

## **Paleoecology of Enugu and Mamu formations in Anambra Basin, Southeastern Nigeria**

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### **ABSTRACT**

*Paleoecology of the Enugu and the Mamu Formations was studied based on microfloral and ichnofossil assemblages preserved in the sedimentary units of the formations. The non marine microfloral is dominated by angiosperm (mostly monocolpate pollen) and pteridophytes (trilete spores). Chorate cyst gonyaulacoid dinoflagellates constitute 86.31% of the marine palynomorphs. The basal shale unit of the Enugu Formation documents very few *Senegalinium bicavatum* and sparse burrows of *Thalassinoides* isp. The middle to upper (heterolithic) units together with the heterolithic units in the Mamu Formation document *Skolithos*, *Planolites* and *Teichichnus*. A paleoecological model developed for the Late Campanian- Mid Maastrichtian ecosystems was interpreted as follows; mangrove vegetation fringed by the pteridophytic plants surrounds the ancient sea. The gonyaulacoids constitute the autotrophs while the peridinoids are the heterotrophs. Marine organisms that constitute the *Skolithos*, *Teichichnus* and *Planolites* are carnivores, deposit and suspension feeders. The greater concentration of these dinoflagellates and the ichnofossils within the neritic zone suggests more productivity. Few *Senegalinium* and sparse burrows recorded by only the basal shale of the Enugu Formation (open marine) are attributed to unfavorable condition due to anoxic bottom condition, salinity fluctuation and poor circulation of the ancient Sea.*

**Keywords:** Microfloral, Palynomorphs, Dinoflagellates, Paleoecology, Ecosystem

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### **INTRODUCTION**

Paleoecology is an aspect of science that uses the fossil record to reconstruct the life habits of past organism, their association in communities and their relationship to the environments in which they lived. Webb (2001) defines paleoecology as the composition and distribution of ecosystems and their changes through time on scales of decades to hundreds of millions of years. Fossil records provide the main data used for Paleocological interpretations. Webb, (2001) and Matthews, et al. (2013) used palynomorphs for paleoecological interpretations. He used palynological data to document Paleocological changes in the Quaternary period. Uchman and Wetzel (2011) noted that organisms living on and within the sea floor disturb the primary sedimentary structures and produce a new fabric, the so-called ichnofabric. Identifiable bioturbational structures of recurrent shape are called trace fossils or ichnofossils. These ichnofossils or trace fossils serve as proxies for in situ palaeoecological conditions. Trace fossils, consisting of fossil tracks, trails, burrows, and other products of organismal behavior, have been used in paleoecology, sedimentology, and stratigraphy (Martin, 2009).

Paleoecology of the Late Campanian- Mid Maastrichtian Enugu and the Mamu Formations in the Anambra Basin, Nigeria has not been properly handled. Previous studies in these formations centered mainly on the stratigraphy, biozonation, age dating, ichnology, paleoenvironmental and sequence stratigraphic interpretations (e.g Oloto, 1994, 2009; Nwajide and Reijers, 1996; Ojo *et al.*, 2009; Onuigbo *et al.*, 2012a and b; Chiaghanam *et al.*, 2013; Onuigbo and Okoro, 2014).

This work integrates microfloral and ichnological data for the reconstruction of paleoecological conditions and a paleoecological model for the Late Campanian - Mid Maastrichtian period.

### REGIONAL TECTONICS AND STRATIGRAPHIC SETTING

The origin of the Anambra Basin is intimately related to the development of the Benue Rift. The Benue Rift was installed as the failed arm of a trilate fracture (rift) system, during the breakup of the Gondwana supercontinent and the opening up of the southern Atlantic and Indian Oceans in the Jurassic (Burke *et al.*, 1972; Olade, 1975; Benkhilil, 1982, 1989; Hoque and Nwajide, 1984; Fairhead, 1988). The initial synrift sedimentation in the embryonic trough occurred during the Aptian to early Albian and comprised of alluvial fans and lacustrine sediments of the Mamfe Formation in the southern Benue Trough. Two cycles of marine transgressions and regressions from the middle Albian to the Coniacian filled this ancestral trough with mudrocks, sandstones and limestones with an estimated thickness of 3,500m (Murat, 1972; Hoque, 1977). These sediments belong to the Asu River Group (Albian), the Odukpiani Formation (Cenomanian), the Ezeaku Group (Turonian) and the Awgu Shale (Coniacian). During the Santonian, epeirogenic tectonics, these sediments underwent folding and uplifted into the Abakaliki- Benue Anticlinorium (Murat, 1972) with simultaneous subsidence of the Anambra Basin and the Afikpo Sub- basins to the northwest and southeast of the folded belt respectively (Murat, 1972; Burke, 1972; Mode and Onuoha, 2001). The Abakaliki Anticlinorium later served as a sediment dispersal centre from which sediments were shifted into the Anambra Basin and Afikpo Syncline. The Oban Masif, southwestern Nigeria basement craton and the Cameroon basement complex also served as sources for the sediments of the Anambra Basin (Hoque and Ezepue, 1977; Amajor, 1987; Nwajide and Reijers, 1996). Fig. 1 is the geologic map of southeastern Nigeria showing the study area.

