OCCURRENCE OF SOME CAMPANIAN-MAASTRICHTIAN ORGANIC-WALLED MICROFOSSILS FROM ENUGU SHALE, ANAMBRA BASIN, SOUTHEASTERN NIGERIA: IMPLICATIONS FOR AGE AND PALEOENVIRONMENTS

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ABSTRACT

Detailed geological field mapping and sampling of the Enugu Formation in the Anambra Basin has been carried out in order to re-examine the age of sediments and reconstruct their paleoenvironments of deposition. A total of ten (10) outcrop samples of shale were subjected to palynological laboratory examination, using conventional method of acid demineralization and maceration techniques for recovering acid-insoluble organic-walled microfossils from sediments. Two main lithological units were distinguished: - carbonaceous fissile shale and siltstone. A late Campanian - Earliest Maastrichtian age was assigned based on index palynomorphs marker taxa Longapertites marginatus (overwhelming abundance), Monocolpites marginatus, Zlivisporis blanensis, and Echitriporites trianguliformis. The age designation was strengthened by the occurrence of a well-known stratigraphic age-diagnostic organic-walled microplankton Coronifera tubulosa, Senegalinium spp. and Andalusiella polymorpha. Palynomorphs of environmental value include Cyathidites minor, (a tree fern of wet, forested, tropical to temperate regions, usually most developed in mountainous / highland terrains under moist and equable climate); Spinizonocolpites baculatus/echinatus, Longapertites marginatus, Mauritsidites crassibaculatus and Monocolpites marginatus, which are palm pollen that inhabit similar brackish water as the mangrove. A non-marine to marginal marine depositional setting has therefore been proposed for the Enugu Formation.

KEYWORDS: Palynoflora, Anambra Basin, Cretaceous, Spore/ Pollen grain, Microplankton,

1. INTRODUCTION

The Anambra Basin of southeastern Nigeria is a funnel-shaped, concave south structure which was filled with sediments of Campanian-Maastrichtian age (Murat, 1975; Umeji, 2000) (Fig. 1). The basin overlies the folded beds of the southern Benue Trough and is overlain by the deposits of Cenozoic Niger Delta Basin. The Nkporo Group (Nwajide, 2006) forms the oldest unit in Anambra Basin, to which the Enugu Formation belongs. The sediments of the Enugu Formation accumulated in "the concave inward" (Reijers, 1996) shaped coastline of the Campanian sea. Previous workers have described the shales exposed in stream channels around Enugu (e.g. Umeji, 2000). Simpson (1954, p.34) described the soft grey-blue shale in the channels of Asata and the Ogbete Rivers, and noted that although very thin lenses of "vitrinite" may occur in dark shales, an unusual 2.5cm band of coal crops out near the top of the formation. Reyment (1965, p.58) observed that occasional beds of white sandstone and striped sandy shale are interlayered with the shale. Ladipo et al. (1992) reports that the facies of the Nkporo Group are inferred to be pro-delta to delta front environments. They noted that the shaly aspects of the group, with their mixed arenaceous and planktonic...
foraminiferal suites, represent the prodelta facies of the Campano-Maastrichtian marine incursion. Petters (1995) interpreted the Enugu Shale as the product of processes in delta flood plains (overbank sheet floods, swamps and channels). He remarked that this interpretation is supported by the presence of sparse marsh arenaceous foraminifera *Miliammina* spp. and *Ammodiscus* spp.

Several studies have been carried out in respect to the age and depositional environments of the formation, of which most of the results and conclusions were drawn based on macrofossils, sedimentological and stratigraphic position of the Nkporo / Enugu Shales (Avbovbo and Ayoola, 1981; Whiteman, 1982; Nwajide, 2006). However, very few workers have demonstrated in detail the use of palynological suites for determining the age and environments of deposition of the formation. The present study therefore aims at re-evaluating the age of the Enugu Formation and reconstructing the depositional setting, using organic-walled microfossils.

2. REGIONAL GEOLOGY AND STRATIGRAPHY

The Anambra Basin is the southern part of the regionally extensive northeast-southwest trending Benue Trough (Fig. 1). The basin is one of the seven sedimentary domains of Nigeria (Nwajide, 2006). The lithic fill of the Anambra Basin originated as a result of the depression of the area.

