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Palynological and Paleoenvironmental Study of Paleogene in Bende – Umuahia, Niger Delta Basin, Nigeria

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SIGNIFICANCE STATEMENT

This study discovers the geologic age and depositional environment of Bende/Umuahia area. The findings will be beneficial for future research especially in the application of high resolution biostratigraphy for hydrocarbon exploration that is being carried out in the inland part of Niger Delta Basin.

AUTHORS CONTRIBUTION

Osita Igwebuike Chiaghanam, Kingsley Chukwuebuka Chiadikobi and Celestine Emmanuel Oguanya interpreted the outcrops, delineated the geological boundaries and general compilations/documentation of the work. Okechukwu, Nicodemus Ikegwuonu assisted in the laboratory preparation of the samples. Charity Nkiru Nwokeabia produced and edited the geological map.

Abstract

Palynological and paleoenvironmental study of outcrops exposed around Bende and Umuahia areas were carried out to re-evaluate its age and reconstruct the environment of deposition. Palynological analysis of the sediments was done by using conventional method of 40% concentrated Hydrofluoric acid maceration to determine the age and paleoenvironment of the area. Lithological units encountered were carbonaceous shale, sandstones, mudstones and limestone. Age determination/correlation was based on occurrence of stratigraphically significant age diagnostic palynomorph assemblages. Imo Formation was dated Middle – Late Paleocene with the following index fossils assemblage, *Proxapertites operculatus, Echitriporites trianguliformis, Retibrevitricolpites triagulatus, Spinizonocolpites baculatus, Scabratriporites simpliformis, Mauritidiites crassibaculatus, Bombacidites* sp., and *Grimsdalea polygonalis*. Ameki Formation was assigned Early-Middle Eocene based on *Monoporites annulatus, Proxapertites cursus, Retistephanocolpites williamsi, Ctenolophonidites costatus, Spinizonocolpites echinatus, Psilatricoplorites crassus, Psilatricolporites operculatus, Retitricolporites irregularis,* and *Striatopollis* sp. Ogwashi Formation was dated Late Eocene-Oligocene on the basis of the age-diagnostic sporomorphs assemblage, such as, *Verrucatosporites usmensis, Laevigatosporites ovatus, Chenopodipollis* sp., *Retibrevitricolporites* sp., *Psilastephanocolporites* sp., and *Racemonocolpites hians*. The environmentally significant palynomorphs species indicate that Imo Formation was deposited in a tidally-influenced shallow marine estuarine setting, while Ameki Formation was deposited in open shallow marine to estuarine-lagoonal settings. Ogwashi Formation was deposited between upper to lower deltaic settings. The palynological study suggests Formtions of Paleogene Age while the paleoenvironment is Deltaic to Shallow-marine.

Keywords: Palynology, Paleogene, paleoenvironment, palynomorph, lithology.

1. INTRODUCTION

Considerable work has been done on the palynology and paleoenvironment of Niger Delta Basin by various workers. Most of the works are basically on the subsurface (down-dip) sector of the basin. They include Chiaghanam, 2007; Ige, 2009; Durugbo et al., 2010;Oloto, 2010; Adebayo et al. 2012; Boboye and Ademola, 2013; Adebayo, 2013; Oloto, 2014; and Oloto et al. 2014. The inland part of the basin has received little attention, which includes Oboh-Ikuenobe et al. 2005; Durugbo, 2013; Ikegwuonu, 2015; Ikegwuonu and Umeji, 2016; and Oguanya, 2016. Oboh-Ikuenobe et al. 2005 documented the lithofacies and palynofacies of the paleogene strata in Bende-Umuahia area. Ikegwuonu and Umeji; 2016 used sporomorpha assemblage from the lignite and carbonaceous Shale at oyivo quarry around umuahia to assign Oligocene to Early Miocene Age to the sediments. They noted that the deposits belong to the Ogwashi-Asaba Formation and were deposited in Upper to Lower deltaic environment. Oloto, et al. 2014 used the ditch cuttings and outcrops of Anambra and Niger-Delta Basin penetrated by Bende-1 well to describe the lithostratigraphy, paleoecology, paleobathymetry, depositional environment and the relative age. Oguanya, 2016 described the lithostratigraphy and depositional environment /relative age of Umuahia/Bende area using palynological information. The study area comprises of three (3)

Formations namely Imo Shale (Middle Paleocene-Early Eocene), Ameki (Early to Late Eocene) and Ogwashi-Asaba (Oligocene-Early Miocene). See Fig. 1 and 2. Imo Formation is the basal unit of the Niger Delta Complex. Its outcropping area describes a concave Southwards and narrows and tapers off northwest of Odukpani area in the Calabar Flank, where it is overlapped by the Benin Formation. The Formation is essentially Blue-grey shales with Sand lenses, marls and fossiliferous limestones, sandstone members- Ebenebe, Umuna and Igbaku Sandstones; shales with foraminifera and ostracods (Nwajide, 2013). The Formation is exposed at Bende Town, extending from Oduenyi Village to Ndiwo Junction along Ndiwo-Ikporom road cut. The Ameki Formation which has its type locality at Ameki Village has a maximum thickness of 1,500m. Being an extensive regressive facies, a shallow marine environment is assigned although with some variability in the subenvironments. The formation which is richly fossiliferous, comprises of four stratigraphic units as members (pebbly Sandstone, argillaceous sandstone, shale and clay). The formation is characteristically calcareous clays and silts with thin shelly limestone, rich in foraminifera, mainly sands, minor silt and clay intercalations (Nwajide, 2013). At Itumbuzor in Bende, the Formation directly overlies the Imo Formation and terminates westward around Isiadu Ameke and Amaogugu where it is completely buried by the overlying Ogwashi Formation (Ikegwuonu, 2015; Ikegwuonu and Umeji, 2016). The Ogwashi-Asaba Formation which is regarded as the lignite series stretched from Okitipupa Ridge and occurred in outcrop pattern at Onitsha, Ozubulu, Nnewi, Southeastwards to Umuahia, Ikot-Ekpene, Uyo and Calabar where it is overlapped by the Benin Formation. Its type locality is at Eke Mgbalimbga in Ogwashi-Asaba. The formation may be characterized as consisting of white, blue and pink clays, cross-bedded sands, carbonaceous mudstone, shales and seams of lignite. The beds are nearly horizontal with dips of 2º to 3º. The lignite seams are occasionally jointed in places and display a conchoidal fracture. They vary from woody to earthly type and contain considerable amount of palm debris, which amounts for their high resin and wax content (Nwajide, 2013). The outcrops of this formation were observed within and around Ubakala, Oyivo, Ohiya, Okaluga in Umuahia. See table 1. The study was undertaken to determine the age and depositional environment of Bende/Umuahia area using palynological informations generated from outcrop of the study area.