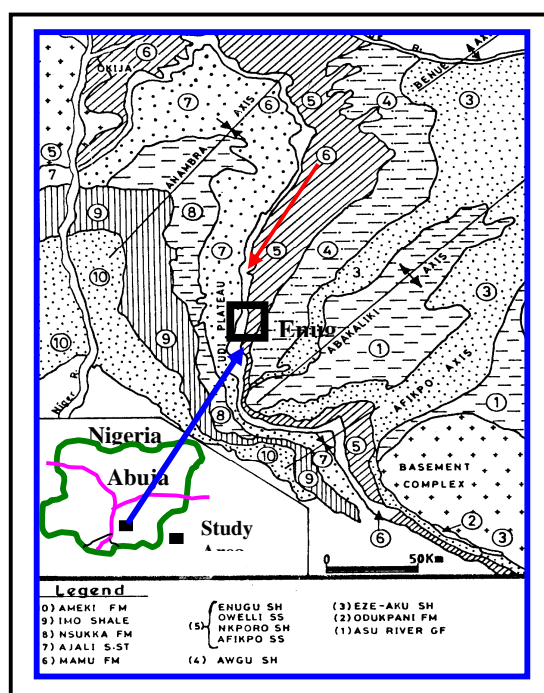
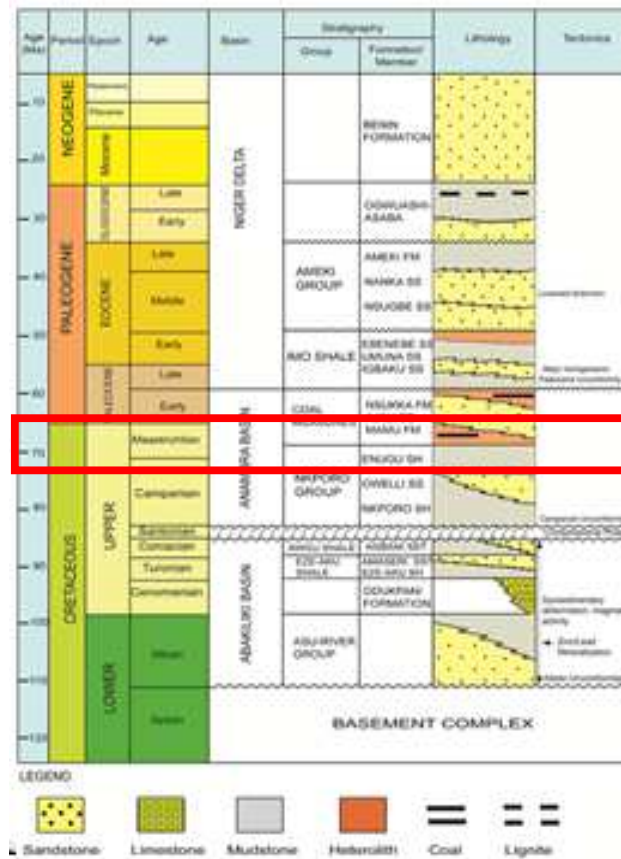


Fig. 1: Geologic map of southeastern Nigeria showing the study area (modified from Hoque, 1977)

After the installation of the Anambra Basin following the Santonian epeirogeny, the Campanian- Early Maastrichtian transgression deposited the Enugu Formation alongside its lateral equivalents of the Owelli

Sandstone, Nkporo Shale, Afikpo Sandstone, Otobi Sandstone and Lafia Sandstone. This was followed by the Maastrichtian regressive event during which the Coal Measures (ie the Mamu, Ajali and Nsukka Formations) were deposited. Table 1 shows the stratigraphic succession of the Cretaceous and Tertiary basins of southern Nigerian with the Anambra Basin sandwiched between the Abakaliki Basin and the Niger Delta.

**Table 1: Summarized Stratigraphy of the Benue Trough and Anambra Basin (after Reyment, 1965; Short and Stauble, 1967 and Nwajide, 2005)**



Outcrop sections of the Enugu and the Mamu Formations were logged from the base to the top (Figs.2 & 3) and ichnofossils were carefully studied. Samples of shales and heteroliths collected from the outcrops were analyzed for palynomorphs.

The samples were prepared according to the standard methods of acid maceration, alkali treatment and staining. The recovered palynomorphs were studied under transmitted light microscopy. Counts were made to determine the relative frequency of each species in each sample. A minimum of 200 grains were counted and where the grains are fewer than 200, the total counts were taken.

The palynomorph assemblage data were integrated with the ichnofossils data in the interpretation and the development of a paleoecological model for the Late Campanian- Mid Maastrichtian studied.

**RESULTS AND DISCUSSION**

**The Enugu Formation**

Figs 2a - d show the lithologic section of the Enugu Formation and outcrops described in the Formation. The 40 m thick section of the Enugu Formation can be subdivided grossly into a lower dark grey to black shale overlain by a heterolithic succession of siltstones, fine grained sandstone and mudstones. The lower dark grey shale is muddy,

laminated and richly pyritic, without distinct bioturbated structures. Plant and carbonaceous remains are noted in this section.

The upper heterolithic section with interbedded succession of laminated sandstones and mudstones contain low diversity and high abundance of ichnofossils of the cruziana ichnofacies such as *teichichnus* and sparse *thalassinoides* isp burrows concentrated on the contacts between the dark grey bioturbated sandstones and overlying siltstone layers (Figs. 2c & d).

**The Mamu Formation**

The Mamu Formation is the coal-bearing stratigraphic unit of the Anambra Basin. The Formation comprises a heterolithic succession of wave ripple laminated and fine grained sandstone, alternating with thin beds of shale, mud laminated sandstone, mudstone and coal beds. The shale and mudstone beds are light grey to dark grey in colour and bioturbated. *Skolithos* and *Ophiomorpha* isp burrows were noted in the fine grained ripple laminated sandstone and muddy sandstone beds (Fig. 3c).

Section	Lithologic Description	Environment
(m) 40 35 30 25 20 15 10 5 0	Gray shale	Shallow Marine
En7	The heterolithic unit (shale/fine sandstone, sandy shale and shaly sandstone interbedded units)	
En6		
En5		
En4		
En3	Basal dark-grey shale	Open Marine
En2		
En1 sand clay		



**Ichnofossil assemblage zone**

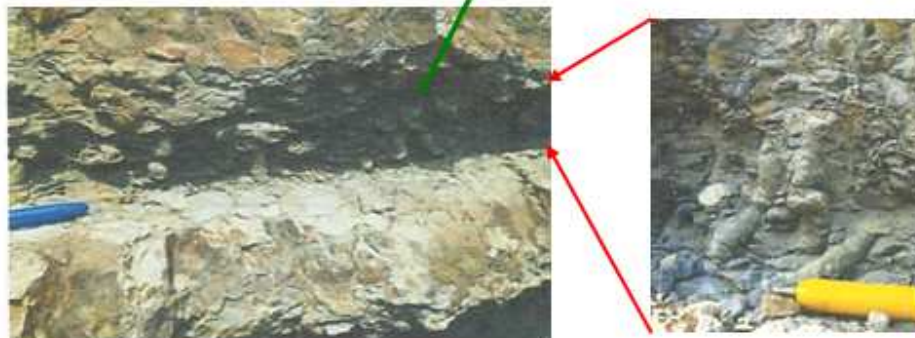


Fig. 2: Lithologic section of the Enugu Formation exposed near flyover about 200 m away from NNPC Filling Station, Enugu