![Regional geologic map of southeastern Nigeria](image1)

**Fig. 1:** Regional geologic map of southeastern Nigeria (modified after Murat, 1972)

![Regional stratigraphy of the Anambra Basin](image2)

**Fig. 2:** Regional stratigraphy of the Anambra Basin (modified after Nwajide, 2006)
around the southern Benue Trough contemporaneous with folding of the latter in the Santonian. The basin became filled with two lithological groups – the Nkporo Group and the Coal Measures Group, following one major transgression and one major regression. The Nkporo Group forms the basal part of the basin and consists of the Nkporo Formation, the Enugu Shale, the Owelli Sandstone, and the Afikpo Sandstone (Nwajide, 2006) (Fig. 2). The Coal Measure Group forms the upper part of the Anambra Basin and of the Mamu Formation overlain by the Ajali Sandstone topped by the Nsukka Formations.

The study area is delimited by longitudes 7° 28' - 7° 35'E and latitude 6° 19' - 6° 30'N and falls within the Anambra Basin (Fig. 3). It is bounded in the east by Emene town, in the north by Abakpa, and toward the west by Trans Ekulu, and to the south by Agbogugu - Owelli town. Major road includes the Ogui - Abakiliki road, which traverses the study area in an east – west direction, and serves as the take-off of the Enugu Port Harcourt express.

3. MATERIALS AND METHODS
The materials for this study were obtained by sampling the shale intervals of the Enugu Formation. Exposures of the formation were systematically logged at different localities, such as Ozalla Junction at unit Loc. 1 in the southwest, along Enugu-Port Harcourt expressway, up to unit Loc. 9, near first flyover across the Enugu-Onitsha expressway, in the northern part of the study area (see Fig. 3).

Ten (10) shale samples were subjected to standard conventional method of acid demineralization and maceration for recovering acid-insoluble organic-walled microfossils. Each sample was thoroughly cleaned to remove field contaminants. 10 g of each shale sample was weighted out using weighing balance and gently crushed with agate mortar and piston. HCL acid treatment was unnecessary since the shale samples signaled non-calcareous. The crushed calcite-free sample was digested for 72 hours in 48 % hydrofluoric acid for removal of silicates. The samples were diluted with distil water to neutralize the acid, and then sieve-washed through 10 microns nylon mesh to enable the organic residue be free from mud and acid. The sieve-washed 10 g residue equivalent was partitioned into two parts, 5 g each, for oxidation and the other 5 g for kerogen studies. The 5 g acid-free organic residue extract from shale was oxidized for 30 minutes in 70% conc. nitric acid 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. Heavy liquid separation using zinc chloride was employed to separate the palynomorphs, and remove resistant coarse mineral particles and undigested organic matter.
The palynomorph residues were collected on the sieve and stained with Safranin – O to increase the visibility for microscopic study. Aliquots were dispersed with polyvinyl alcohol, dried on cover-slips and mounted in petro-poxy resin. One slide was made from each sample for transmitted light microscopic study.

3. RESULTS
Table 1 shows the absolute occurrence and distribution of palynomorphs present in the samples from Loc. 1 to 9. The carbonaceous fissile shale samples generally yielded moderately rich palynomorph assemblage. Terrigenous species such as fern spores were the most abundant in almost all the examined samples, followed by pollen species of mangrove affinity. Marine species such as dinoflagellate cysts recorded very few presence. The peridiniacean species with a proximate cyst affinity predominates over the gonyaulacaceans.

Terrigenous species
Spores: Among the terrigenous species, spores were the most abundant and less diverse. Among the fern spores, Laevigatosporites ovatus was the most abundant (58 counts) in sample En/L9/S10, (Table 1) (Fig. 4). The samples from Loc. 1, 2a, 5, 7, and 8, recorded higher percentage frequency of spores (Table 3), with 45% count at Loc. 1, 2a (71 %), Loc. 5 (57 %), Loc. 7 (70 %), and 83 % at Loc. 8. Fresh water species, such as Azolla cretacea, were also recorded but in a very low numbers.