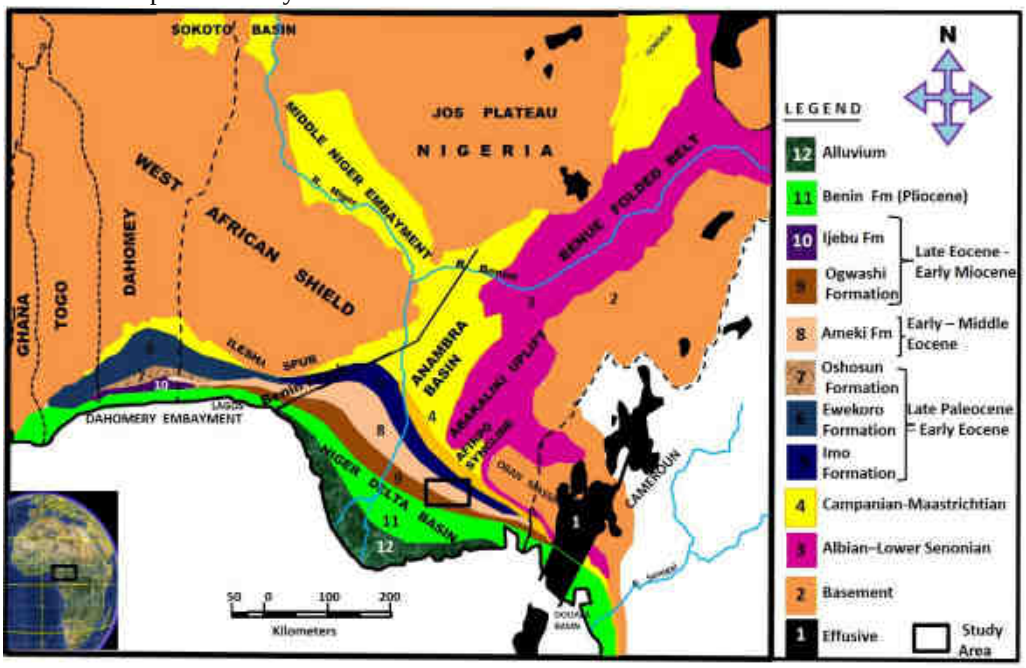

Fig. 1: The Cenozoic succession of the Niger Delta Basin and Location of the study area (after Murat, 1972; Ikegwuonu and Umeji, 2016)

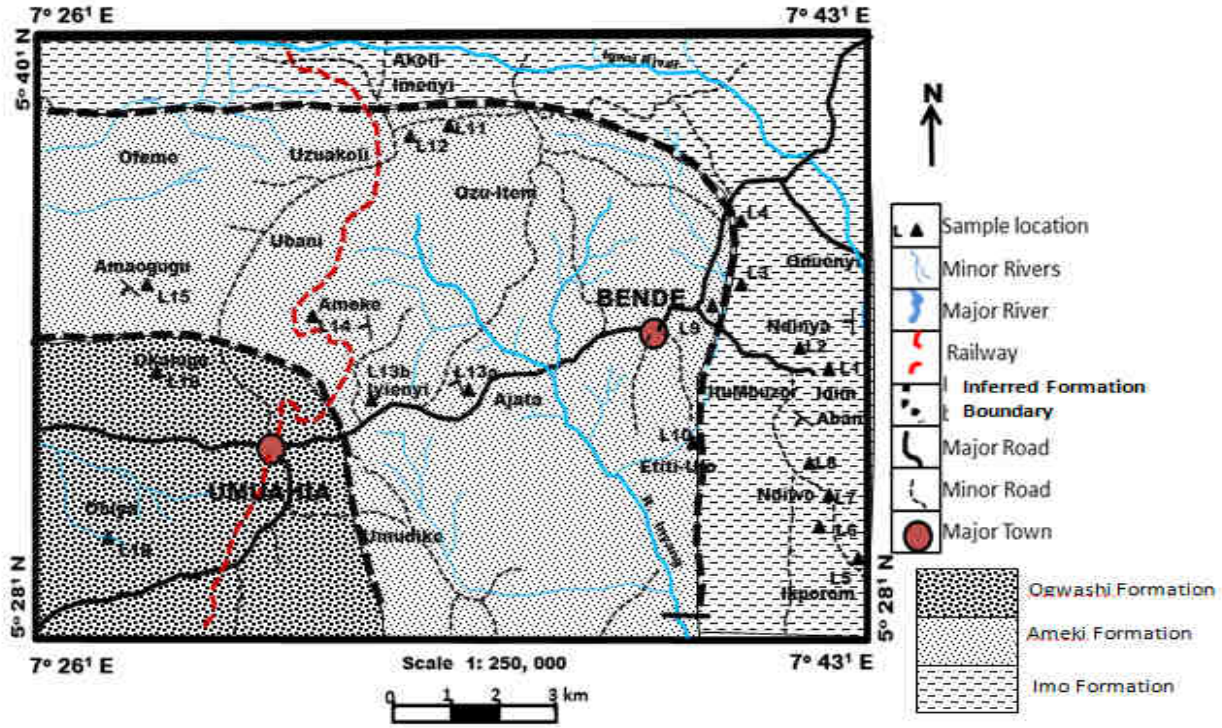

Fig. 2: Geologic Map of the Study Area

Table 1: Stratigraphic column of Niger Delta Basin (modified after Frankyl and Cordry, 1967)