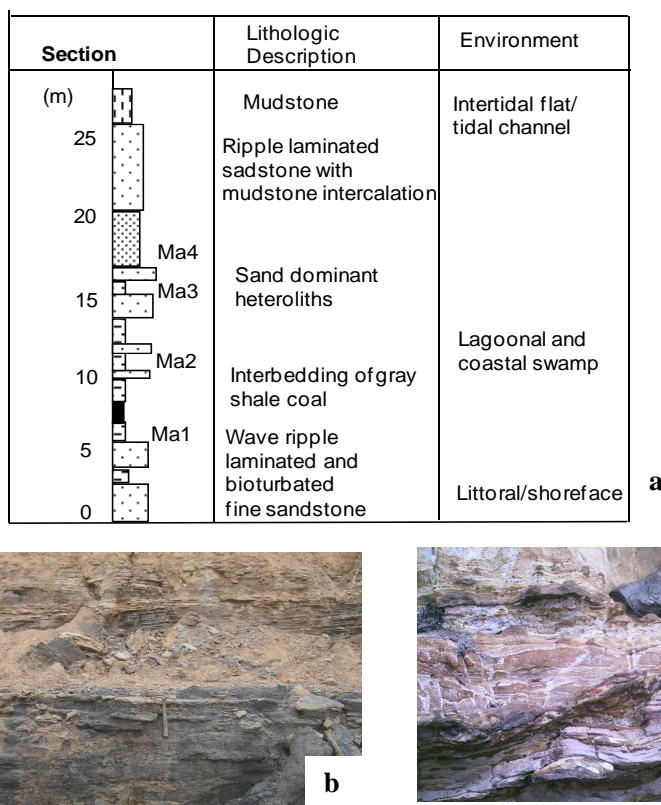


Fig. 3a: Lithologic section of the Mamu Formation exposed opposite Onyeama Mine, along Enugu - Onitsha Expressway, Enugu  
 3b: Interbedded grey and carbonaceous dark grey shale of the Mamu Formation exposed at Ebeuwana  
 3c: Wave ripple laminated sandstone with *skolithos* isp burrows in Mamu Formation exposed in the upper slope of the Nguzu Hill

**PALYNOLOGICAL STUDIES**

**1. Non Marine Palynomorphs**

Ten pollen taxa consisting of 32 genera and 41 species and two spore taxa; the trilete and the monelete spores were recovered from the palynological analysis of the shale and heterolithic samples from the Enugu and the Mamu Formations. The pollen and the spore classes are listed below. The abundance (%) of the pollen and spore taxa as well as the algae and fungal groups recovered are shown in Tables 2 and 3 and Figs. 4 and 5.

The pollen and spore taxa from the formations include the following;

**Division Pollenites** Protonié, 1931

**1. Class Monocolpatae** Iverson and Toels- Smith, 1950 Constructipollenites ineffectus, Longapertites marginatus, Longapertites vaneedenburgi, Longapertites microfoveolatus, Monocolpopollenites sphaeroidites, Monocolpites marginatus, Mauritiidites crassiexinus, Mauritiidites lehmanii, Proxapertites operculatus, Proxapertites marginatus, Spinizonocolpites echinatus, Spinizonocolpites baculatus, Spinizonocolpites kotschiensis, Psilamonocolpites marginatus, Retimonocolpites, Liliacidites, Psilamonocolpites medius, Foveomonocolpites bauchiensis, Proxapertites marginatus, Auriculopollenites, Trichotomosulcites and Arcipites.

**2. Class Triporatae** Iverson and Toels- Smith, 1950

Echitriporites trianguliformis, Proteacidites dehaani, Proteacidites sigali, Proteacidites longispinosus, Triolites and Scabratriporites simpliformis.

**3. Class Diporatae** Iverson and Toels- Smith, 1950

Retidiporites magdalenensis

**4. Class Tricolpatae** Iverson and Toels- Smith, 1950

Aquillapollenites, Hexaportricolpites emelianovi, Psilatricopollenites

**5. Class Tricolporatae** Iverson and Toels- Smith, 1950

Retitricolporites, Psilatricolporites

**6. Class Syncolpatae** Iverson and Toels- Smith, 1950

Periretisyncolpites magnosagenatus, Syndemicolpites

**7. Class Syncolporatae** Iverson and Toels- Smith, 1950

Syncolporites marginatus, Syncolporites usame

**8. Class Stephanocolporatae** Iverson and Toels- Smith, 1950

Tubistephanocolporites cylindricus, Psilastephanocolporites

**9. Class Periporatae** Iverson and Toels- Smith, 1950

Buttinea andreevi

**10. Class Inaperturatae** Iverson and Toels- Smith, 1950

Ephedripites multicostatus

**Division Sporites** Protonié, 1893**1. Class Trilete** (Reinsch, 1881), Protonié and Kremp, 1954

Cyathidites minor, Cyathidites australis, Cingulatisporites ornatus, Rugulatisporites caperatus, Zlivisporis blanensis, Ariadnaesporites spinosa, Ariadnaesporites nigeriensis, Foveotrilete margaritae, Retitrilete, Deltoidospora and Distaverrusporites simplex.

**2. Class Monolete** Ibrahim, 1933

Laevigatosporites

**Table 2: Abundance (%) and diversity of the microflora in the Enugu Formation**

S/n	Class	Abundance (%)	Diversity
1.	Monocolpate pollen	46.36	18
2	Trilete spores	31.11	12
3	Diporate pollen	8.64	1
4	Triporate pollen	6.71	6
5.	Syncolporate pollen	2.29	2
6.	Syncolpate pollen	0.78	2
7.	Stephanocolporate pollen	0.57	2
8.	Periporate pollen	0.47	1
9.	Tricolpate pollen	0.42	3
10.	Tricolporate pollen	0.31	2
11.	Inaperturate pollen	0.21	1
12	Monolete spore	0.21	1
13	Algae	1.14	2
14	Fungi	0.78	1
	<b>Total</b>	<b>100.00</b>	<b>54</b>

**Table 3: Abundance (%) and diversity of the microflora in the Mamu Formation**

S/n	Class	Abundance (%)	Diversity
1.	Monocolpate pollen	41.95	12
2	Trilete spores	39.29	11
3	Diporate pollen	6.55	1
4	Triporate pollen	4.99	5
5.	Syncolporate pollen	1.00	1
6.	Syncolpate pollen	-	-
7.	Stephanocolporate pollen	0.33	2
8.	Periporate pollen	-	-
9.	Tricolpate pollen	0.44	2
10.	Tricolporate pollen	-	-
11.	Inaperturate pollen	0.11	1
12	Monolete spore	0.22	1
13	Algae	0.44	1
14	Fungi	4.66	1
	<b>Total</b>	<b>99.98</b>	<b>38</b>

