

Microfossil Assemblages of the Subsurface Parts of the Enugu Formation: Proxies to Depositional Environment and Age of the Formation

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Abstract

Two boreholes sunk into Enugu Formation within Enugu Metropolis were logged from the base to the top and samples collected were analyzed for palynomorphs and foraminifera in order to interpret the paleoenvironment and assign age to the formation. Four lithofacies identified include; dark fissile shale lithofacies, heterolithic lithofacies, sand laminated shale lithofacies and greyish shale lithofacies. Palynomorphs recovered consist of pteridophytic spores, angiosperm pollen, fungal spores and *Botryococcus braunii*. *Echitriporites trianguliformis*, *Cytheidites* sps., *Retitricolporite* sp., *Retidiporite magdalenensis*, *Laevigatosporites* sp., *Zlivisporites blanensis* among others were recorded. Five genera of arenaceous benthic foraminifera (*Ammobaculites* sps., *Haplophragmoides* sp., *Trochamina* sp., *Ammotium* sp. and *Saccamina* sp.) dominated by *Ammobaculites* sps. were also recovered. The coarsening upwards of the lithofacies succession from basal shale to sand laminated greyish shale lithofacies and the heterolithic lithofacies observed in borehole 1 is an attribute typical of a prograding sea. Evidences from the lithofacies and association, palynomorphs and foraminiferal assemblages showed sediment deposition in a marginal marine setting. Low abundance and diversity of the arenaceous foraminiferal species with the predominance of *Ammobaculites* sps. is characteristics seen in almost all the samples analyzed. These are suggestive of stressful environment due to low water salinity, rapid sedimentation with influx from terrestrial environment which resulted to stagnant and restricted low oxygen bottom water condition.

Keywords: Palynomorphs, Lithofacies, Foraminifera, Environment, Deposition, Shale

1. Introduction

The Enugu Formation in Anambra Basin of southeastern Nigeria is the basal stratigraphic unit of the basin deposited after the Santonian tectonic event which led to the development of the basin (Reyment, 1965; Nwajide, 2005). Different research work on sedimentology, stratigraphy, palynology, sequence stratigraphy, ichnology and paleoecology (e.g Nwajide and Reijers, 1996; Onuigbo et al., 2012a and b, 2014, 2015; Omoboriowo et al., 2012; Nwajide, 2013) have been carried out on the outcrop sections of this formation but the subsurface part has been given little or no attention in these aspects.

Although surface exposures are considered representatives of the subsurface, the exposures however, must have been affected to some extent by sedimentary processes of weathering. This invariably must have altered the preservative states and abundance of the microfossils as well as posing limitations to the recognition and identification of their morphological features. Subsurface no doubt are more likely to preserve these fossils in their original state as climatic and weathering effects have not had much impact on them.

In this paper, lithofacies and biofacies (palynomorphs and foraminifera) of the subsurface part of the Enugu Formation will be evaluated in order to interpret the paleoenvironment and assign age to the formation. For a better and systematic evaluation of the microfossil contents and more coherent data that will aid higher resolution stratigraphic interpretation, borehole samples have been utilized in the study.

Figure 1 is the geologic map showing the Enugu Formation studied.

