RESEARCH ARTICLE

Biostratigraphy and Paleogeography of Late Campanian–Early Maastrichtian (Nkporo Formation) Sections in Awgu, Southeastern Nigeria

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ABSTRACT

Surface Late Cretaceous sediments of the Nkporo Shales of Anambra Basin have been studied for their foraminifera and palynomorphs contents in order to interpret depositional architecture associated with the formation using lithofacies parameters and hence date the shale samples of the formation. The Environments of depositions were interpreted through integration of lithology, textures, sedimentary structures and boundary contacts between one bed and another (facies parameters). The work encompasses both field and laboratory exercises. The field work involved detailed field mapping, outcrop logging and rock sample collection for laboratory utilization. The obtained shale samples were processed in the laboratory for palynological and micropaleontological analysis in order to determine the age and compartimerize the analyzed sections through age range chart and biozonations. The Owelli Sandstone was interpreted to be deposited in a tidally influenced estuary while Nkporo Shale was interpreted to be deposited in a Shore face zone environment. The results from both palynological and micropaleontological analysis of Nkporo Formation dated the analyzed sections Late Campanian to Early Maastrichtian.

Key Words: *Biostratigraphy; Palynology; Foraminifera; Late Campanian-Early Maastrichtian; Biozonation; Nkporo Formation; Estuarine environment; Shoreface zone.*

INTRODUCTION

The Anambra Basin is one of the three tectonic subdivisions of the Southern Nigeria Sedimentary Basin as recognized [1]. Anambra Basin is a region within the Southern Benue Trough bounded by the Abakaliki Anticlinorium in the east, the Benin hinge line in the west, the Niger hinge line in the north and the Niger Delta hinge line in the south (Figure 1) [2]. The first of the depositional cycles occurred in the pre-Albian times, and was confined mainly to the Benue Trough. The second depositional phase dominated the Anambra Basin as well as narrow Afikpo synclinorium. The Anambra Basin contains over 2000 m. of cretaceous marine, paralic and deltaic facies sediments in outcropping sections which extended into adjacent tectonic basins such as the Benue Trough, the Afikpo Syncline and the Calabar Flank [2]. Detailed lithostratigraphic compilations, such as Simpson [1, 3-6] among others have been presented for the Cretaceous Sediments of the Southern Benue Trough including the Anambra Basin.

However, the bulk of biostratigraphic studies on surface sediments in Anambra Basin were based on foraminifera studies. Palynological information is limited for most of the formations in Anambra Basin [2]. The

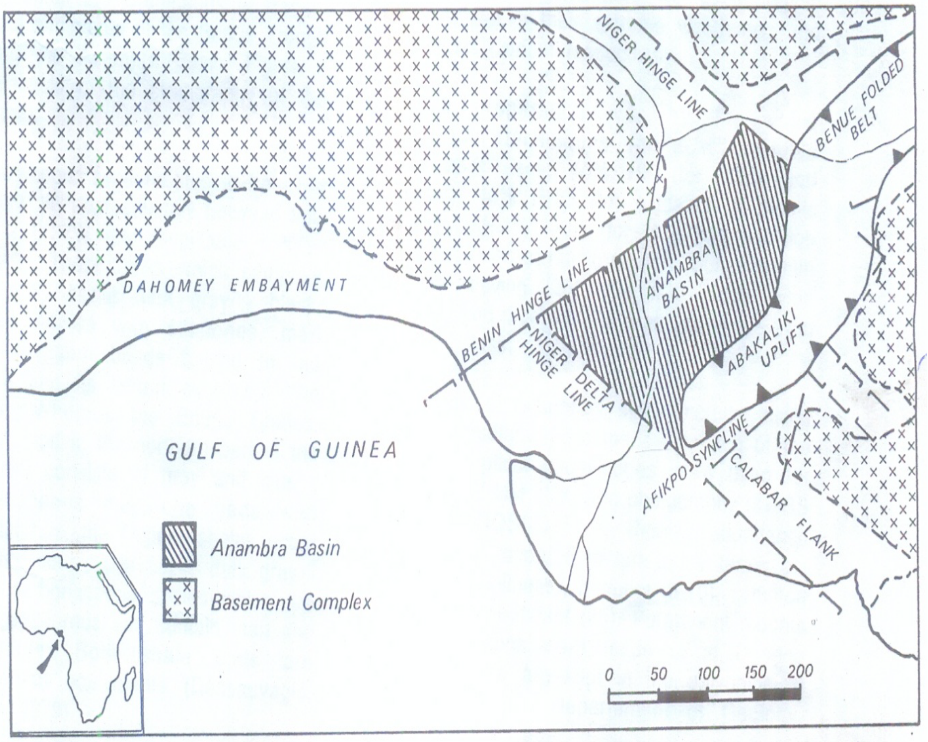

Figure 1) Tectonic Subdivisions of the Southern Nigeria Sedimentary Basin showing the Anambra Basin.

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significant among the few palynological publications in this basin are those of Van Hoeken-Klinkenberg [2, 7-11], on the “coal measures” facies within the Anambra Basin. This article therefore serves as a complimentary publication on biostratigraphic literatures on Late Campanian-Early Maastrichtian exposures in Anambra Basin at Awgu areas.

