites anummensis*	*Retibrevitricolporites triangulatus*	*Monocolpites marginatus*	*Scabratisporites ibadanensis*	*Psilatricolporites calabarensis*	*Margocolpites foveolatus*	*Psilatricolpites sp.*	*Retitricolporites irregularis*	*Striatricolporites undulatus*	*Retitricolporites ituensis*	*Syncolporites marginatus*	*Incerti cerdi*	*Costatricolporites reticulatus*	*Pachydermites diederixi*	*Periretitricolpites anambraensis*	*Retimonocolpites asabaensis*	*Clavainaperturopollenites clavatus*	*Praedapollis africanus*	*Striatricolporites bellus*	*Periretipollis spinosus*	*Psilamonocolpites sp.*	*Psilatricolpites okezei*	*Mauritidites sp*	*Gemmatricolporites psilatus*	*Alinpollis venus*	*Laevigatosporites sp.*	*Leiotrilete sp*	*Verrucatosporites sp*	*Cyathidites minor*	*Polypodiaceoisporites sp*	*Cordosphaeridium cantharellus*	*Leiosphaeridia*	*Microforaminiferal test lining*	*Fungi*
NAK 5a	20	69	8	2	12	3	4	3		3	4	2	3		4			1				1										15	11					5	1	5
NAK 5b	36	59	16	13	7	7	8	7		4		7	1		2	1	1															22	18		2					4
NAK 5c	39	52	11	9	8	2	2	13	3	1	5	3	3		2	1	2	1				5		1			2					23	24					5	1	6
NAK 5d	14	39	19	7	4	3	1	3	4	1	7	2			2		1			1		3			1							7	22					6		10
NAK 5f	12	51	27	19	8	4	3	5	5	4	5	4	6		3	1		1		1	2			2				1				50	37					1	1	6
NAK 5g	24	20	5	7	4	2		3	3	2	6	8			3			1														28	23	7	1	1	1	2	1	4
NAK4	26	46	12	10	5	4	9	5		3	1	4	3			3	1		1			1	1		1	6					1	16	11	4				6		7
NAK 3	23	33	10	9	4	1	6	2	4	7	1	3	11	1	1			1	7	1	1								1	1		19	5	1				1		7

Table 3. Total count and percentage occurrences of the palynomorph groups recovered in the study

Palynomorph group	Total count	% Occurrence
Pollen	1,114	72.20
Spores	349	22.62
Fungi	49	3.18
Acritarch	26	1.69
Foraminiferal wall lining	4	0.25
Dinoflagellates	1	0.06
	Total = 1543	100