Charts of the microfloral (Late Campanian – Mid Maastrichtian) in Figure 4 show that the assemblage is dominated by the monocolpate pollen grains and trilete spores. However, triporate and diporate pollen are also elements. Some of the pollen taxa that occurred in the Enugu Formation (Campano- Maastrichtian) were not found in the Mamu Formation. These taxa include;

1. Monocolpate pollen such as Mauritiidites, Foveomonocolpites, Auriculopollenites and Arecipites
2. Tricolporates such as Retitricolporites and Psilatricolporites
3. Tricolpate such as Hexaporotricolpites emelianovi
4. Syncolpate
5. Periporate

Pollen taxa has also been grouped into three based on the vegetation type. These groups are;

1. Angiosperm (monocolpate, diporate, triporate, tricolpate, stephanocolpate, tricolporate periporate and stephanocolporate).
2. Gymnosperm (inaperturate dominated by only one genera Ephedripites multicostatus).
3. Pteridophytes (trilete and monolete spores)

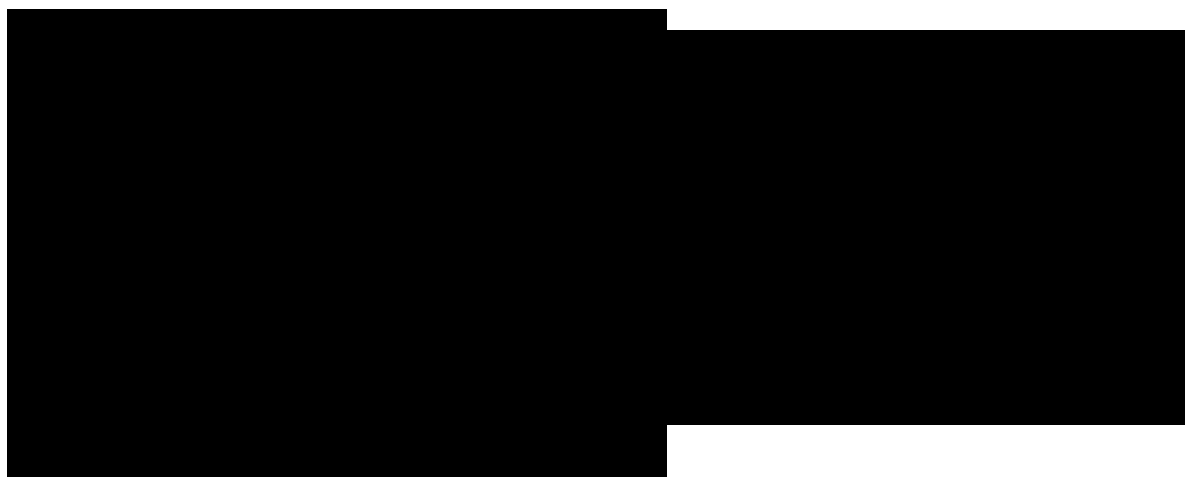
**Fig. 4a: Microfloral taxa in the Enugu Formation**



Fig. 4b: Microfloral taxa in the Mamu Formation

Figures 5a and 5b show the charts of the different microfloral groups. The assemblages in both formations are dominated by angiosperm (over 60% and 50% in the Enugu and the Mamu Formations respectively) and pteridophyte (slightly over 30% and approximately 40% in the Enugu and the Mamu Formations respectively). Fungal spores are more in the Mamu Formation (4.66% of all the microflora).

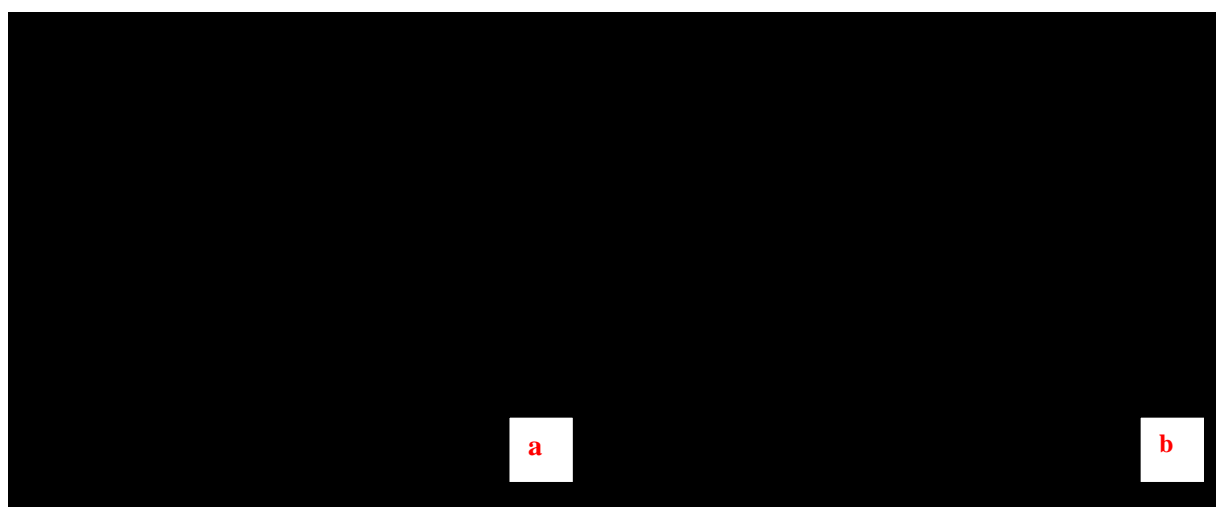


Fig. 5: Palynofloral group in the (a) Enugu Formation (b) Mamu Formation

## 2. Marine Palynomorphs

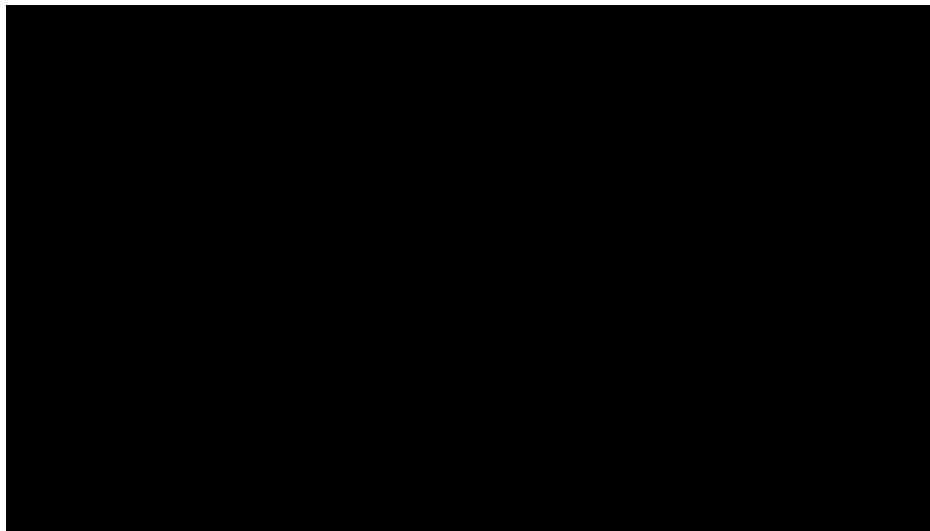
The marine palynomorphs recovered from the Enugu Formation include;