GEOLOGIC SETTING AND SAMPLE LOCALITIES

Chronostratigraphic and palaeocologic investigations have been carried out on various cretaceous sequences of the Benue Trough using ammonites calcareous nannoplanktons, especially coccoliths and palynomorphs [4, 9, 11-20]. The Earlier workers took the Nkporo Group as the oldest sedimentary deposits in the Anmabra Basin [21, 23]. But recent works opened up the possibility of having pre-Santonian Sediments, at least at the northwestern part of the basin [23]. The Nkporo Group forms the basal facies of the Mid to Late Cretaceous Sedimentary cycle in the southern Benue Trough and Anambra Basin, deposited during Late Campanian. The Nkporo Group is made up of three members: Afikpo/Owelli Sandstone, Nkporo and Enugu shales. The arenaceous facies of the Afikpo and Owelli Sandstone are laterally equivalents to the Nkporo Formation in the Afikpo and Anambra Basin respectively [24].

The Nkporo Group is essentially marine sediments deposited by the third transgressive cycle within the Anambra Basin. Its deposition ended in the Early Maastrichtian in both Abakaliki- Anambra and Afikpo synclines (Figure 2). The Enugu shales are made up of carbonaceous shales and coals with upper half deposited in lower flood plain and swampy environment that overlie the Nkporo Formation [25]. It is found in the North of Awgu and exposed at Milliken Hills at Enugu, restricting the facies to the central and Northern parts of the Basin [26, 27]. The sediments have a poorly developed foreshore and shore face with extensive coastal swamps, and were assigned Campanian to Lower Maastrichtian (Figure 2), based on diagnostic species of palynomorphs such as Cingulatisporites ornatus and Tricolpites tienebaensis [28]. Indicated that the deposition of the sediments of the Enugu/Nkporo Formations reflect a funnel-shaped shallow marine setting that graded into channeled low energy marshes[25].

The Late Cretaceous Sections studied from the Anambra Basin in Awgu area lie approximately between latitudes 6° 0’ N-6° 8΄N and longitudes 7° 26’- 7° 30΄ E (Figure 3). These rocks which comprise of bioturbated sandstone and occasional siltstones belong to the Owelli Sandstone member while the Nkporo Shale which is distributed in the northwestern part of the Anambra Basin consists of highly fissile dark grey-black shales with occasionally clay and siltstone nodules. Samples were collected from three outcrop sections in Anambra Basin. Two of these outcrops are located along Awgu-Mmaku road and one of the outcrops is located at Community Secondary School Mmaku. Both outcrops belong to Nkporo Shales (Figure 3). In all, six samples which yielded a rich microfossil assemblage including pollen, spores and foraminifera species were studied.

m.y	AGE	ABAKALIKI – ANAMBRA BASIN	AFIKPO BASIN
30	Oligocene	Ogwashi-Asaba Formation	Ogwashi-Asaba Formation
549	Eocene	Ameki/Nanka Formation/ Nsugbe Sandstone (Ameki Group)	Ameki Formation
65	Palaeocene	Imo Formation Nsukka Formation	Imo Formation Nsukka Formation
73	Maastrichtian	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation
	Campanian	Npkoro Oweli Formation/Enugu Shale	Nkporo Shale/ Afikpo Sandstone
83 87.5	Santonian	Agbani Sandstone/Awgu Shale	Non-deposition/erosion
88.5	Coniacian		Eze Aku Group (incl. Amasiri Sandstone)
	Turonian	Eze Aku Group	
93 100	Cenomanian – Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Units	
	Precambrian	Basement Complex	

Figure 2) Correlation chart for Early Cretaceous-Tertiary Strata in South Eastern Nigeria [22].

MATERIALS AND METHODS

The study is located at Awgu and its environs in Enugu state within the western flank of Abakaliki Anticlinorium, South Eastern Nigeria. Detailed field mapping was carried out with the aid of the accessibility (topographic) map (Figure 3), GPS for locating the study sections in the map and compass clinometer for determining the trend of the geologic boundaries. The laboratory materials used include: transmitted light binocular microscope, SedLog version 3.0, excel spread sheet and other relevant journals for studying of the previous works in the study area. The boundaries were inferred from the gradual changes in lithology, vegetation and topography. However, the boundaries between one formation and other were inferred based on the gradational changes in lithofacies. The shale samples collected from three outcrops along Awgu-Mmaku Road and Community Secondary School, Mmaku were analyzed for foraminifera and palynomorph contents. Available sandstone materials were unsuitable for foraminifera and palynological analysis due to their extreme weathering and low matrix contents respectively. Outcrop logging was carried out at different locations where they are exposed as a result of road cut, erosion and stream channels. The observation and recording of the features started from the base of the exposures. The geological features recorded are: The lithotypes, bed thickness, grain size, colour, mineral composition, nature of contact between one bed and the other, the sedimentary structures which include physical, biogenic and chemical, attitude of the bed and cross bed azimuth. The intensity of bioturbations at different beds was noted while illustrations of their structures were made on the field notebook. Dilute HCl were applied to beds suspected to contain carbonates for possible confirmation. Samples were prepared for foraminifera and palynomorphs contents. The foraminifers’ preparation was by washing and treating samples of small quantity (about 20 g-30 g) of the outcrop sample with one teaspoonful of anhydrous sodium carbonate for thorough disintegration. This was followed by sieving the samples into coarse, medium and fine fractions which were later stored in well-labeled sample bags. The samples were finally subjected to mounting procedures. The palynomorphs preparation followed the proper routine process as

Carbonate digestion

Crushing to 2 mm in a mortar, adding 10% HCL which was stirred until effervescence ceased, thereby allowing it to settle for 5 minutes.