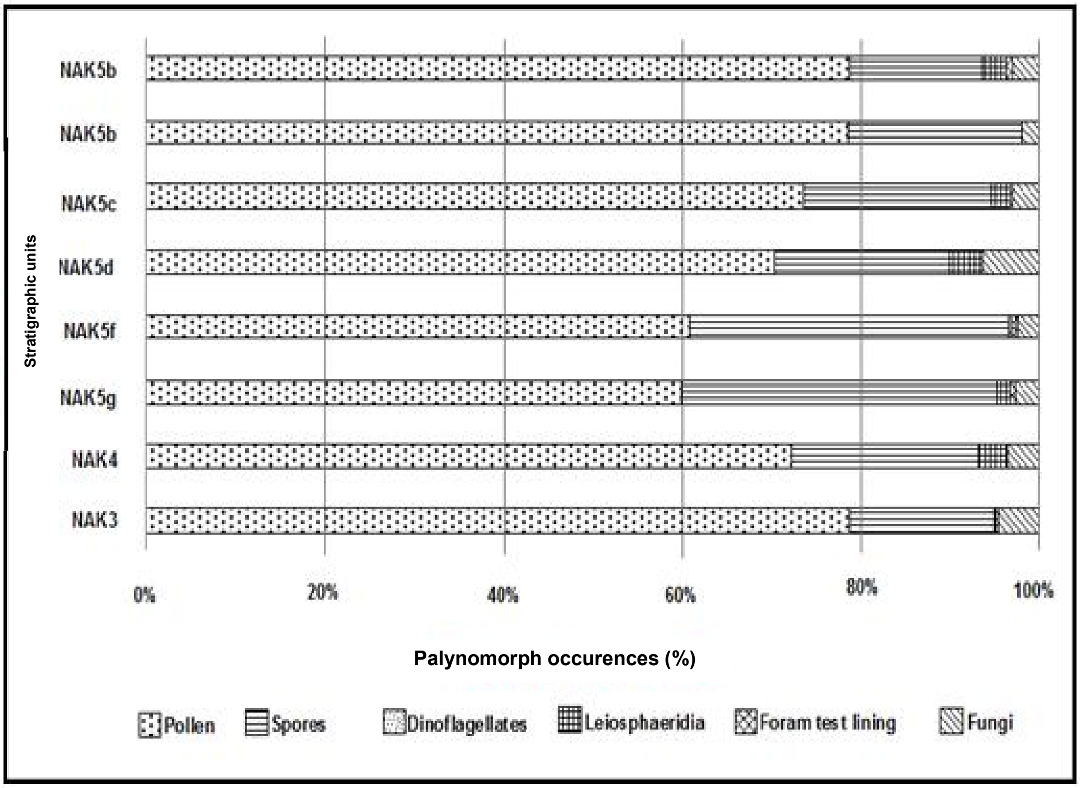

Fig. 7. Percentage distribution of palynomorphs groups in the stratigraphic units

3.1.7 Fresh water swamp

Fresh water swampis dominated by the pteridophyte ferns such as *Laevigatosporites* sp and *Leiotriletes* sp which are fairly abundant in the samples. Others include *Verrucatosporites* sp., *Syncolporites marginatus* and fungal hyphae which show minor occurrences. These suggest fresh water influx from terrestrial environments.

3.1.8 Marine group

The marine group recorded very low counts of *an* acritarch *(Leiosphaeridia),* foraminiferal test linings and dinoflagellate cyst (*Cordospharedium cantharellus).*

Paleoclimatic condition of the period based on the palynomorphs is inferred to vary from wet to dry but wetter periods predominated over dry ones (Table 4). The climate is interpreted as humid and warm (tropical). Mangrove vegetation was dominant during wetter climates whereas rainforest was minimal. They expanded further into the coastal plain/savanna.

3.2 Discussion

3.2.1 Depositional environment

Lithofacies and biostratigraphic analyses of the Ogbunike old toll gate succession show that the

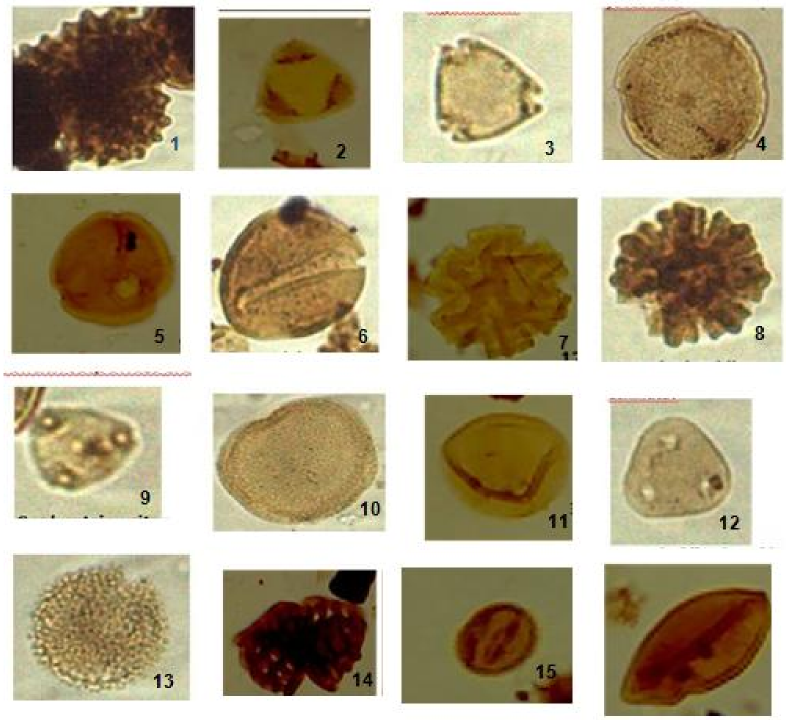

Fig. 8a. Photomicrograph of some of the palynomorphs recovered in this study. All the palynomorphs are of the same size (X400)