Pollen: Pollen gains were the second most abundant in all the samples but were the most diverse of the palynomorphs. Among the pollen grains, Longipertites marginatus produced the highest counts (30) in sample En/L4/S5 (Fig. 4). The samples OZ/L3/S4 from Loc. 3 recorded higher percentage frequency of pollen count (71 %) followed by sample OZ/L2b/S3 (64 %) and EN/L4/S5 (49 %).

Marine species
Dinoflagellate cyst: Among the marine dinoflagellate species, the peridiniacean species Andalusiella polymorpha recorded the highest absolute count of (4) in sample EN/L4/S5. Other samples from locations such as, Loc. 2a, 2b, 4, 5, and 7, with (10 %, 5 %, 7 %, 9 %, and 2 %, respectively), relative percentage marine influence, were also recorded. Samples from Loc. 3, 6, 8, and 9, recorded no marine species.

5. DISCUSSIONS
5.1 AGE DETERMINATION AND CORRELATIONS
The abundance of stratigraphically significant miospore species as well as the presence of some marker taxa in the examined samples constitutes the basis for assigning an age to the Enugu Formation (see Table 1). The stratigraphic distribution of palynomorphs in the studied lithologic sections (Fig. 5) shows that the assemblage is similar to those of the Campanian-Maastrichtian interval of coeval tropical-subtropical Africa, South America and India (Van Hoekenklinkenberg, 1964, 1966; Jardine and Magloire, 1965; Herngreen, 1975; Jan du Chene et al., 1978, Salard-
Table 1: Absolute occurrence and distribution of palynomorphs present in the examined samples.