Age			Group	Niger Delta Basin This Study	
				Down-dip	Up-dip
Quaternary				Alluvium	
NEOGENE	Pliocene		Benin Group	Benin Formation	Benin Formation
	Miocene				
PALEOGENE	Oligocene		Ameki Group	Upper Agbada Formation	Ogwashi Formation
	Eocene	L		Lower Agbada Formation	Ameki Fm/ Nanka Sand/ Nsugbe Sst
		M			
		E			
	Paleocene		Imo Group	Akata Formation	Imo Fm/ Umuna Sst/ Ebenebe Sst
	Danian				
LATE CRETACEOUS	Late Maastrichtian		Coal Measures Group		

Major Unconformity

L =Late; M= Middle; E= Early; sst=Sandstone; Fm=Formation

2. Method

A total of Twenty-one (21) samples of shales and mudstones were sampled across the study area and analyzed

for their palynological contents. The study area lies between latitudes $5^{\circ}28^{1}$ N - $5^{\circ}40^{1}$ N and longitudes $7^{\circ}27^{1}$ E - $7^{\circ}43^{1}$ E. The sample preparation was carried out using the convention maceration technique for recovering acid insoluble organic-walled microfossils from sediments. Each sample was digested for 30 minutes in 38% hydrochloric acid to remove carbonate and 72 hours in 40% hydrofluoric acid for removal of silicate. The extracts were washed through 10 microns nylon sieve mesh. The sieve-washed residues were oxidized for 30 minutes in 70 % HNO_3 and 5 minutes in schulze solution to render the fossils translucent for transmitted light microscopy. The oxidized residues were rinsed in 2 % KOH solution to neutralize the acid. Swirling treatment was undertaken in order to remove the resistant coarse inorganic mineral particles. The residues were stained with Safranin-O to increase the contract for study and photography.

Aliquots were dispersed with polyvinyl alcohol, dried on cover-slips and mounted in araldite resin. Two slides were made from each sample in which palynomorph assemblages, including markers and species of environmental value were identified and recorded. Light photomicrographs were taken with Kyowa binocular microscope.

3. Results

Palynological distributions in the studied sections

Imo Formation

Table 2 shows the absolute counts of the distribution of palynomorphs species in the studied sections. Representative samples from these formations at Locations 1, 2, 4 and 8, yielded very rich palynomorphs species while sample from (Loc 6) recorded very few palynomorphs with low counts. **Terrigenous Species**: The spores recovered included *Laevigatosporites ovatus, Verrucatosporites usmensis, Leiotriletes adriennis, Cyathidites* sp., *and Polypodiaceoisporites* sp. The algal spore, *Schizosporis* sp,, was also recovered, **(Fig. 3).** The pollen includes *Grimsdalea polygonalis, Longapertites marginatus* (rare), and *Proxapertites operculatus* (common). Others are *Proxapertites cursus, Mauritidiites crassibaculatus, Spinizonocolpites baculatus, S. echinatus, Retibrevitricolpites triangulatus, Psilatricolporites crassus, Bombacidites* sp., *Psilatricolporites minutus, Retistephanocolpites williamsi, Monoporites annulatus, Scabratriporites simpliformis, Echitriporites trianguliformis, Pachydermites diederixi, and Echiperiporites icacinoides.*

Marine Species: Palynomorphs of marine origin were recovered. The dinoflagellate cysts included *Apectodinium homomorphum* (overwhelming*), A. qiunquelatum, A. paniculatum, and A. augustum*. Other species are *Operculodinium centrocarpum, Adnatosphaeridium* sp., *Homotryblium tenuispinosum, Polysphaeridium subtile, Areoligera senoniensis, Glaphyrocysta ordinata, Achilleodinium biformoides, Hystrichokolphoma* sp., *Spiniferites ramosus, Achomosphaera membraniphora, Hystricosphaeridium* sp., *Diphyes colligerum*, *Cleistosphaeridium diverspinosum*, and *Cordosphaeridium* sp.

However, the fissile shale sample from Location 6 recorded only few terrigenous palynomorphs which includes *Laevigatosporites ovatus, Cyathidites* sp., and *Longapertites marginatus* (2 grains). Marine species was absent.

Ameki Formation

The representative shale and mudstone samples from Locations 9, 10, 13A, 13B and 14, in this formation bear very rich terrigenous sporomorphs than marine species, **table 2 (Fig. 3)**

Terrigenous species: The spores are *Laevigatosporites ovatus, Verrucatosporites usmensis, Cyathidites* sp, *Polypodiaceoisorites retirugatus* and *Cicatricosisporites dorogensis.* The freshwater algae such as *Schizosporis parvus* were also recorded. Among the pollen are *Retibrevitricolpites triangulatus, Retitricolporites irregularis, Monoporites annulatus, Proxapertites cursus, P. operculatus, Longapertites marginatus, Mauritidiites crassibaculatus, Spinizonocolpites echinatus, Psilatricolporites crassus, Bombacidites* sp., *Striatopollis* sp., *Psilatricolporites minutus, Psilatriporites rotundus, Ctenolophonidites costatus, Retistephanocolpites williamsi,. Pachydermites diederixi, Retibrevitricolporites* sp. and *Echiperiporites icacinoides*.

Marine species: Recovered palynomorphs of marine origin include dinoflagellate cysts, such as *Spiniferites ramosus, Achilleodinium biformoides, Operculodinium centrocarpum, Diphyes colligerum, Cordosphaeridium* sp., *Polysphaeridium subtile, Hystrichokolpoma* sp., *Homotryblium tenuispinosum, Kallosphaeridium* sp., *Glaphyrocysta ordinata, Areoligera senoniensis, Cleistosphaeridium* sp. Also recovered are foraminifers test lining and *Perdiastrum* sp.