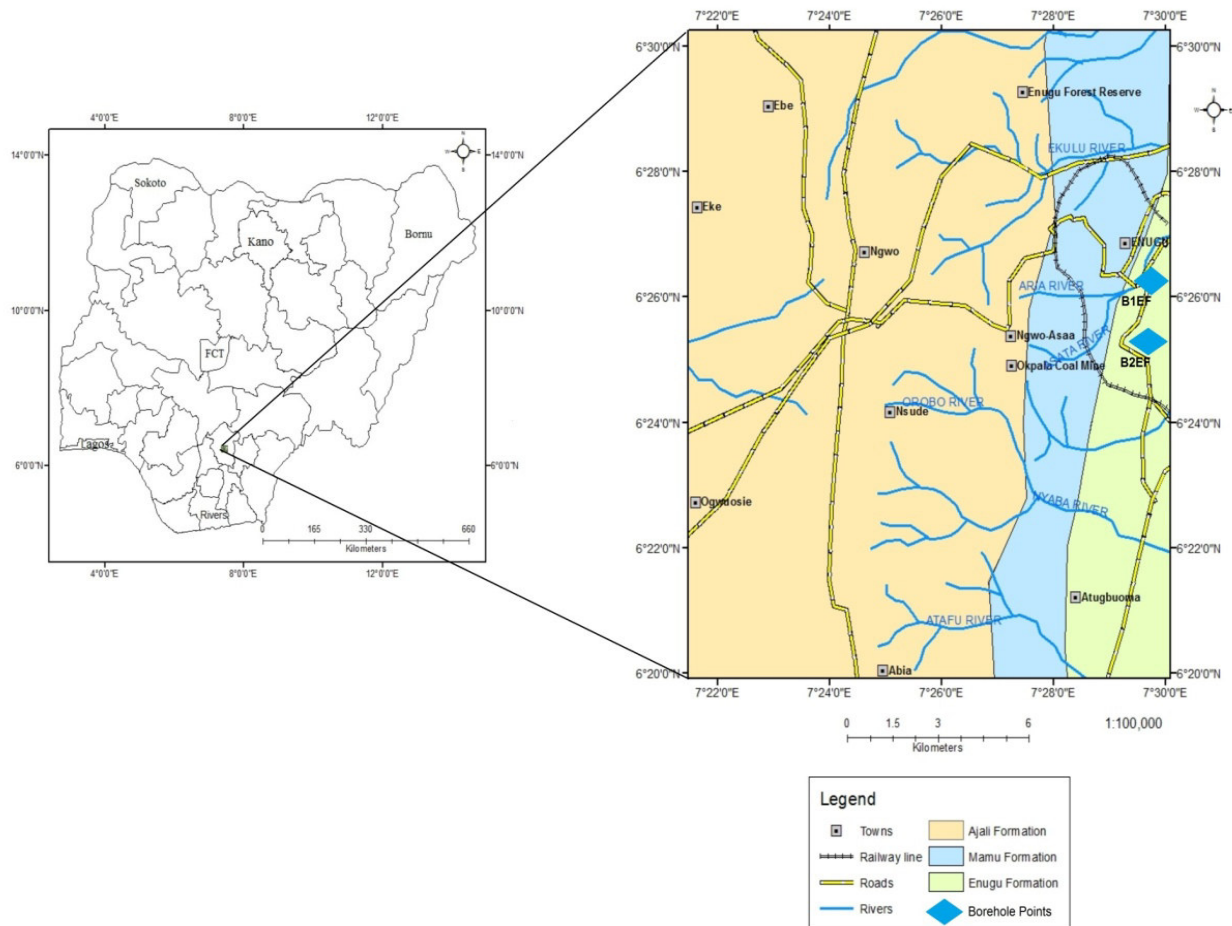


Fig. 1: Geologic map of the study area (modified from Geological Survey of Nigeria, 1957)

2. Regional Tectonics and Stratigraphic Setting

The tectonic origin of the Anambra Basin is intimately related to the development of the Benue Rift (Murat, 1972). The Benue Rift was installed as a failed arm of a tripartite rift system during the Cretaceous breakup of the Gondwana supercontinent and the opening of the South-Atlantic and Indian oceans in the Jurassic period (Nwajide and Reijers, 1996). The fault bounded Benue Trough is framed and floored by Precambrian granitic basement rocks of the continental crust (Aja and Igwe, 2015). The stratigraphic history of Southern Benue Trough is generally best described in terms of three tectono-sedimentary cycles as described by Murat (1972).

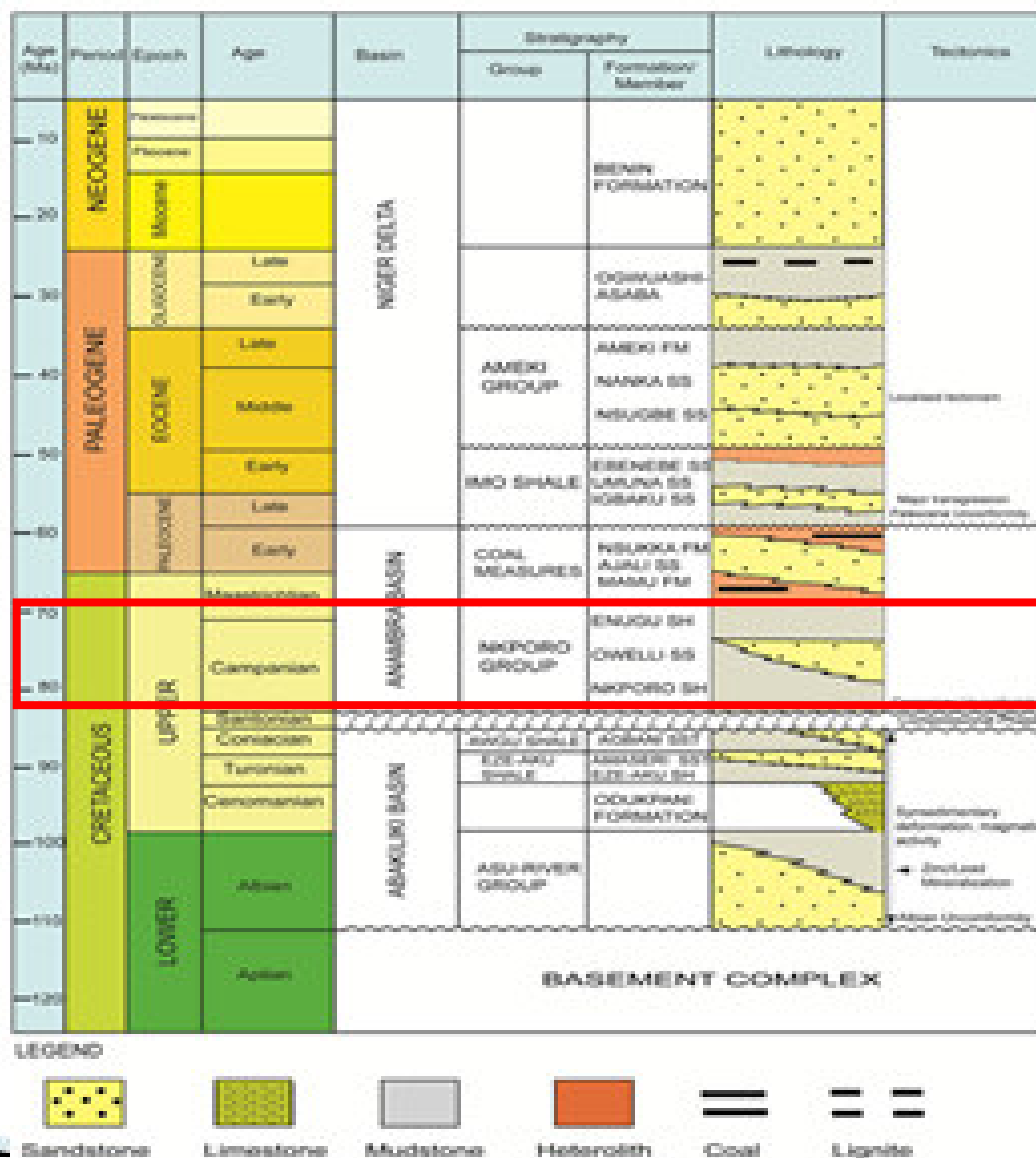
Sedimentation in the northwestern part of the subsided Abakaliki Anticlinorium is however, categorized by two sedimentary cycles. The first cycle which commenced in the lower Cretaceous was as a result of the post Aptian deposition of sediments in the trough. These sediments were subjected to the Santonian epeirogenic events (faulting, folding, and uplift) during the second cycle which led to the emergence of the Abakaliki Anticlinorium and the consequential basins flanking on both sides of the anticlinorium.