1. Margocolporites foveolatus [27],2. Retibrevitricolporites triangulatus [28]. 3. Retibrevitricolporites triangulates[28], 4. Psilatricolporites crassus[29]. 5. Psilatricolporites crassus[29], 6. Monocolpites marginatus[30], 7. Ctenolophonidites costatus[31,28],8. Ctenolophonidites costatus[31,28], 9. Scrabratisporites simpliformis [28], 10.Proxapertites cursus,[28], 11. Proxapertites operculatus [32],12. Anacolosidites luteoides [33],13. Gabonisporites viaourouxii[34],14. Margocolporites foveolatus, 15. Psilatricolporites sp,16. Longapertites marginatu [31]

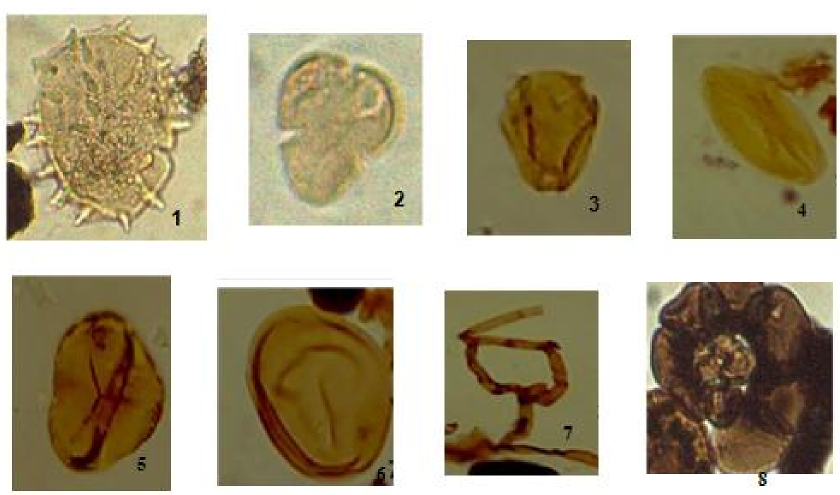

Fig. 8b. Photomicrograph of some of the palynomorphs recovered. All the palynomorphs are of the same size(X400)

(1). Spinizonocolpites echinatus [35], (2). Bombacacidites sp,(3) Psilatricolporites owerriensis [10],(4) Psilamonocolpites sp, (5) Leiotrilete sp.(6) Laevigatosporites sp. (7) Fungal hyphae (8) Foraminiferal wall lining

Table 4. Summary of age and bathymetry of recovered foraminifera

Sample no	Lithofacies	Foraminifera Species	Bathymetry	Age
NAK5a	Carbonaceous mudstone	Barren of foraminifera	Non marine	Indeterminate
NAK5b	Greyish shale	Barren of foraminifera	Non marine	Indeterminate
NAK5c	Dark pyritic shale	*Heterolepa pseudoungeriana* *Florilus exgrcostiperium* *Ammobaculites sp,* *Cibicides sp.* Shell fragment	Inner Neritic	Non- diagnostic
NAK5d	Dark pyritic shale	*Hanzawaia strattoni* *Haplophragmoides cf. excavatus* *Haplophragmoides sp* *Reophax sp.* *Ammobaculites sp.* Echinoid remains	Inner Neritic	Indeterminate
NAK5f	Dark pyritic shale	*Heterolepa pseudoungeriana* *Haplophragmoides sp.* *Ammobaculites sp.* *Nodosaria sp.* *Uvigerina subperegrina* *Bolivina sp.* *Uvigerina sp.* *Uvigerinella sp.*	Inner Neritic	Non- diagnostic
NAK5g	Dark pyritic shale	*Fursenkoina bowie* *Haplophragmoides sp.* *Miliammina sp.* *Textularia sp.*	Inner Neritic	Indeterminate
NAK4	Dark pyritic shale	*Florilus atlanticus*	Inner Neritic	Non- diagnostic
NAK 3	Greyish shale	Barren of foraminifera	Non marine	Indeterminate