1. The gonyaulaceans (chorate cysts) are dominant and include; Exochosphaeridium, Cleistosphaeridium, Cordosphaeridium, Diphyes colligerum, Kallosphaeridium, Eocladophysis, Cometodinium, Spiniferites ramosus, Polysphaeridium, Impletosphaeridium, Cyclonephelium Coronifera oceanica, Adnatosphaeridium and Areoligera.
2. Peridiniaceans are represented by Senegalinum bicavatum, Phelodinium and Phantanoperidinium. Members of this group are few and were only found on the basal shale unit in one location.
3. Acritarch: Only Leiospharidia was recovered.



86.31% of the marine dinoflagellates in the Enugu Formation are chorate cyst gonyaulaceans, 3.37% are peridiniaceans and 10.11% belong to acritarch (Fig. 6).

However, palynological analysis of the Mamu Formation yielded only acritarch represented by *Leiosphaeridia*.



**Fig. 6: Marine dinoflagellates in the Enugu Formation**

#### **Ichnofossils**

The basal shale unit of the Enugu Formation documents sparse horizontal burrows of *Thalassinoides* isp. The heterolithic unit that overlies the basal shale documents abundant horizontal burrows of especially *Teichichnus* and *Thalassinoides* (shale units). *Skolithos* and *planolites* occur in the fine sandstone units (Fig. 2) of the heteroliths. The shale, sandstone and heterolithic units of the Mamu Formation also have similar assemblages.

### **DISCUSSION**

#### **PALEOECOLOGICAL SIGNIFICANCE**

The microfossil assemblage of the Upper Cretaceous in the Anambra Basin, southeastern Nigeria can be fixed into the Late Cretaceous Palmae Province of Africa, South America and India described by Herngreen (1980), Herngreen and Chlonova (1981), Herngreen et al. (1996) and Morley (2000). This province has been noted to have high frequency of taxa consisting of pollen grains with affinities to modern palm taxa attributed to the palmae and by the absence of the Normapolles group of pollen grains. These pollen include; *Psilamonocolpites*, *Retimonocolpites*, *Longapertites*, *Spinizonocolpites*, *Proxapertites* and *Mauritiidites*. Such pollen assemblage has been recovered from the Campanian- Maastichtian deposits in the coastal regions of western, northern and eastern Africa (Somalia). It also occurred in tropical South America and South East Asia (Van der Hammen, 1954, 1957; Jardine and Magloire, 1965; Muller, 1968; Germeraad et al., 1968; Herngreen, 1975; Thanikaimoni et al., 1984; Schrank, 1987, 1997; El-Beilay, 1995; Atta- Petters and Salami, 2004; Pan et al., 2006; Vivi, 2009).

Similar floral assemblage dominated by monocolpate pollen grains especially the palm type, trilete and monoete pteridophytic spores has also been documented in Ghana (Atta- Peters and Salami, 2004).

Late Cretaceous palm were abundant and often dominant in coastal swamp and mangrove vegetation (Morley, 2000; Jacobs, 2004).

The palmae province suggests a hot tropical to subtropical climate. The assemblages can be interpreted to indicate warm and humid climate (Herngreen, 1998).

The dominance of the angiosperm over the gymnosperm in the ecosystem is as a result of the radiation of flowering plants during the Cretaceous which led to a marked evolutionary turnover (Urich and Petter- A., 2010). The

dominance of monocolpate angiosperm over other pollen taxa suggests increase in the frequency of pollen grains that have affinities to modern palm.

The paleovegetation of the Campanian- Maastrichtian in the Anambra Basin can be interpreted as follows;

1. Mangrove vegetation: This is based on the abundance of mangrove elements such as Spinizonocolpites group (*Nypa*) and Psilatricolporites (Mehmet et al., 2008).
2. The back- mangrove vegetation: Characterized by elements such as Mauritiidites, Proxapertites group, Longapertites group and Monocolpopollenites which are indicative of brackish water condition (Mehmet et al., 2008)
3. Pteridopytic plants represented by the trilete spores which are also very abundant.
4. Algae: This group is represented by two genera (*Botryococcus braunii* and *Pediastrum*)
5. Fungi: The *Azolla*

The elements of the mangrove and back- mangrove vegetations listed above have been interpreted as belonging to the mangrove swamp environment of the humid tropics (Herngreen, 1998; Schrank, 1987, 1994). The pteridophytes (trilete spores), the algae and fungal spores are evidences of the existence of freshwater swamp and marshes. Freshwater species such as *Laevigatosporites* (monoete spore) also occur but their abundance is very low. The presence of algae (*Botryococcus* though very low in abundance), Fungal spores (over 4%) and the absence of marine palynomorphs in the Mamu Formation (Early- Mid Maastrichtian) indicate deposition in a lacustrine environment (Vivi, 2009). *Botryococcus* is a planktonic colonial algae exclusively found in standing bodies of freshwater or brackish water (Colbath and Grenfell, 1995), and its tolerance to salinity is low (Rull 1997). *Pediastrum* inhabits freshwater, lakes, ponds and slow- moving streams.

Dinoflagellates constitute the majority of the marine eukaryotic phytoplankton and are therefore, important primary producers (Sluijs, 2005; Zonneveld et al., 2006). They play a prominent role in the food chains of marine realm and in the global carbon cycle (Basier, 1985).