Ogwashi Formation

The sample from this formation at Location 15 yielded moderately rich palynomorphs assemblage. The terrestrially land-derived spores and pollen were the most predominant. Marine species was rare to absent. The spores include *Verrucatosporites usmensis, Laevigatosporites ovatus, Cyathidites* sp., and the fresh water algae, *Schizosporis purvus*. The pollen is *Psilatricolporites operculatus, Monoporites annulatus, Chenopodipollis* sp., *Psilastephanocolporites* sp, *Retibrevitricolporites* sp., *Racemonocolpites hians, Psilatricolporites crassus,* and *Retibrevitricolpites triangulatus,* (Fig. 3).

Discussion

Biostratigraphic Age determination/ correlation

Fig. 4 shows the stratigraphic range chart of selected age-diagnostic species across the study area. The shale samples from Locations 1 and 2 were assigned Middle – Late Paleocene age, while samples from Locations 4, 6 and 8 were dated Late Paleocene age on the basis of the following recovered palynomorph assemblage. They include *Proxapertites operculatus* overwhelming in most of the samples. Others are *Spinizonocolpites baculatus, Echitriporites trianguliformis, Retibrevitricolpites triagulatus, Scabratriporites simpliformis, Mauritidiites crassibaculatus, Bombacidites* sp, and *Grimsdalea polygonalis* (Germeraad *et al*., 1968; Takahashi & Jux, 1998, Oloto, 2010; Lucas, 2010; and Ikegwuonu, 2015) **(Fig. 4).** The age is further strengthen by co-occurrence of stratigraphically significant dinoflagellate cysts assemblage, such as *Apectodinium homomorphum* (overwhelming), *Apectodinuim augustum, Homotryblium abbreviatum, Exochosphaeridium bifidium Operculodinium centrocarpum, Ifecysta spp., Cyclonephelium deckonincki, Diphyes colligerum, Kallosphaeridium yorubaensis, Adnatosphaeridium* and *Hystrichokolpoma* sp. The above sporomorphs assemblage correlates well with the Middle – Late Paleocene of the **Imo Formation**, and corresponds to the **pantropical** *Proxapertites operculatus* Zone of Germerrad *et al*., 1968. On the basis of Niger Delta pollen zonations, the Imo Formation (Middle-Late Paleocene) correlates from **P200 to P300** pollen zone of Evamy *et al*., 1978.

The **Imo Formation** also correlates well with the Middle – Late Paleocene miospore (**Zone E – G)** of (Lucas, 2010) in Gbekebo-l well, Benin Flank, southwestern Nigeria, based on *Proxapertites cursus, Verrucatosporites usmensis* and *Spinizonocolpites echinatus.* The formation also coincides with the Paleocene (Selandian – Thanetian) dinoflagellate cysts (**Zone 2 – 4)** of (Awad and Oboh-Ikuenobe, 2016) based on *Apectodinium spp., Ifecysta spp., Homotryblium abbreviatum, Areoligera spp., Exochosphaeridium bifidium* and *Kallosphaeridium yorubaensis.*

The shale and mudstone samples from Locations 9, 10, 13a, 13b, 14 and 15, were dated **Early-Middle Eocene** with the following index fossils assemblage, *Retibrevitricolpites triangulatus, Monoporites annulatus, Proxapertites cursus, Retistephanocolpites williamsi, Ctenolophonidites costatus, Spinizonocolpites echinatus, Psilatricoplorites crassus, Psilatricolporites operculatus, Retitricolporites irregularis, Striatopollis* sp. and *Bombacidites* sp. (Van Hoeken-klinkenberg, 1966 Germeraad *et al*., 1968; Takahashi & Jux, 1998; Oloto, 2010; Lucas, 2010; Chiaghanam *et al*, 2014; Ikegwuonu, 2015; and Okeke and Umeji, 2016). The age is further confirmed by the presence of stratigraphically notable Eocene dinoflagellate cysts assemblage, *Operculodinium centrocarpum, Muratodinium fimbriatum, Cleistosphaeridium diverspinosum, Polysphaeridium subtile, Cyclonephelium deckonincki, Homotryblium tenuispinosum, Diphyes colligerum, Adnatosphaeridium multispinosum, Cordosphaeridium spp.* and *Hystrichokolpoma* sp. (Oloto, 2010; Lucas, 2010; Chiaghanam *et al*, 2014; and Ikegwuonu, 2015). The above sporomorph assemblage possibly belongs to the **Ameki Formation** and coincides with the Middle Eocene **pantropical** *Monoporites annulatus* Zone of Germeraad *et al.,* 1968. The assemblage correlates from **P300 to P450** pollen zone of Evamy *et al.,* 1978, in the Niger Delta Basin, and from CP8b – CP9B Nanoplankton zones of Shafik *et al*., 1998. The assemblage also correlates well with the Early-Middle Eocene *Monoporitis annulatus* **Zone H** of (Lucas, 2010) miospore zones in Gbekebo-l well, Benin Flank, southwestern Nigeria.

The recovered dinoflagellate cysts assemblage of the Ameki Formation correlates well with the Eocene (Ypresian) dinoflagellate cysts **Zone 5** of (Awad and Oboh-Ikuenobe, 2016) based on the species *Adnatosphaeridium multispinosum, Polysphaeridium spp., Homotryblium tenuispinosum, Muratodinium fimbriatum* and *Cordosphaeridium spp.*

Moreover, the grey shale sample from Location 15 was probably assigned Late Eocene-Oligocene age due to the overwhelming abundance of *Verrucatosporites usmensis* and *Laevigatosporites ovatus.* The age is further strengthen by co-occurrence of the sporomorphs assemblage, such as *Chenopodipollis* sp., *Retibrevitricolporites* sp., *Psilastephanocolporites* sp., and *Psilatricolporites crassus* in the examined sample (Umeji, 2002, 2003; Oloto, 2010; Umeji and Nwajide, 2014; Ikegwuonu, 2015; Ikegwuonu and Umeji, 2016). The above assemblage undoubtedly belongs to the **Ogwashi Formation** in the Niger Delta Basin.