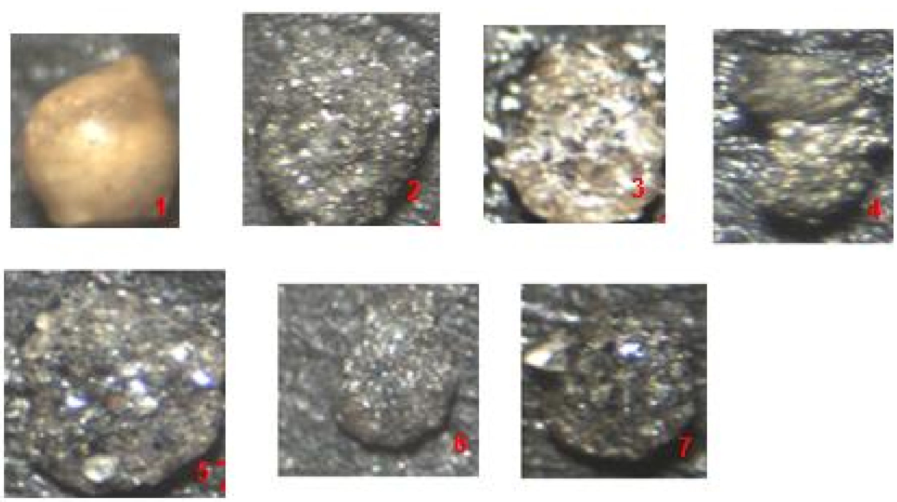

Fig. 9. Some of the foraminifera recovered from the study

1. Nodosaria sp (Fragment)(Magnification: x402, Dimension: 176.1x27.1um); 2. Milliammina sp (Magnification: x610, Dimension: 375.3x217.2um); 3. Ammobaculites sp (Magnification: x360, Dimension: 251.3x152.1um, 4. Reophax sp (Magnification: x360, Dimension: 232.1x93.1um);5. Haplophragmoides cf excavatus(Magnification: x420, Dimension: 300.2x202um); 6. Ammobaculites sp (Magnification: x320, Dimension: 207.3x176um); 7. Haplophragmoides sp (Magnification: x375, Dimension: 214.2x168um)