Based on the template of Branta biostratigraphy in Onuigbo et al., (2012a), two dinoflagellate associations were identified in the Enugu Formation based on the depositional environment. These include;

1. The cyclonephelium association consisting of *Cyclonephelium*, *Exochosphaeridium*, *Cordosphaeridium*, *Cleistosphaeridium*, *Areoligera*, *Coronifera oceanica*, *Diphyes colligerum*, *Kallosphaeridium* and *Cometodinium*.
2. Spiniferites association consisting of *Spiniferites ramosus*, *Areoligera*, *Exochosphaeridium* and *Coronifera oceanica*.

These dinoflagellates have been interpreted as occupying different positions (outer, middle and inner) within the neritic zone (Oloto, 1992; Lana, 1997; Carvaliho, 2004; Torricelli, 2005).

*Senegalinium bicavatum* has been recorded by Johan (2010) as a specie that thrive most in the area of elevated nutrient availability, freshwater tolerant and increase water forcing. *Homotryblium tenuispinosus* thrives in hypersaline or low salinity environment (Dybkaer, 2004).

Harland (1973) and Sluijs et al. (2003) attributed the high abundance of peridinioids (i.e low G/P values) to a supply of nutrients through freshwater influx from land. Peridinoid cysts are considered to represent heterotrophic dinoflagellates that thrived on diatoms, other phytoplankton and organic debris whereas gonyaulacoid cysts mainly represent autotrophic dinoflagellates (Powell et al., 1992; Amogi- Labin et al., 1993). The low abundance of peridinioids such as *Senegalinium bicavatum* in the basal shale unit to its completely absence in the middle and upper units of the outcrop of the Enugu Formation may be attributed to the unfavourable condition caused by anoxic bottom condition, change in water salinity (open to shallow water) as well as poor circulation (mixing) of the Campano- Maastrichtian Sea. The restriction of the dinoflagellates within the neritic zones can be useful in the reconstruction of productivity of the marine ecosystem (Dale, 1996). Reconstruction of eukaryotic productivity patterns in many environments are of great interest because they are directly linked to important climate characteristics such as surface current patterns, upwelling systems, water mass mixing, surface winds and global carbon cycle (Berger et al., 1989; Bertrand et al., 1996). In this work, productivity variation was interpreted based on the ratio of peridinoid (P) and gonyaulacoid (G) cysts (P/G) of the dinocysts assemblages recovered. More diverse and abundant microplankton associations within the neritic zone may be attributed to warmer and more favorable conditions for microplankton development influenced by the invasion of warm water masses (Ekatarina, 2008). The

Enugu Formation is strongly influenced by the influx of freshwater from the continent, this freshwater input might load large amount of nutrients such as nitrogen and phosphate into the ecosystem.

The ichnofossils are mostly carnivores which feed on other organisms and detritus. The sparse burrows of *Thalassinoides* on the basal shale unit of the Enugu Formation are also in support of unfavourable condition. Abundant burrows comprising of horizontal, inclined and vertical u- tubes of *Teichichnus*, *Planolites* and *Skolithos* respectively recorded by the heterolithic units of the two formations suggest fluctuation in energy, food availability and shallower depth. These ichnofossil assemblages are found within littoral, sublittoral and open shelf environments (Lewis, 1985).

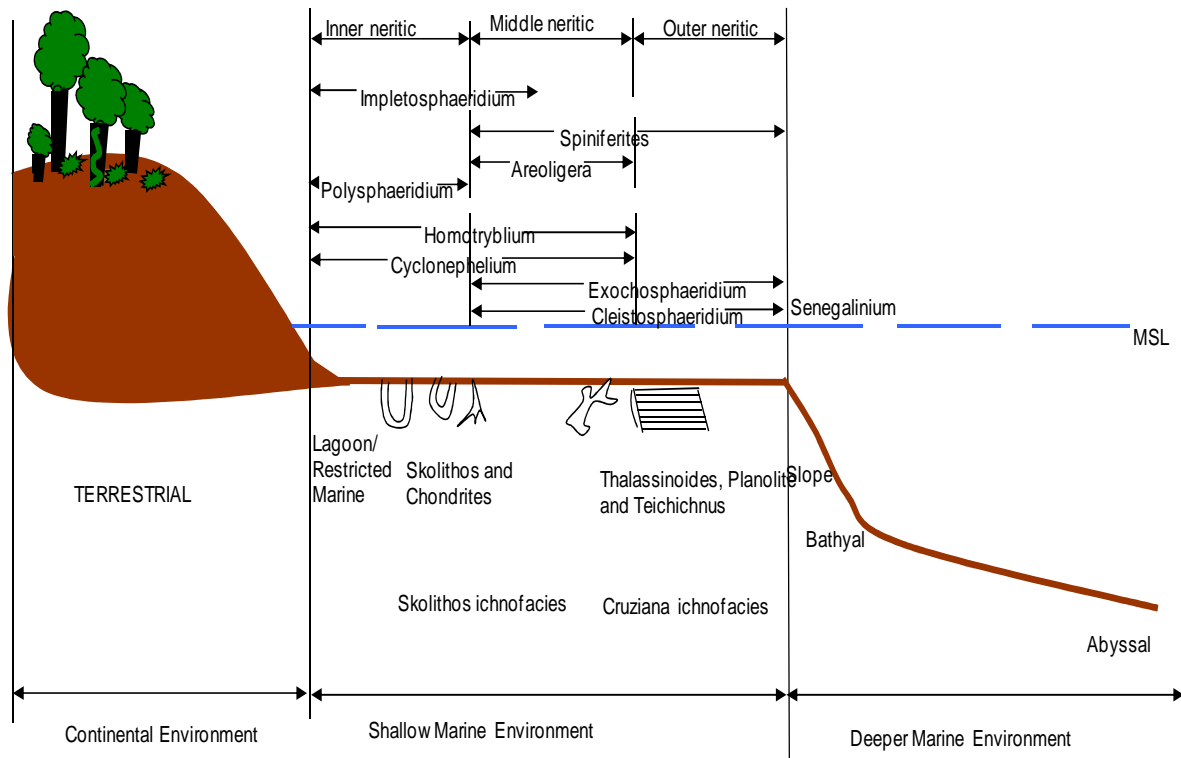
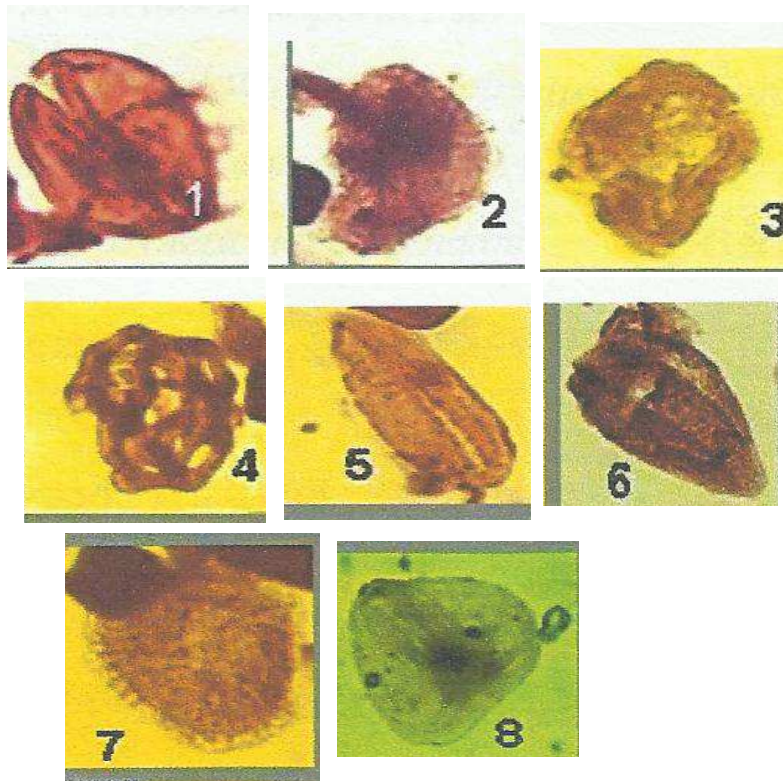