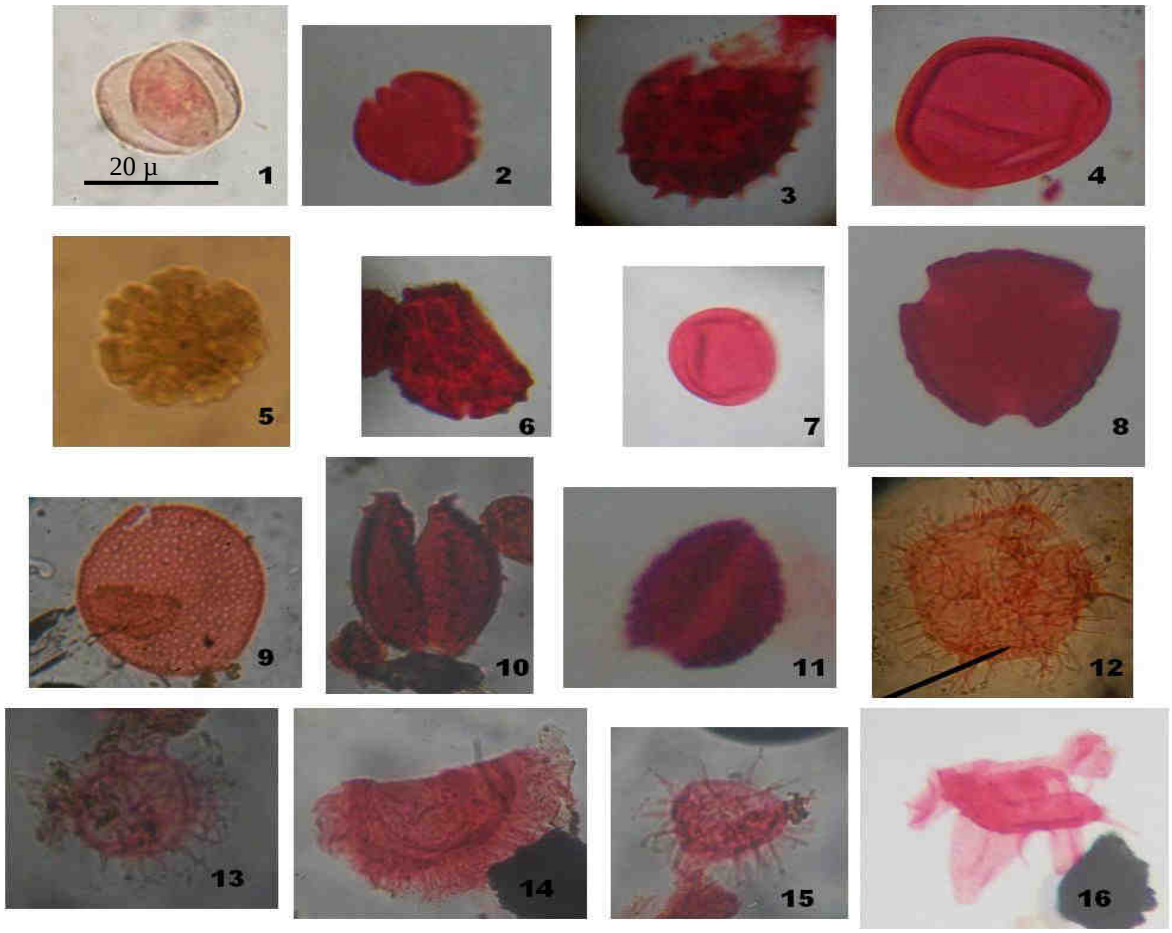

Fig. 3: Micrographs of some recovered palynomorph species in the study area.
Magnifications nos. 3, 4 and 5 (X 100 oil immersion), others (X 40), Scale bar in 20 microns.

1. *Proxapertites operculatus*
2. *Psilatricolporites operculatus*
3. *Echiperiporites icacinoides*
4. *Laevigatosporites ovatus*
5. *Ctenolophonidites costatus*
6. *Verrucatosporites usmensis*
7. *Monoporites annulatus*
8. *Psilatricolporites crassus*
9. *Proxapertites cursus*
10. *Spinizonocolpites echinatus*
11. *Racemonocolpites hians*
12. *Apectodinium homomorphum*
13. *Spiniferites ramosus*
14. *Glaphyrocysta ordinata*
15. *Diphyes colligerum*
16. *Achilleodinium biformoides*

Table 2: Absolute counts of the occurrence and distribution of palynomorph species in the study area.

Sample No. / Palynomorphs species	Ok/L1/01	Ok/L1/02	Ok/L1/03	Ok/L1/04	Ok/L1/05	NY/L2/01	NY/L2/02	NY/L2/03	OKT/L4/01	NI/L6/01	NW/L8/01
TERRIGINOUS SPECIES											
SPORES											
Verrucatosporites usmensis	0	1	0	3	0	0	2	0	0	0	0
Laevigatosporites ovatus	5	8	3	9	4	3	5	2	4	2	4
***Cyathidites* sp**	2	0	1	3	0	1	2	4	2	1	3
Leiotriletes adriennis	1	0	3	1	1	0	0	1	0	0	1
Cicatricosisporites dorogensis	0	0	0	0	0	0	0	0	0	0	0
***Schizosporis* sp.**	0	0	1	2	0	0	2	0	1	0	2
***Polypodiaceoisporites* sp.**	0	0	0	1	0	0	1	0	0	0	0
POLLEN											
Proxapertites operculatus	13	8	11	6	12	7	5	9	4	0	10
Proxapertites cursus	5	2	4	1	2	2	2	3	1	0	4