Removal of silicates

200 ml of concentrated Hydrofluoric Acid (HF) was added. This was followed

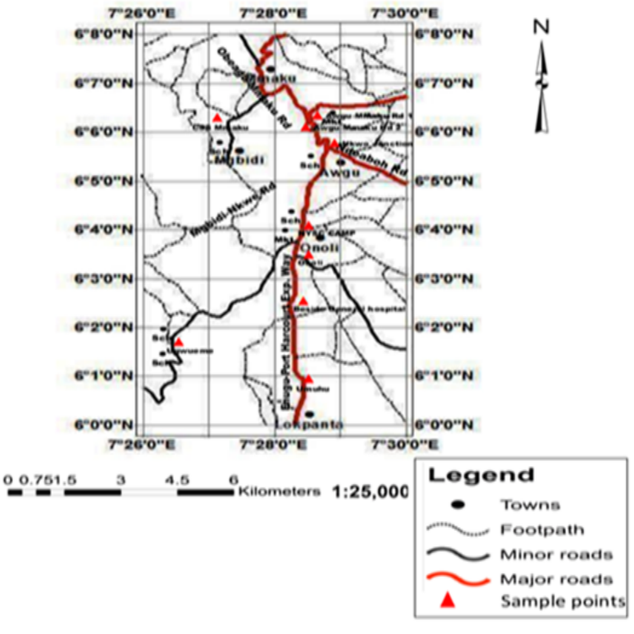

Figure 3) Accessibility Map of the study area.

by addition of 40% HNO3 for oxidation of humic matter and 1% of KOH for acid neutralization and dissolution of humic matter. Concentration was by sieving (200 and 400 mesh nylon screens) and pipetting the organic residue from a watch glass.

Six slides of temporary strew mounts, using Apathy's medium were made for each of the samples. Optical light and binocular microscopes were used for study. Relative abundance counts of the miospores were recorded in qualitative terms as: rare (1-5 specimens), frequent (6-10 specimens), common (11-25 specimens) and abundant (greater than 25 specimens).

RESULT

Geologic Map of the Study Area

There are three formations encountered during the study but my interest is in Nkporo Formation where detailed study actually took place. The three formations seen are shown in the geologic map of the study area (Figure 4). The oldest among the three is the Eze-Aku Formation in which its sandstone facies were conspicuously shown. The formation is located towards the Southern part of the study area (Figure 4). This formation is overlain by Awgu Formation that comprised of Awgu Shale and Agbani Sandstone. The study area is however, capped by Nkporo Group which includes Owelli Sandstone that transgressively deposited at the basal part of the formation while the Nkporo Shale that ended the sequence deposited at the upper part of the formation. The general trend of the three formations (Eze-Aku, Awgu and Nkporo) is NE-SW direction with a westerly dip direction. The geologic map of the area is shown in Figure 4.

LITHOLOGY WITH FORAMINIFERA AND PALYNOMORPH OCCURRENCES

Awgu-Mmaku road 1

This outcrop section which is Owelli Sandstone facies is about 12 m thick and located within latitude 06° 05´14.1" N and longitude 007°28´57.5" E along Awgu-Mmaku road with a ground elevation of 278 m. It consists of a basal 0.9 m thick of dark grey fissile shale which is overlain by a 0.3 m thick silt dominated hetrolith with clay. This is overlain by about nine successive sandstone facies with grain sizes that range from fine-medium-coarse-conglomeratic. The section is characterised by the presence of planar cross beds and trace fossils such as *Ophiomorpha sp*. The topmost unit of the section consists of parallel laminated sand dominated heterolith with siltstone of about 2.4 m thick. The lithologic section is shown in Figure 5 below.

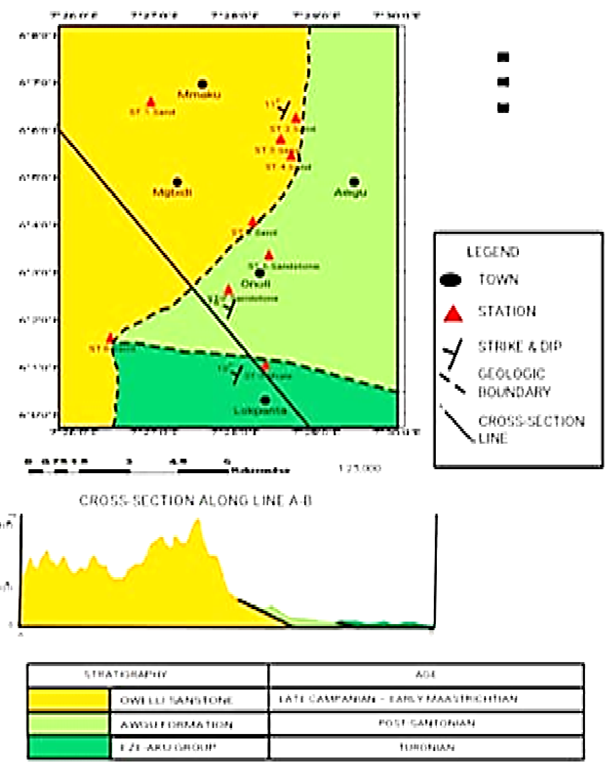

Figure 4) Geologic Map of the study area.