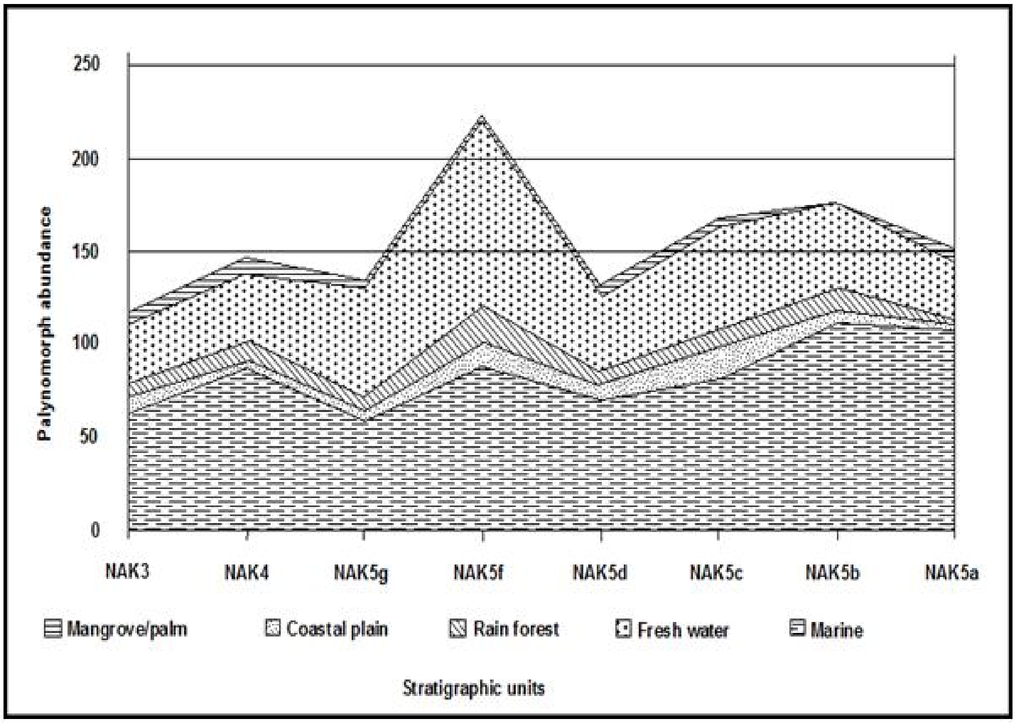

Fig. 10. Paleoecology of the palynomorphs showing the five classes

Table 5. Paleoecology and paleoclimatic conditions based on the palynomorphs

Palynomorph Group	Species	Vegetation/paleoecology	Climate
Pollen	*Spinizonocolpites echinatus*	Mamgrove	Wet
	Pilatricolporites crassus	Mangrove	Wet
	Psilatricolporites sps.	Palmae/ mangrove	Wet
	Longapertites marginatus	Palmae/ mangrove	Wet
	Proxapertites operculatus	Palmae/mangrove	Wet
	Mauritidiites sp	Palm/back- mangrove	Wet
	Psilamonocolpites sp.	Back- mangrove	Wet
	Bombacacidites sp.	Rainforest/back- mangrove	Wet
	Psilastephanocolporites laevigatus	Rain forest	Wet
	Retitricolporites irregularis	Coastal plain/Savanna	Dry
	Retibrevitricolporites triangulatus	Upper coastal plain	Dry
	Monocolpites marginatus	Upper coastal plain	Dry
	Pachydermites diederixi	Coastal plain	Wet
	Syncolporites marginatus	Fresh water	Wet
Spores	*Laevigatosporites sp.*	Fresh water	Wet
	Leiotriletes	Fresh water	wet
	Verrucatosporites sp	Fresh water	wet
	Polypodiaceoisporites sp	Coastal plain	wet
Marine palynomrphs	Acritarch	Marine	Wet
	Microforaminiferal wall lining	Marine	Wet
	Dinoflagellates	Marine	Wet

sediments were deposited in a varying environmental settings that fluctuated from fluvial channelthrough marginal marine to shelf (shallow marine). Deposition of the units started with the lower shoreface bioturbated and wave ripple laminated fine grained sandstone and claystone at the base of the succession. Abundant burrows of *Thalassinoides* and low amplitude wave ripples which occur on the sandstone are indications of deposition under low energy wave influenced setting. The overlying dark shale shows deepening of the ancient sea which is evidenced from the marine palynomorphs which co- occur with foraminifera as well as the long burrows of *Thalassinoides* in the facies. General absence of marine palynomorphs and foraminifera on the greyish shale and mudstones which overlie the channel sandstone above the dark shale suggest them to be fluvial marsh. A change from marine to fluvial conditions observed in the succession is attributed to regression (shallowing) of the ancient sea. Further deepening of the sea commenced upwards the succession with the overlying marginal marine sandstones and mudrock (mixed flat/lagoonal) and finally subtidal facies association at the topmost part of the outcrop. The vertical burrows of *Ophiomorpha* which occur on the subtidal sandstone facies is attributed to high energy condition which prevailed in the environment. This interpretation is in agreement with variability in depositional settings of the Nanka Formation discussed in Nwajide [1].

3.2.2 Age determination

Pollen and spore assemblages recovered from the shale and mudstone are typical of Middle Eocene age. The pollen and spores fall within the P400 zone (subzones P430- P450) of [36] for the Niger Delta, Nigeria as well as [37] and correlates with Monoporites annulatus Pan tropical zone of [38]. It is also comparable with the *Retimonocolpites asabaensis* palynozone of [39] for southern Sudan. The P430- P450 subzone is dated Middle Eocene. Abundant occurrences of stratigraphic marker pollen such as *Ctenelophonidites costatus, Margocolporites foveolatus, Monocolpites marginatus, Retibrevitricolporites triangulatus, Proxapertites cursus, Bombacacidites* sp. and common occurrences of *Scrabratisporites simpliformis, Anacolosidites luteoides, Psilatricolporites crassus, Gabonisporis vigourouxii, Striatricolporites catatumbus* and *Retistephanocolporites williamsi* are attributes of the assemblages. The assemblages have been recovered from the Eocene sediments in West and Eastern Africa as well as Northern South America [40,38,41,10,42-44,39]. *Cordosphaeridium cantharellus,* the only dinoflagellate recovered has been reported in the Eocene sediments in North America [45-48], Europe [49-51], Asia [52-55] and Africa [56-59].