| Sample No. | OZ/L1/S1 | OZ/L2/S2 | OZ/L2/S3 | EN/L3/S4 | EN/L4/S5 | EN/L5/S6 | EN/L6/S7 | EN/L7/S8 | EN/L8/S9 | EN/L9/S10 |
|------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| **Spores** |          |          |          |          |          |          |          |          |          |          |
| Laevigatosporites ovatus | 14 | 10 | 8 | 4 | 35 | 20 | 8 | 26 | 14 | 58 |
| Cyathidites minor | - | - | - | - | - | - | - | - | 3 | - |
| Cyathidites austrialis | 2 | - | 1 | - | - | - | - | - | 1 | - |
| Leiotriletes adriennis | - | - | - | - | - | - | - | - | - | - |
| Lycopodiumsporites fastigides | - | - | - | - | 7 | 1 | - | - | - | - |
| Leiotriletes major | - | - | - | - | - | - | - | 1 | - | - |
| Verrucatosporites usmensis | - | - | 3 | - | 1 | 2 | 1 | 2 | - | - |
| Leiotriletes adriennis | 1 | - | - | - | - | - | - | 6 | 2 | - |
| Distaverrusporites simplex | 1 | - | 1 | - | 1 | - | - | - | - | - |
| Leiotriletes minor | - | 2 | - | - | - | - | - | - | - | - |
| Rugulatisporites capratus | - | - | - | - | - | - | 1 | - | - | - |
| Azolla cretacea | 1 | - | - | - | 1 | - | - | - | - | - |
| Zivisporis blanensis | - | - | - | - | 3 | 1 | - | 1 | - | - |
| **Pollen** |          |          |          |          |          |          |          |          |          |          |
| Longapertites vaneeedenburgi | 2 | 1 | 3 | - | 1 | 2 | - | 1 | - | - |
| Scabratriporites simpiformis | - | - | - | - | - | 1 | - | - | - | - |
| Proxapertites operculatus | 1 | - | 1 | 1 | 10 | 3 | 1 | 1 | 1 | 1 |
| Proxapertites anisoscutus | - | - | - | 1 | 1 | - | - | - | - | - |
| Echitriporites trianguliformis | 1 | - | 2 | - | - | - | - | - | - | - |
| Retidiporites magdalenensis | 1 | - | - | - | 3 | 1 | - | - | 2 | - |
| Spinizonocolpites baculatus | - | - | 2 | 1 | 1 | - | - | - | - | - |
| Maurtidites crassibaculatus | 2 | - | 1 | 1 | - | - | - | - | - | - |
| Auriculitides reticulatus | - | - | - | - | 1 | - | - | - | - | - |
| Longapertites marginatus | 3 | 1 | 12 | 3 | 30 | - | 6 | - | 2 | 4 |
| Psilamonocolpites magnus | 2 | - | 1 | - | - | - | - | - | - | - |
| Species                        | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 |
|-------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|
| Monoporites annulatus         | -  | -  | 3  | -  | -  | -  | 1  | -  | -  | -  | -  | -  |
| Cycadopites ovatus            | -  | -  | 2  | 2  | 4  | 2  | 9  | 1  | 6  | -  | -  | -  |
| Spinizonocolpites echinatus   | -  | -  | -  | -  | -  | -  | 1  | -  | -  | -  | -  | -  |
| Ephiedripites sp              | -  | -  | -  | -  | -  | -  | -  | -  | -  | 1  | -  | -  |
| Monocolpites marginatus       | 2  | -  | -  | 4  | -  | 2  | -  | 1  | -  | -  | -  | -  |
| Mauritidites crassibaculatus  | -  | -  | -  | 1  | -  | -  | -  | -  | -  | -  | -  | -  |
| Proxapertites cursus          | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | 2  |
| Proteacidites miniporatus     | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| Proteacidites dehaani         | -  | -  | -  | -  | 1  | 1  | -  | -  | -  | -  | -  | -  |
| Psilricolporites crassus      | -  | -  | -  | -  | -  | 1  | -  | -  | -  | -  | -  | -  |
| Echitriporites trianguliformis| -  | -  | -  | -  | 1  | -  | -  | -  | -  | -  | -  | -  |
| Syncolpites marginatus        | -  | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| Retitirolpites irregularis    | -  | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| Psilatricolpites sp.          | -  | -  | 1  | -  | -  | 2  | -  | -  | -  | -  | -  | -  |
| MARINE SPECIES                |    |    |    |    |    |    |    |    |    |    |    |    |
| Coronifera tubuloss           | -  | -  | -  | -  | 1  | -  | -  | -  | -  | -  | -  | -  |
| Andalusiella polymorpha       | 2  | -  | 1  | -  | 4  | -  | -  | -  | -  | -  | -  | -  |
| Dinogymnum sp.                | 1  | -  | -  | -  | 3  | -  | -  | -  | -  | -  | -  | -  |
| Paleocystodiium sp            | -  | -  | -  | -  | 1  | -  | -  | -  | -  | -  | -  | -  |
| Phelodinium sp.               | 1  | 1  | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| Cordosphaeridium deckoninki   | -  | -  | 1  | -  | 2  | 2  | -  | 1  | -  | -  | -  | -  |
Cheboldaeff, 1979; Salami, 1983, 1988; Lawal and Moullade, 1986; Schrank, 1987; Edet and Nyong, 1994; Umeji, 2007). Based on palynological results, a late Campanian-Earliest Maastrichtian age was established for the formation based on the following index marker taxa: Longapertites marginatus (Overwhelming), Monocolpites marginatus, Zlivisporis blanensis, Echitriporites trianguliformis, and organic-walled microplanktons Coronifera tubulosa, Senegalinium spp. and Andalusielia polymorpha, (Schrank, 1987; Lawal and Moullade, 1986; Edet and Nyong, 1994) (Fig. 5). The species of Coronifera tubulosa and Andalusielia polymorpha have been reported from the Campanian of Egypt by Schrank (1987). Edet and Nyong (1994) identified the organic-walled microplanktons Coronifera tubulosa, Senegalinium spp. and Andalusielia polymorpha in the Nkporo Shale within the Calabar Flank, and remarked that in the tropical-subtropical regions, these species are mainly recorded from Campanian-Maastrichtian intervals (Herngreen, 1975b; Jain and Millepied, 1975; Salami, 1986, 1988; Schrank, 1986).

Edet and Nyong (1994) further reported that microfloral distribution within the Nkporo Shale in the Calabar Flank shows a frequent to common occurrence of stratigraphically significant miospore species typical of Campanian-Maastrichtian deposits of tropical-subtropical regions. The species include Monocolpites marginatus, Longapertites marginatus, Longapertites sp. 3 (Lawal and Moullade, 1986), Echitriporites trianguliformis, and Dinogymnium acuminatum. The presence of these species in the recovered assemblage from the examined samples in the study area thus supports a late Campanian-Earliest Maastrichtian age for the Enugu Formation. This age designation based on palynological result is in accord with the age indications...
of the ammonites and foraminifera. The age assignment correlates well with the late Campanian-Maastrichtian assemblage of (Chiaghanam et al., 2012), based on Longapertites marginitus, Echitriporites trianguliformis, Monocolpites marginatus, and Dinigymnium acuminatum and Andalusiella polymorpha.