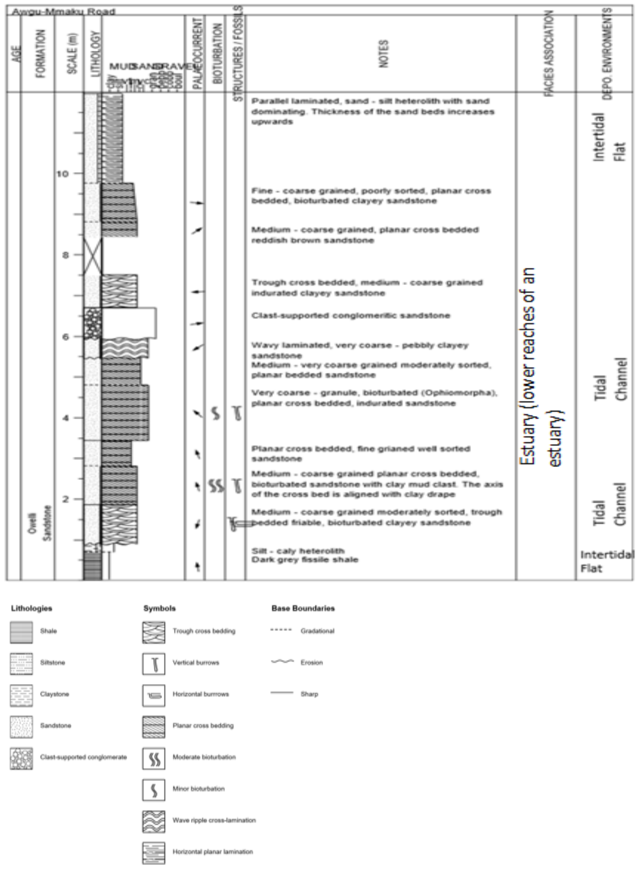

Figure 5) Litholog of Awgu-Mmaku Road 1.

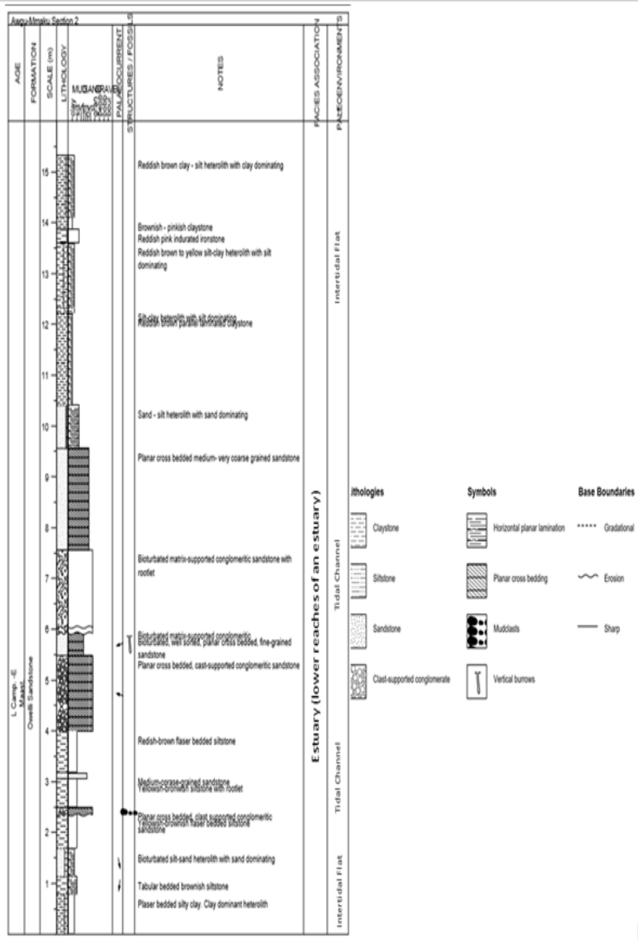

Figure 6) Litholog of Awgu-Mmaku Road 2.

The significant palynomorph contents include Gleicheniidites senonicus, Leiotriletes adreevi, Leiotriletes adriennis, Ephedripites sp, Longapertites microfoveolatus, Monocolpites marginatus, Monosulcites sp 2, Tubistephanocolpites cylindricus (Plate 2). Others include the significant foraminifers' species such as *Haplophragmoides excavata, Haplophragmoides spp, Ammobaculites amabensis, Trochammina sp, Textulariopsis dukamajina and Saccamina sp*. (Plate 1).

Awgu-Mmaku road 2

This outcrop section which is Owelli Sandstone facies is located within the latitude 06° 06 8.1" N and longitude 007° 28' 40" E with ground elevation of 283 m. The section is about 15.42 m. thick and situates at about 2 km from Awgu-Mmaku road 1. It consists of a 0.78 m basal clay heterolithic siltstone with clay dominating and characterised by the presence of flaser beddings. The middle part of the section is overlain by intercalations of siltstone and sandstone facies. The upper part of the section is dominated by sandstone facies while the topmost part consists of clay dominant heterolithic facies with siltstone. The litholog of the section is shown in Figure 6 below. The significant palynomorph contents in this section include *Longapertites marginatus, Monosulcites Sp 1, Monosulcites Sp 2 and Psilastephanocolpites variabilis* (Plate 2).

Community Secondary School, Mmaku

An outcrop exposure in the upper part of Nkporo Formation is seen at Community Secondary School, Mmaku (Figure 7), where it situates within latitude N06° 06' 15.2" and longitude E007° 27' 10" with ground elevation of 318 m. The section is about 7.3 m thick. The basal part of about 2 m. comprises highly fissile dark grey shale with oolitic ironstone of about 1 m thick overlying the basal top. The middle part of the section comprises of mud dominated facies hetrolith with clay-silt, showing horizontal parallel lamination with thickness of about 0.7 m thick. This is overlain by intercalations of sandstone and shale facies of about 1.9 m thick. The sequence is capped by about 1.7 m thick sand dominated heterolithic facies with siltstone. The litholog is represented in Figure 7 below and Stratigraphic Age Range Charts has been shown in Figures 8-10. The Palynomorph contents analysed in this section include the significant spores such as *Gleicheniidites sp., Leiotriletes adreevi, Psilatriletes sp, Pterospermopsis* helios and significant pollen such as *Ephedripites sp., Ephedripites strobilaceus, Echitriporites trianguliformis, Buttinia*