Retibrevitricolpites triangulates	1	0	2	0	2	0	0	1	2	0	2
Mauritidiites crassibaculatus	3	0	2	1	3	2	0	2	1	0	1
Grimsdalea polygonalis	0	2	0	0	1	0	1	0	0	0	0
Spinizonocolpites baculatus	4	2	1	1	0	2	3	0	0	0	1
Spinizonocolpites echinatus	3	1	0	2	0	1	2	2	1	0	0
Psilatricolpites minutus	2	0	1	0	0	2	0	0	0	0	2
Longapertites marginatus	1	0	0	3	0	0	1	1	0	2	0
***Bombacidites* sp.**	2	0	0	1	0	0	0	0	0	0	1
Echitriporites trianguliformis	3	1	0	0	2	0	1	0	0	0	0
Scabratriporites simpliformis	1	0	1	0	0	0	1	0	0	0	2
Monoporites annulatus	3	2	0	0	1	3	0	2	0	0	3
Tricolpites hians	2	0	0	0	1	0	3	0	2	0	2
***Striatopollis* sp.**	0	0	0	0	0	0	0	0	0	0	0
***Retitricolpites* sp.**	4	3	1	2	3	4	2	0	0	0	5
Retistephanocolpites williamsi	2	1	0	1	0	2	1	0	1	0	3
Retitricolporites irregularis	1	0	0	0	0	1	0	0	0	0	2
Ctenolophonidites costatus	0	0	0	0	0	0	0	0	0	0	0
Psiltricolporites operculatus	0	1	0	3	0	0	1	1	0	0	2
Psilatriporites rotundus	0	0	1	0	1	0	2	0	0	0	0
Pachydermites diederixi	0	0	0	2	0	0	0	2	0	0	0
***Chenopodipolis* sp.**	0	0	0	0	0	0	0	0	0	0	0
***Psilastephanocolporites* sp.**	0	0	0	0	0	0	0	0	0	0	0
***Retibrevitricolporites* sp.**	0	0	0	0	0	0	0	0	0	0	0
Racemonocolpites hians	0	0	0	0	0	0	0	0	0	0	0
Echiperiporites icacinoides	1	2	0	0	0	0	1	0	0	0	0
Psilatricolporites crassus	0	1	0	2	0	1	0	3	1	0	2
***Echitricolporites* sp.**	0	0	0	0	1	0	0	0	0	0	0
DINOFLAGELLATE CYSTS											
Apectodinium homomorphum	9	11	7	4	5	5	4	8	6	0	7
Apectodinuim augustum	0	0	0	0	0	0	0	0	0	0	2
***Apectodinium* sp.**	26	14	17	10	8	11	7	13	5	0	16
Homotryblium abbreviatum	4	1	*0*	2	0	2	1	3	0	0	3
Spiniferites ramosus	3	0	*1*	3	0	2	0	2	0	0	4
Glaphyrocysta ordinate	4	1	*0*	2	0	0	1	0	0	0	2
***Adnatosphaeridium* sp.**	3	2	*0*	1	0	3	0	2	0	0	2
Achilleodinium biformoides	0	0	*0*	0	0	0	0	0	0	0	0
Exochosphaeridium bifidium	4	0	*2*	0	1	4	1	0	0	0	2
Diphyes colligerum	2	0	*0*	1	0	0	0	2	0	0	1
Operculodinium centrocarpum	5	3	*1*	5	3	2	0	1	3	0	3
Homotryblium tenuispinosum	3	2	*5*	1	0	3	2	4	2	0	4
***Hystrichokolpoma* sp.**	1	0	*0*	0	0	1	0	1	0	0	0
***Cordosphaeridium* sp.**	2	0	*0*	0	0	0	0	2	0	0	2
Kallosphaeridium yorubaensis	3	1	*0*	0	2	2	0	1	1	0	1
Ifecysta spp.	2	0	*0*	3	0	0	2	0	0	0	3
Areoligera	0	1	*1*	0	2	0	0	0	0	0	0

senoniensis											
SPORES											
Verrucatosporites usmensis	0	0	1	0	0	2	6	9	13	17	
Laevigatosporites ovatus	5	4	*7*	2	5	8	10	16	15	23	
***Cyathidites* sp.**	2	3	*0*	1	0	1	3	2	1	1	
Leiotriletes adriennis	0	0	*2*	0	0	2	0	0	0	2	
Cicatricosisporites dorogensis	0	0	*0*	0	0	0	0	0	2	0	
Schizosporis parvus	0	0	*1*	2	0	0	2	4	2	2	
Polypodiaceoisporites retirugatus	0	2	*0*	0	0	4	2	5	1	0	
POLLEN											
Proxapertites operculatus	7	6	*4*	10	0	1	0	0	0	0	
Proxapertites cursus	3	2	*0*	2	0	6	3	2	0	0	
Retibrevitricolpites triangulates	0	1	*0*	2	1	4	2	0	1	1	
Mauritidiites crassibaculatus	1	2	*0*	0	0	0	1	0	0	0	
Grimsdalea polygonalis	0	0	*2*	0	0	0	0	1	0	0	
Spinizonocolpites baculatus	2	0	*3*	0	0	0	0	0	0	0	
Spinizonocolpites echinatus	0	2	*1*	0	0	5	2	3	1	0	
Psilatricolpites minutus	0	1	*0*	0	0	0	0	0	0	0	
Longapertites marginatus	0	0	*2*	0	0	0	0	0	0	0	
***Bombacidites* sp.**	0	0	*1*	0	0	3	2	1	0	0	
Echitriporites trianguliformis	1	0	*0*	0	0	0	0	0	0	0	
Scabratriporites simpliformis	0	0	*0*	0	0	0	0	0	0	0	
Monoporites annulatus	3	2	*0*	1	3	2	6	2	8	1	
Tricolpites hians	2	0	*0*	0	0	1	0	0	2	0	
***Striatopollis* sp,**	0	0	*0*	0	0	2	3	4	1	0	
***Retitricolpites* sp**	4	5	*2*	0	1	1	0	2	0	0	
Retistephanocolpites williamsi	2	0	*1*	0	0	4	2	3	0	0	
Retitricolporites irregularis	1	3	*0*	0	0	3	1	0	2	0	
Ctenolophonidites costatus	0	0	*0*	0	1	3	2	1	3	0	
Psiltricolporites operculatus	1	0	*2*	0	1	2	1	0	2	1	
Psilatriporites rotundus	0	0	*1*	0	0	0	2	0	0	0	
Pachydermites diederixi	0	1	*0*	0	0	2	0	0	0	0	
***Chenopodipolis* sp.**	0	0	*0*	0	0	0	0	0	1	3	
***Psilastephanocolporites* sp.**	0	0	*0*	0	0	0	0	0	2	2	
***Retibrevitricolporites* sp.**	0	0	*0*	0	0	0	0	0	1	4	
Racemonocolpites hians	0	0	*0*	0	0	0	0	2	3	2	
Echiperiporites icacinoides	1	0	*0*	0	0	1	2	1	0	0	
Psilatricolporites crassus	2	1	*0*	3	0	4	7	3	4	2	
***Echitricolporites* sp.**	0	0	*0*	0	0	1	2	0	0	0	
DINOFLAGELLATE CYSTS											
Apectodinium homomorphum	7	3	*5*	4	0	1	0	0	0	0	
Apectodinuim augustum	2	1	*0*	2	0	0	0	0	0	0	
***Apectodinium* sp.**	17	7	*10*	5	0	0	1	0	0	0	
Muratodinium fimbriatum	2	0	*0*	1	0	0	0	0	0	0	
Spiniferites ramosus	3	0	*5*	7	12	3	3	0	3	0	
Glaphyrocysta ordinate	2	0	*3*	0	0	0	2	7	0	0	