The age of the samples could not be determined from the benthic foraminiferal assemblages due to non-recovery of age diagnostic forms. The succession is stratigraphically assigned to the Ameki Group (Nanka Formation).

3.2.3 Paleoecological interpretation

Five paleoecological groups of palynomorphsidentified in this study is also attributed to fluctuation in paleoenvironmental conditions of deposition. *Spinizonocolpites echinatus* recovered in this work is a mangrove pollen. *Psilatricolporites crassus* has been described as a woody mangrove community, widespread across Africa [38] and South America [29,60] but endemic today to central and northern South America [61-64]. *Longapertites marginatus, Proxapertites operculatus, Retimonocolpites asabaensis, Psilatricolporites* sp., *Mauritidites* sp. are elements of mangrove swamp forest (though considered as weak mangrove) recovered in abundance and are referred to as pollen with affinity to modern palms [38,65,44]. The mangrove must have resulted from tides along the margins of the coastal lagoons and brackish tidal waters [66]. The predominance of the mangrove and palm groups over other palynomorphs in the stratigraphic units probably is suggestive of the deposition of the sediments during a predominantly wet and warm period when mangroves and palms thrived most.

Paleoecological parameters evaluated from the foraminiferal data in Table 4 include; paleobathymetry, oxygenation and paleo-temperature.

3.2.3.1 Paleobathymetry

Foraminifera are considered as an important tools in paleoenvironmental and paleoecological studies (e.g Cicha [67-68]. The benthic ones are widely used for paleobathymetric reconstruction because they dwell in a wide range of environment varying from shallow marine to deep marine settings. Benthic foraminiferal assemblages recovered from the dark shale lithofacies suggest shallow marine (inner neritic) setting for the lithofacies. Similar assemblages were recovered from the inner neritic environment in the subsurface part of the Niger Delta [69-70]. According to Allen [71], inner neritic environment lies within 0- 30 m on the continental shelf.

3.2.3.2 Oxygenation

The usefulness of benthic foraminifera in the reconstruction of paleo- oxygenation in marine is documented [72-77]. Abundance of *Bolivina, Fursenkoina* and *Uvigerina* has been noted as a good indicator of oxygen- depleted environments [78-80,72-73,81-83,74]. Association together with low abundance of *Bolivina, Fursenkoina* and *Uvigerina* in the dark shale may probably indicate suboxic condition of deposition for the facies. Moreover, calcareous benthic foraminifera such as *Bolivina* sp. and *Cibicides* sp. have been described and grouped as oxic to suboxic foraminiferal indicators [84].High diversity and abundance of such foraminiferal assemblages with thick- walled, large and ornamented tests are possible indication of oxygenated marine environment [85-86]. Low abundance of these indicator foraminifera agrees with suboxic condition of deposition for the dark shale.

3.2.3.3 Paleotemperature

The diversity of planktonic foraminifera is related to paleotemperature conditions of the sea [87-88]. Its diversity in modern oceans was reported to be lower in cool water than in warm waters [89]. Rare occurrence of planktonic foraminiferal assemblage in the dark shale studied suggests deposition mostly during the period of cool water temperature. *Bolivina* and *Uvigerina* have been referred to as cold water assemblages [85].

4. CONCLUSION

Lithofacies analysis of the outcropping succession at Ogbunike old toll gate have shown that the exposure was deposited in an environmental settings that vary from fluvial to marginal and shallow marine (inner shelf). Pollen and spores assemblages recovered from the shale and mudstone lithofacies indicated Middle Eocene age for the succession. The exposure is stratigraphically assigned to the Ameki Group and the age is here interpreted as Middle Eocene. Five paleoecological groups consisting of mangrove/palm, coastal plain, rain forest, fresh water swamp and the marine groups were identified based on palynomorphs. Benthic foraminiferal assemblages from dark shale lithofacies suggest sub- oxic, nutrient- rich, inner shelf setting. Paleoclimatic condition from biofacies was warm and humid (tropical).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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