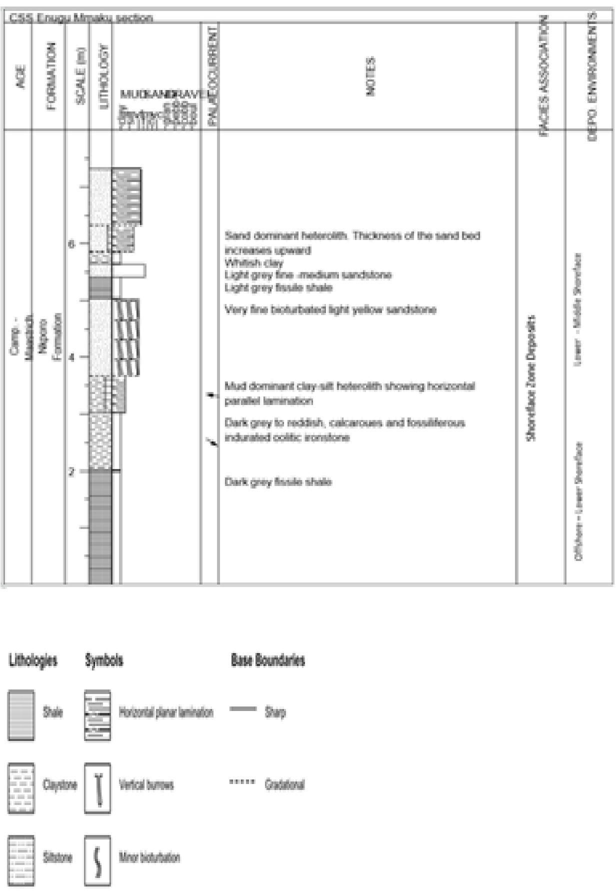

Figure 7) Litholog of Section 3, at Community Secondary School, Mmaku.

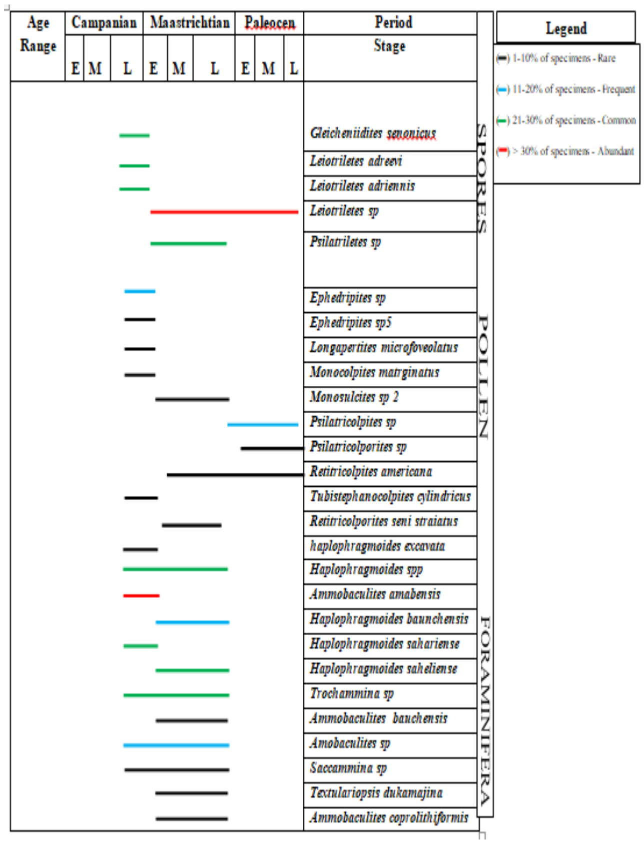

Figure 8) Stratigraphic Age Range Chart of Palynomorphs and Foraminifera species from Awgu-Mmaku Road1.

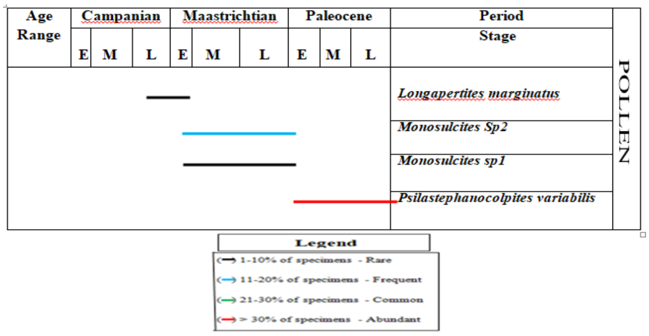

Figure 9) Stratigraphic Age Range Chart of Palynomorphs from Awgu-Mmaku road 2.

adreevi, Achomosphaera crassipellis, Longapertites microfoveolatus, Longapertites marginatus, Longapertites sp3, Monocolpites marginatus, Tubistephanocolpites cylindricus, Tricolpites sp. and Proteacidites sp (Plate 2). Others include the significant benthic foraminiferas' species such as *Haplophragmoides excavata, Haplophragmoides sahariense, Ammobaculites sp, Haplophragmoides hausa, Reophax sp, Trochammina dustsuna and Haplophragmoides Sp.* (Plate 1).

BIOZONATIONS

The characteristic Appearance Datum (AD) of the palynomorph and foraminifera species was used for the analysis of their biozones. However, Tables 1-3 represent the biozonations of Awgu-Mmaku road 1, Awgu-Mmaku road 2 and Community Secondary School, Mmaku respectively.