Adnatosphaeridium multispinosum	1	2	*0*	4	2	0	1	3	0	0	
Achilleodinium biformoides	0	0	*0*	0	1	2	4	5	2	0	
Cyclonephelium deckonincki	2	0	*1*	1	0	0	0	2	0	0	
Diphyes colligerum	2	1	*0*	0	0	1	2	0	4	0	
Operculodinium centrocarpum	3	0	*2*	3	2	0	0	0	0	0	
Homotryblium tenuispinosum	5	0	*2*	0	0	0	1	2	3	0	
***Hystrichokolpoma* sp.**	0	2	*0*	0	0	0	1	0	0	0	
***Cordosphaeridium* sp.**	0	0	*1*	0	0	0	3	2	0	0	
Kallosphaeridium yorubaensis	2	0	*3*	0	0	2	2	0	0	0	
Cleistosphaeridium diverspinosum	2	0	*1*	0	0	0	0	0	0	0	
Areoligera senoniensis	0	0	*2*	0	0	0	0	0	0	0	
Polysphaeridium subtile	2	0	*4*	0	0	0	3	1	2	0	
Foram test linings	0	2	*0*	0	0	2	7	0	0	0	
***Pediastrum* sp.**	0	0	*0*	0	0	0	0	1	2	0	

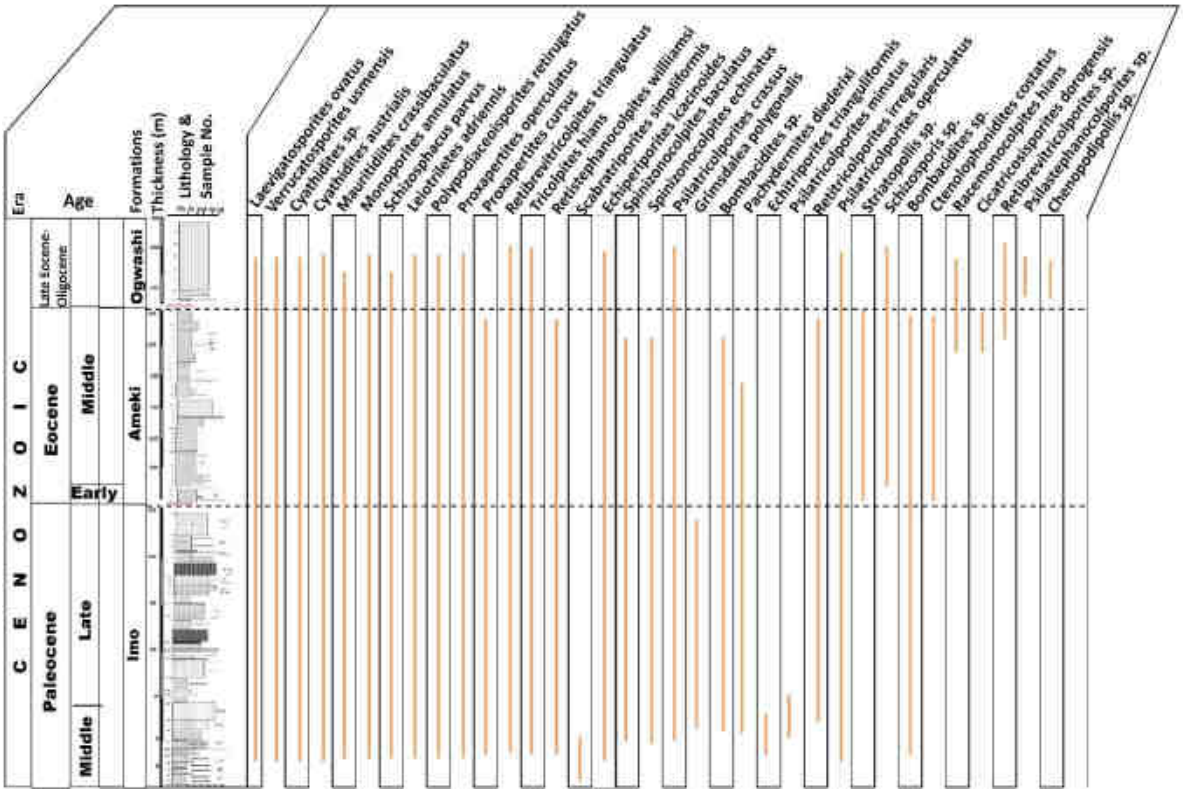

Fig. 4: Stratigraphic distribution range chart of selected palynomorph species in the study area.