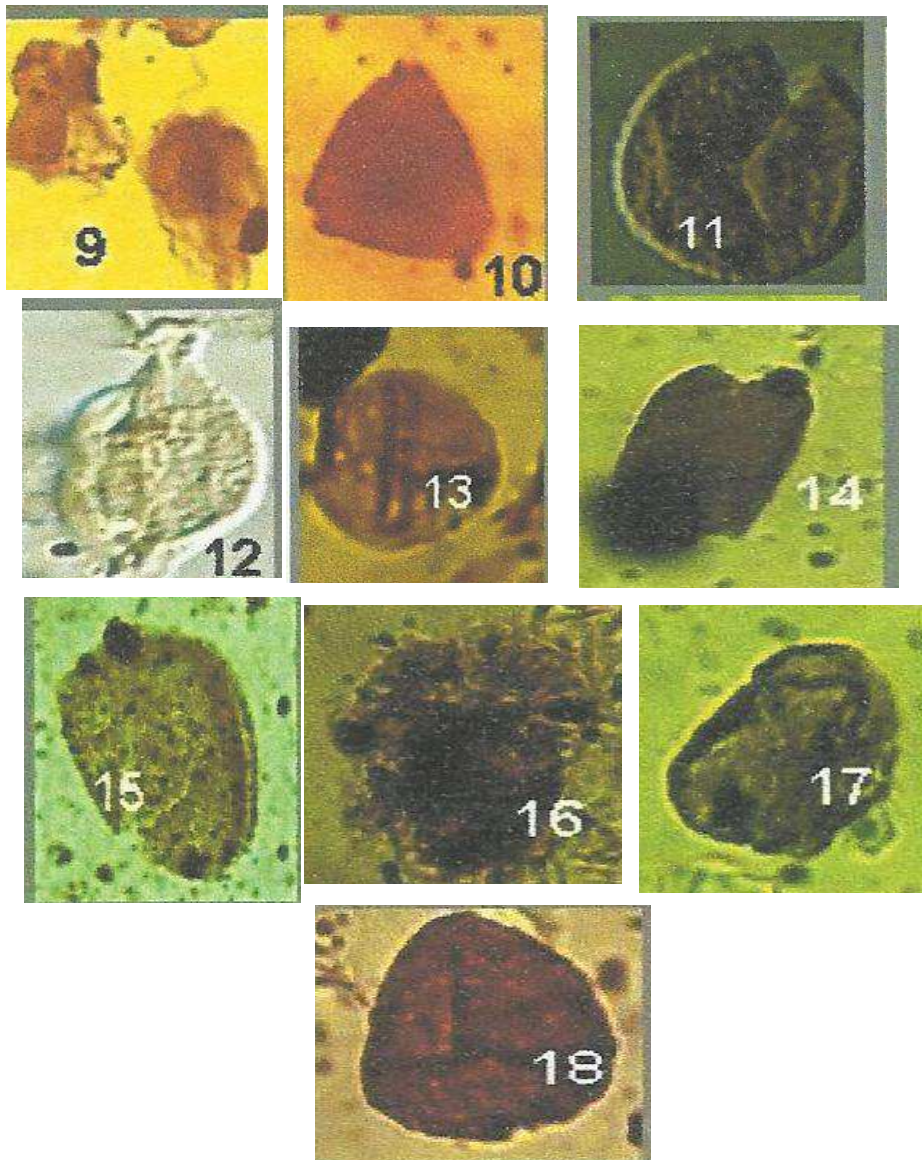
Fig. 7: Paleoecological model for the Late Campanian- Mid Maastrichtian in the Anambra Basin

PLATES



1. *Monocolpopollenite sphaeroidites* Jardine and Magloire, 1965
2. *Ariadnaesporites* sp. Protonie, 1956
3. *Cingulatisporites ornatus* Van Hoeken- Klinkenburg, 1964
4. *Buttinea andreevi* Boltenhagen, 1967
5. *Monocolpites marginatus* Van der Hammen, 1954
6. *Longapertites vanedeenburgi* Germeraad *et al.*, 1968
7. *Constructipollenites ineffectus* Van Hoeken- Klinkenburg, 1964
8. *Cyathidites minor* Couper, 1953