DISCUSSION

Paleogeographic reconstruction

The transgressive movement at the base of the Nkporo Group after the Late Santonian event that caused a widespread deformation (folding, faulting and erosion) of Agbani Sandstone led to the deposition of Owelli Sandstone in a stillstand stacking pattern. The infilled sediment of the Owelli Sandtsone is interpreted to be deposited in a tidally influenced estuary as Incised Valleys Fill (IVF). However, the Nkporo Shale was interpreted to be deposited in a

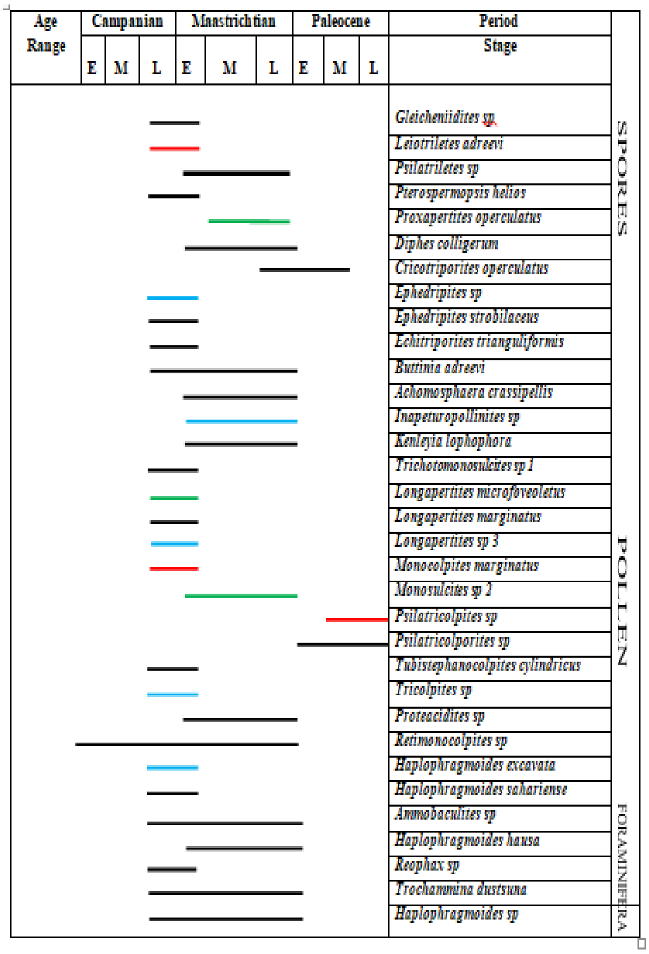

Figure 10) Stratigraphic age range chart of palynomorphs and foraminifera species from Community Secondary School, Mmaku.

Shore face facies association thereby exhibiting an offshore to middle Shore face depositional environments.

Microfossils assemblages and age determination

The studied micrcofossils include both palynomorphs and foraminifera

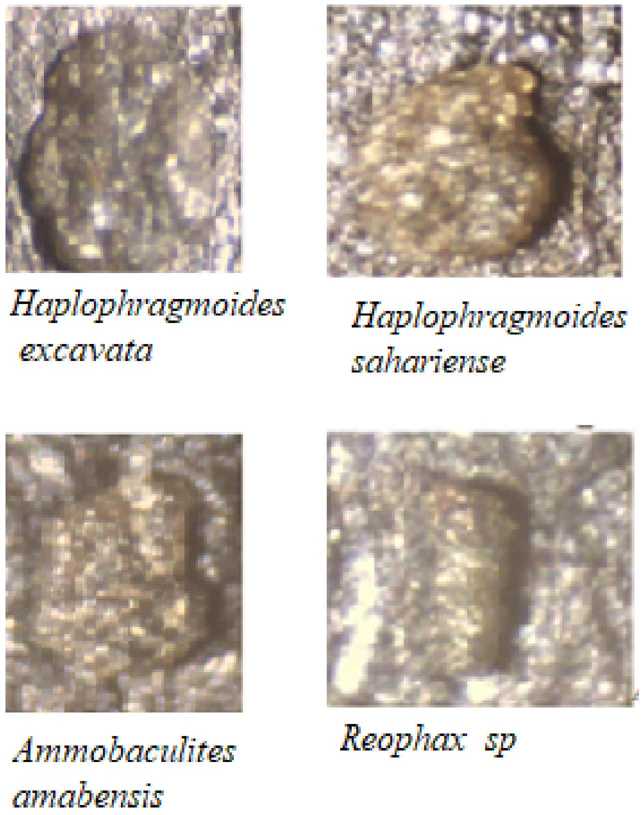

Plate 1) Significant Index Markers of Foraminifera species analyzed from Nkporo Shales [9, 33-35].

TABLE 1
Biozone of Awgu-Mmaku Road 1, using Appearance Datum of the palynomorph and foraminifera species obtained.

Zones	Biochron	Species of Palynomorphs and Foraminifera
Zone ɪɪɪ	Early Paleocene	This zone is characterized by the association of First Appearance Datum (FAD) of *Psilatricolpites sp and Psilatricolporites sp*
Zone II	Early Maastrichtian	This zone is characterized by the association of First Appearance Datum (FAD) of *Leiotriletes sp, Psilatriletes sp, Monosulcites sp2, Retitricolpites Americana, Retitricolporites senistraiatus, Haplophragmoides sp, Haplophragmoides saheliense, Ammobaculites bauchensis, Saccamina sp and Ammobaculites coprolithiformis*
Zone I	Late Campanian	This zone is characterized by the association of Last Appearance Datum (LAD) of *Gleicheniidites senonicus, Leiotriletes adreevi, Leiotriletes adriennis, Ephedripites sp, Ephedripites sp5, Longapertites microfoveolatus, Monocolpites marginatus, Tubistephanocolpites cylindricus, Ammobaculites amabensis and Haplophragmoides excavata*

TABLE 2
Biozone of Awgu-Mmaku Road 2, using Appearance Datum of the palynomorph species obtained.