Table 3 below shows **t**he palynomorphs % frequency distribution and their paleoenvironmental inferences. Some of the environmentally significant palynomorphs encountered in most of the examined samples from the **Imo Formation** included ***Proxapertites operculatus/cursus, Spinizonocolpites baculatus/echinatus*** and ***Psilatricolporites crassus.*** These are pollen of brackish water palms inhabiting similar environment as that of mangrove swamp, (Umeji, 2002; Umeji and Nwajide, 2014; Ikegwuonu, 2015). The abundance of these species especially ***Proxapertites operculatus*** in the samples indicate deposition in a near-shore brackish water estuarine setting, **see table 3**. The depositional environments were further confirmed by the overwhelming abundance of the near-shore brackish water species, ***Apectodinium*** group, especially the ***Apectodinium homomorphum*** in almost all the analyzed samples from the Imo Formation.

Meanwhile, the examined samples from the Ameki Formation yielded mostly the gonyaulacacean species, ***Spiniferites ramosus***, indicating deposition in an open marine shelf setting at the basal unit. Samples from the middle of the sequence were mostly deposited in a brackish water estuarine setting due to the dominance of the

near-shore peridiniacean species, such as, ***Achilleodinium biformoides, Glaphyrocysta ordinata*** and ***Homotryblium tenuispinosum***. ***Homotryblium* spp**. is typical of warm water masses of lower latitudes (Williams and Bujak, 1977) and has also been related to near-shore and reduced salinity conditions (Dybkjaer, 2004). The occurrence of ***Achilleodinium biformoides*** in association with species such as ***Homotryblium tenuispinosum.,Cordosphaeridium* sp .**and ***Diphyes colligerum*** in the samples indicate restricted neritic to outer neritic depositional environments (Van Mourik and Brinkhuis**,** 2001). However, samples from the upper part of the Ameki Formation were mostly deposited under estuarine/lagoonal settings due to the presence of fresh water species, ***Pediastrum* sp** and ***Schizosporis parvus. Schizosporis parvus*** is a fresh water algal spore which inhabited fresh water swamp environment (Umeji, 2002; Umeji and Nwajide, 2014; and Ikegwuonu and Umeji, 2016). The species of *Pelliciera* (*Psilatricolporites crassus*), is the only known mangrove forming trees present, and usually occurs alongside with *Rhizophora* (*Zonocostites ramonae*), forming an intermediate association between typical Eocene and post-Eocene mangroves (Rull, 2001). It represents a transitional phase after the terminal Eocene impoverishment of these and their progressive Neogene enrichment (Rull, 2001). However, the Ogwashi Formation indicates deposition between upper to lower deltaic plain within the tropical rainforest (Ikegwuonu and Umeji, 2016).

Table 3: Summary of the palynomorphs % frequency distribution and their paleoenvironmental inferences

SAMPLE NO.	PALYNOMORPHS % FREQUENCY			PALEO-SALINITY	PALEOENVIRONMENTS
	Spores	Pollen	Dinoflagellate cysts		
OH/L15/01	74 %	26 %	0 %	Fresh water	Non-marine /Upper deltaic plain
AK/L14/01	42 %	38 %	20 %	Brackish water	Marginal marine (lagoon)
IY/13b/01	43 %	30 %	27 %	Brackish water	Marginal marine (lagoon)
AJ/L13a/01	25 %	42 %	33 %	Brackish water	Marginal marine (estuary)
EU/L10/01	23 %	62 %	15 %	Brackish water	Marginal marine(distal estuary)
ID/L9/01	17 %	24 %	59 %	Normal marine	Open marine/shallow shelf
NW/L8/05	10 %	36 %	54 %	Brackish water	Marginal marine (estuary)
NW/L8/04	16 %	28 %	56 %	Brackish water	Marginal marine(estuary)
NW/L8/03	17 %	49 %	34 %	Brackish water	Marginal marine(estuary/lagoon)
NW/L8/02	8 %	34 %	58 %	Brackish water	Marginal marine (estuary)
NW/L8/01	9 %	39 %	52 %	Brackish water	Marginal marine (estuary)
NI/L6/01	42 %	58 %	0 %	Fresh water	Non-marine/Upper deltaic plain
OKP/L4/01	35 %	65 %	0 %	Fresh water	Non-marine/Upper deltaic plain
NY/L2/03	9 %	34 %	57 %	Brackish water	Marginal marine (estuary)
NY/L2/02	21 %	46 %	33 %	Brackish water	Marginal marine(estuary/lagoon)
NY/L2/01	6 %	40 %	54 %	Brackish water	Marginal marine (estuary)
OK/L1/05	9 %	53 %	38 %	Brackish water	Marginal marine(estuary/lagoon)
OK/L1/04	24 %	33 %	43 %	Brackish water	Marginal marine (estuary)
OK/L1/03	12 %	35 %	53 %	Brackish water	Marginal marine(estuary)
OK/L1/02	12 %	38 %	50 %	Brackish water	Marginal marine (estuary)
OK/L1/01	6 %	39 %	55 %	Brackish water	Marginal marine (estuary)

Conclusion

Palynological study of the Paleogene sediments exposed in the study area has been undertaken. Four main lithological units were encountered. They included carbonaceous shales, sandstones, mudstones, and limestone. Age determination was achieved on the basis of the stratigraphically significant age-diagnostic palynomorph assemblages recovered from the examined samples. Imo Formation was assigned Middle-Late Paleocene, Ameki Formation was dated Early-Middle Eocene Age and Ogwashi Formation was assigned Late Eocene-Oligocene Age. Palynomorphs of environmental value indicated various paleoenvironments of deposition of the formations across the study area. Imo Formation was deposited in a tidally-influenced shallow marine estuarine setting, Ameki Formation was deposited in an open shallow marine to estuarine-lagoonal settings and Ogwashi Formation was deposited between upper to lower deltaic settings.

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Conflict of Interest

There is no conflict of interest

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