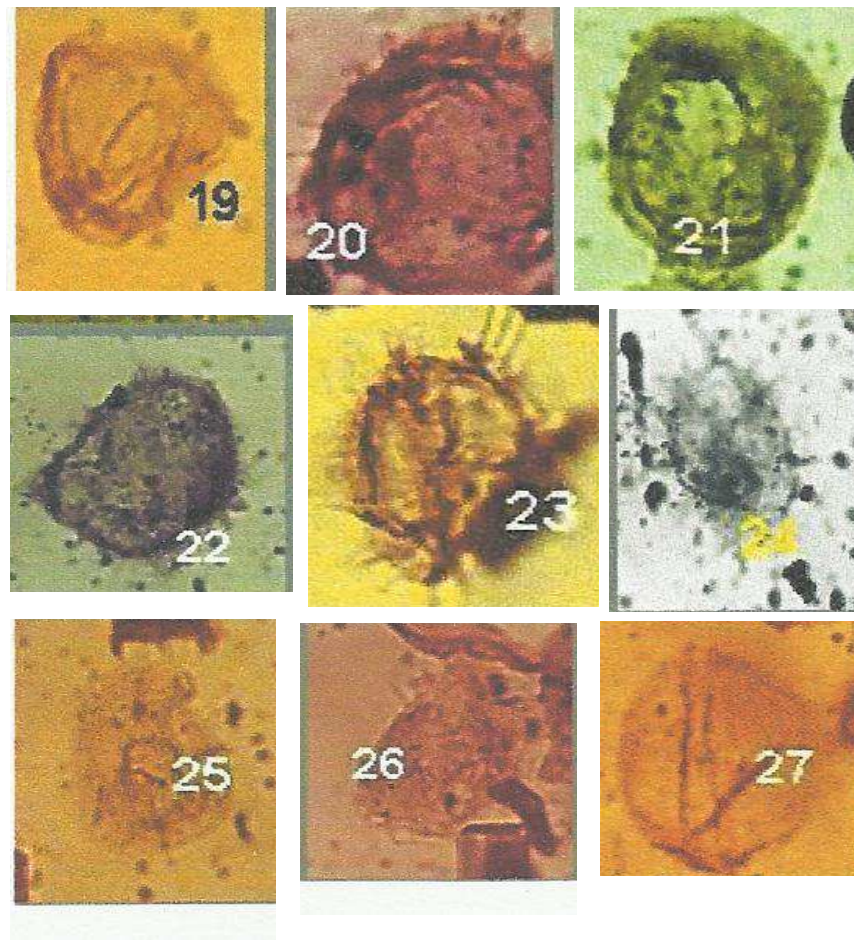
**Plate 1a: Pollen and spore assemblages from the Enugu and Mamu Formations**



- 9. *Ariadnaesporites* sp. Elsik, 1966
- 10. *Rugulatisporites caperatus* Van Hoeken- Klinkenburg, 1964
- 11. *Monocolpopollenite* sp. Jardine and Magloire, 1965
- 12. *Proteacidites dehaani* Germeraad *et al.*, 1968
- 13. *Auriculipollenites reticulatus* Elsik, 1964
- 14. *Retidiporites magdalenensis* Germeraad *et al.*, 1968
- 15. *Longapertites marginatus* Van Hoeken- Klinkenburg, 1964
- 16. *Botryococcus* sp. Kutzinger, 1849
- 17. *Syncolporites marginatus* Van der Hammen, 1954
- 18. *Distaverrusporites simplex* Muller, 1958

**Plate 1b: Pollen and spore assemblages from the Enugu and Mamu Formations**





- 19. *Leiosphaeridia* sp. Einsnack, 1958
- 20. *Exochosphaeridium* sp. Davey *et al.*, 1966
- 21. *Kallosphaeridium* sp. J. De Coninck, 1969
- 22. *Areoligera* sp. Lejeune Carpentier, 1938
- 23. *Cleistosphaeridium* sp. Davey *et al.*, 1966
- 24. *Spiniferites* sp. Loeblich and Loeblich, 1966
- 25. *Exochosphaeridium* sp. Davey *et al.*, 1966
- 26. *Adnatosphaeridium* sp. Williams and Downie, 1966
- 27. *Senegalinium* sp. Jain and Millipied, 1975

**Plate 1c: Dinoflagellate assemblage from the Enugu and Mamu Formations**



*Summary*

Paleoecology of the Enugu and the Mamu Formations in the Anambra Basin has been studied based on microfloral distribution and ichnofossils preserved in the sedimentary units of the formations. The non-marine microfloral groups are dominated by angiosperm (mostly monocolpate pollen) and pteridophytes (trilete spores). These have been interpreted as evidence for the existence of mangrove vegetation (coastal swamps and estuaries) fringed on the land-ward side by the pteridophytic plants of terrestrial environments. The pollen and spore assemblages recovered have abundant forms which have affinity with modern palms and have been grouped as palmae. The Upper Cretaceous Anambra Basin therefore belongs to the Cretaceous Palmae Province of Africa, South America and India (. Hot, tropical (humid) climatic condition characterized such province.

Marine dinoflagellates are dominated by eukaryotic (primary producers) gonyaulacoid dinoflagellates. The peridinoids are few and constitutes the heterotrophs. The occurrence of few to the general absence of the peridinoids has been attributed to an unfavourable physico-chemical environmental condition that existed at the sea bottom (open marine). These conditions include anoxicity and poor circulation of the water. There is marked change in the salinity (brackish water) of the water based on ichnofacies characteristics and palynomorphs assemblages from the heterolithic units at the middle and towards the upper part of the Enugu Formation and the Mamu Formation as they suggest existence of lagoon/estuaries. This may not be favourable for lower salinity dinoflagellate species such as *Senegalinium bicavatum*.

However, the gonyaulacoids in this study have been found to be abundant and diverse. Most of them lived within the middle to inner neritic zone. The zones also document abundant burrows of *Skolithos*, *Teichichnus* and *Planolite* burrows. These suggest high productivity (by the producers), food availability (for the carnivores, deposit and suspension feeders), shallow depth of light penetration and fluctuation in the energy within the ecosystem. Nitrogen and phosphates may have been supplied by fluvial influx from the continental ecosystem.

**CONCLUSION**

Palynological and ichnological data from the Enugu and the Mamu Formations have shown that three main ecosystems existed in southeastern Nigeria during the Upper Cretaceous Era. These are the continental, transitional and marine ecosystems. The continental ecosystem was inhabited by pteridophytic plants some of which are tree climbers. The transitional ecosystem comprising coastal swamps, tidal flats and estuary supported mostly mangrove vegetation and sediment dwelling, suspension feeding organisms that made the *skolithos* isp burrows in the Mamu Formation. The marine ecosystem on the other hand was occupied by the marine dinoflagellates and the collection of organisms that constructed the *Skolithos*, *Teichichnus* and *Planolite* burrows. While the gonyaulacoids and algae were serving as primary producers, organisms are the consumers. This study also show that the sea bottom did not support abundant life while the middle to inner neritic zones were areas of higher productivity and food availability, thus many and diverse forms settled there. The orientation of the burrows of organisms is an indication of fluctuation in the energy within this zone.

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