5.2 PALEOENVIRONMENTS OF DEPOSITION

Table 2 below shows the summary of palynomorphs percentage (%) frequency distribution and their paleoenvironmental inferences in the studied sections. The environments of deposition of the sediments of formation have been a subject of discussion in various published works (e.g. Chiaghanam et al., 2012). The authors suggested marginal marine environments for the shale of the Enugu Formation. Some other authors however recognized and reported certain non-marine sedimentological features in these sediments. The occurrence of well preserved terrestrial miospores from the shaly intervals of the formation in the study area, being recorded here, is therefore significant in elucidating the processes of sedimentation.

The paleoenvironments of the Enugu Formation may be reconstructed by evaluating its palynological attributes. The environmental changes are reflected in the palynological assemblages and are especially noticeable in the composition and relative proportion of different classes of palynomorphs, (Oloto, 1989; Ikegwuonu et al. 2020). The major components include spores and pollen grains. The associated elements include dinoflagellate cysts. Palynological data have been found useful as a paleoenvironmental synthesis tool (Oloto, 1989; Petters and Edet, 1996; Ojo, 1999, 2009). In these studies, the interpretation is based on the ratio of land derived miospores to marine dinoflagellates and also the morphology of the dinocysts. (Ojo, 2009). Schrank (1984) suggests that a palynomorph assemblage with higher content of land derived miospores indicates terrestrial influence and vice versa.

In this study, the palynomorphs of environmental value include: Cyathidites minor, a tree fern which inhabits a well forested, tropical to temperate regions, usually most developed in mountainous / highland localities under moist and equable climate; Spinizonocolpites baculatus/echinatus, Longapertites marginatus, Mauritidites baculatus and Monocolpites marginatus are palm pollen which inhabit similar brackish waters as the mangrove (Umeji and Nwajide, 2014; Ikegwuonu and Umeji, 2016). The overwhelming occurrence of well-known terrestrial miospores such as, Laevigatisporites ovatus, Longapertites marginatus, Monocolpites marginatus, and with few marine dinoflagellates of peridinoid affinity such as Andalusella spp., Dinogymnium spp., and Senegalininum spp., generally indicate strong terrestrial conditions, with minor marine flooding. This is evident from the high dominance of miospore pollen with abundance fresh water fern spores over the marine microplankton in almost the entire samples. The samples OZ/L1/S1, OZ/L2/S2, OZ/L2/S3, EN/L4/S5, EN/L5/S6 and EN/L7/S8, recorded higher percentage frequency of miospore species, especially the fresh water fern spores Laevigatosporites ovatus and pollen grain of palmae Longapertites marginatus, than the marine species, indicating deposition in a marginal marine/ or brackish water condition probably in a proximal estuarine environment, whereas samples EN/L3/S4, EN/L6/S7, EN/L8/S9 and EN/L9/S10 documented only

![Fig. 5: Biostratigraphic range chart of some palynomorphs from the Enugu Formation.](image-url)
the terrestrial miospore species with no marine species, indicating deposition in a non-marine/ fresh water condition probably in a mangrove swamp setting (see table 2). In general, following these observations, the depositional paleoenvironment of the Enugu Formation ranged from non-marine to marginal marine settings.

5. CONCLUSIONS
Detailed palynological studies of the Enugu Formation based on the occurrence of both miospores and dinoflagellate cysts have been undertaken within Enugu and environs. The recovered palynofloral assemblage essentially demonstrates the typical features of the Senonian Palmae province comprising mostly of Campano-Maastrichtian taxa reported from tropical-subtropical regions of South America, India and Africa. Based on the result obtained from this study, a Late Campanian - Earliest Maastrichtian age interval was assigned for the formation following the stratigraphically significant age marker palynomorph taxa recovered. Environmentally significant palynomorph species encountered were equally utilized in delineating the environments of deposition of the sediments, which ranged from non-marine to marginal marine within the upper to lower deltaic setting.

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