Zones	Biochron	Species of Palynomorphs
Zone ɪɪɪ	Early Paleocene	This zone is characterized by the association of First Appearance Datum (FAD) of *Psilastephanocolpites variabilis*
Zone II	Early Maastrichtian	This zone is characterized by the association of First Appearance Datum (FAD) of *Monosulcites sp1* and *Monosulcites sp2*
Zone I	Late Campanian	This assemblage zone is characterized by the association of Last Appearance Datum (LAD) of *Longapertites marginatus*

TABLE 3
Biozone of Community Secondary School, Mmaku, using Appearance Datum of the Palynomorph and Foraminifera species obtained.

Zones	Biochron	Species of Palynomorphs and Foraminifera
Zone ɪɪɪ	Middle Maastrichtian	This zone is characterized by the association of First Appearance Datum (FAD) of *Proxapertites operculatus*
Zone II	Early Maastrichtian	This zone is characterized by the association of First Appearance Datum (FAD) of *Psilatriletes sp, Diphes colligerum, Achomosphaera crassipellis, Inapeturopollenites sp, Kenleyia lophophora, Monosulcites sp1, Monosulcites sp2, Proteacidites sp. and Ammobaculites sp.*
Zone I	Late Campanian	This assemblage zone is characterized by the association of Last Appearance Datum (LAD) of *Gleicheniidites sp, Leiotriletes adreevi,Pterospermopsis helios, Ephedripites sp, Ephedripites strobilaceus, Echitriporites trianguliformis, Trichotomonosulcites sp1, Longapertites microfoveolatus, Longapertites marginatus, Longapertites sp 3, Monocolpites marginatus, Tubistephanocolpites cylindricus, Tricolpites spp, Haplophragmoides excavata, Haplophragmoides sahariense and Reophax sp.*

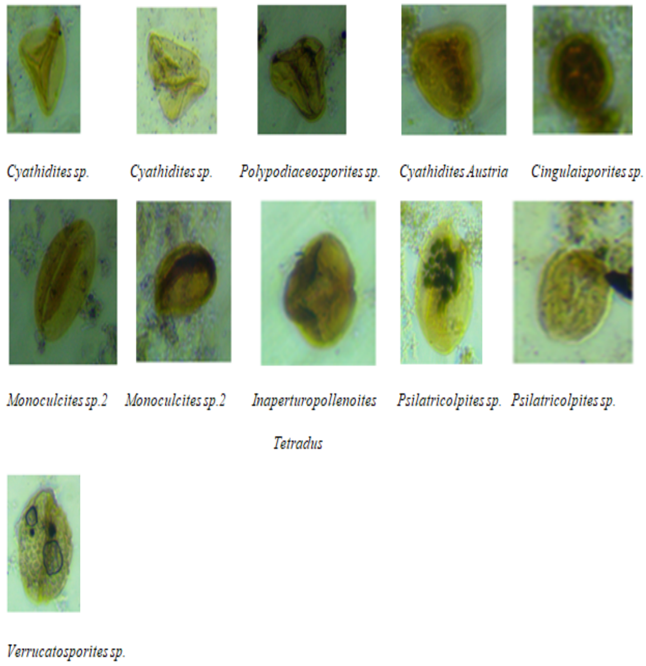

Plate 2a) Photographs of some important Palynomorphs as analyzed from the samples picked from the Nkporo Formation in the study area.

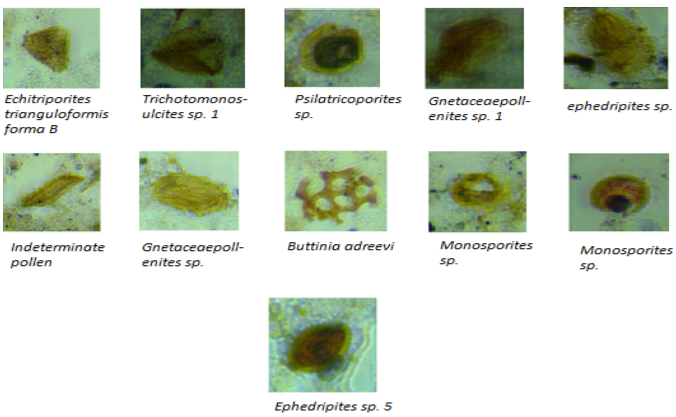

Plate 2b) Photographs of some important Palynomorphs as analyzed from the samples picked from the Nkporo Formation in the study area.

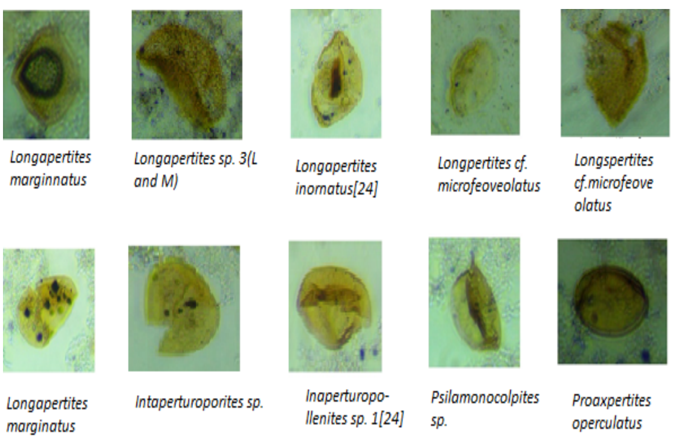

Plate 2c) Photographs of some important Palynomorphs as analyzed from the samples picked from the Nkporo Formation in the study area.

assemblages. The palynomorphs and foraminifera contents of the studied Nkporo shale outcrops exhibited close relationships in composition and biozonation; hence appear to be a continuous chronospecific unit outcropping at various locations.

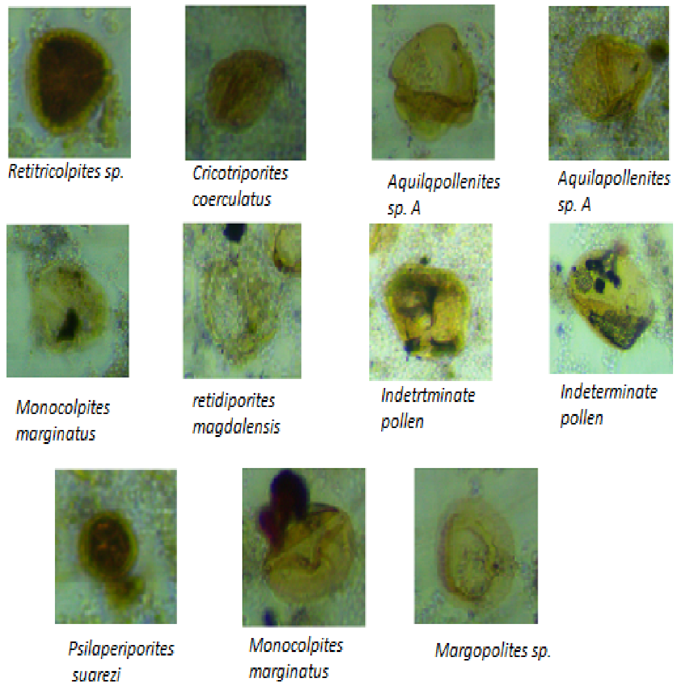

Plate 2d) Photographs of some important Palynomorphs as analyzed from the samples picked from the Nkporo Formation in the study area.

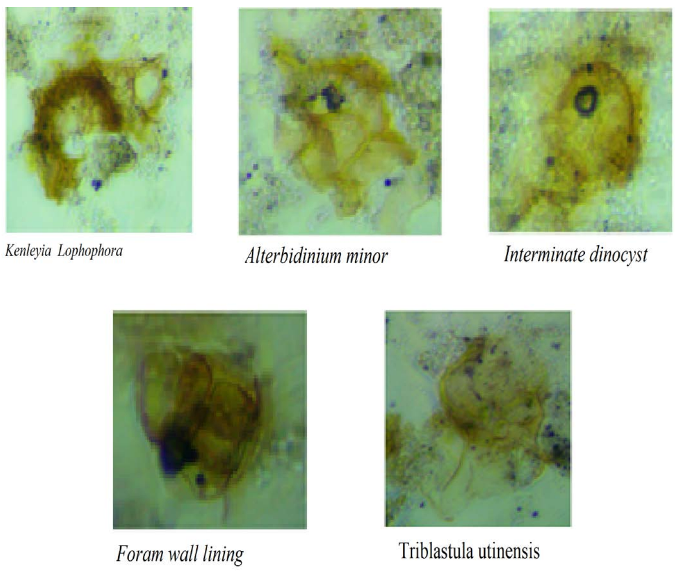

Plate 2e) Photographs of some important Palynomorphs as analyzed from the samples picked from the Nkporo Formation in the study area.

Since the sections of other formations (Eze-Aku and Awgu) in the study area were not studied to allow a complete assessment of the stratigraphic extent of miospores in the region, therefore, the dating was based on the relative frequency and consistent association of a few stratigraphically important forams and miospores of Nkporo Formation.

However, the assignment of an age to the sediments from the Nkporo Formation in the Anambra Basin has been based on the stratigraphic age ranges of the following selected index markers: *Haplophragmoides excavata, Haplophragmoides sahariense, Ammobaculites amabensis* and *Reophax sp.* (Plate 1). Others are *Gleicheniidites senonicus, Leiotriletes adreevi, Leiotriletes adriennis, Ephedripite sp., Ephedripites sp.5, Longapertites microfoveolatus, Monocolpites marginatus, Tubistephanocolpites cylindricus, Gleicheniidites sp., Ephedripites strobilaceus, Echitriporites trianguliformis, Trichotomonosulcites sp.1, Longapertites sp.3, Pterospermopsis helios* and *Tricolpites sp* (Plates 2a-2e). These palynomorphs taxa analyzed from the Nkporo Shales shown in plate 2 below have comparable age ranges to those described by earlier workers on Coeval tropical-subtropical regions [2, 7, 9, 18, 28-35]. The synopsis of the stratigraphic ranges of the selected foraminifera and palynomorph species according to the above earlier workers indicate that the recovered assemblage is significant in the Campanian-Maastrichtian interval. The stratigraphic overlap defined by the presence of the above index markers from the foraminifera and palynomorph species is suggestive of Late Campanian-Early Maastrichtian age for the Nkporo Shales.

CONCLUSION

The depositional architecture of Nkporo Formation ranges from tidally influenced estuary to Shore face facies associations which include tidal channel to intertidal flat depositional environments for owelli Sandstone and offshore to middle Shore face depositional environments for Nkporo shales. The foraminifera species obtained from the micropaleontological analysis were benthic arenaceous taxa. The palynomorph preservatation from the palynological analysis was relatively fair, and the outcrop samples yielded fairly rich to moderate diverse assemblages of miospores. The assignment of age to the Nkporo Formation was based on the stratigraphic age ranges of the selected index markers of the foraminifera and palynomorph species. The stratigraphic overlap defined by the presence of the selected index markers is a suggestive of Late Campanian-Early Maastrichtian for the Nkporo shales.

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