Synthesis of the works of several authors (Murat, 1972; Nwachukwu, 1972, Nwajide and Reijers, 1996; Mode and Onuoha, 2001) reveal that the Santonian epeirogenic movements characterized by compressional tectonics dating back to about 84 Ma was accompanied by wide spread magmatism, folding, faulting and uplifting of sediments deposited in the trough. This Santonian tectonics caused the Abakaliki area to become flexurally inverted to form Abakaliki Anticlinorium with simultaneous formation of depressions on its two flanks (displacement of depocentres by tectonic forces): the small Afikpo Syncline and the wider Anambra Basin to the southeast and northwest of the trough respectively.

The Anambra Basin is thus generally considered as an Upper Cretaceous descendant of Southern Benue Trough which was the site of deposition of sediments derived from the erosion of Abakaliki Anticlinorium (Akaegbobi and Schmitt, 1998, Akaegbobi and Boboye, 1999). Other provenance areas for texturally matured sediments which found its way into Anambra Basin include Southwestern Nigeria Craton, crystalline basement areas of the Oban Massif and Cameroon basement granites which had undergone prolonged chemical weathering (Hoque and Ezepeue, 1977, Nwajide and Reijers, 1996, Akaegbobi and Schmitt, 1998).

The stratigraphic sequence of the Anambra Basin (Table 1) started with the deposition of the marginal-shallow marine Nkporo Group which constitutes the basal and the oldest sediments of the lithostratigraphic unit of the Late Campanian-Maastrichtian transgressive successions of the Anambra Basin. Nkporo Group comprises of the Nkporo Shale and its lateral equivalents the Enugu Formation and Owelli Sandstone. The broad shallow sea gradually become shallower because of gradual subsidence, initiating a regressive phase during Maastrichtian that deposited deltaic forests and flood plain sediments of the Mamu Formation (Lower Coal Measure). The Mamu Formation is overlain by the continental beds of Ajali Sandstone (False bedded Sandstone) which was followed by a return to partially paralic conditions and the deposition of the Nsukka Formation.

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



3. Methodology

Two boreholes sunk at Ibagwa- Nike and Liberty Estate in Enugu Metropolis were logged from the top to the depth of 22 m and 18 m in boreholes 1 and 2 respectively. Samples of shales and heteroliths were collected at the intervals of 4 m depth in each of the boreholes and were analyzed for palynomorphs and foraminiferal contents. For palynological analysis, samples were prepared according to the standard methods of acid maceration, alkali treatment and staining. The palynomorphs recovered were studied under transmitted light microscopy. In order to determine the relative frequency of each species in each sample, counts were made and the total counts were taken since the grains were less than 200.

Foraminifera was washed out of the shale samples using the routine techniques of washing the sample with hydrogen peroxide (H₂O₂) and deionized water. The identification was carried out under the binocular

microscope.

The lithofacies, palynomorphs and foraminiferal data were employed in the interpretation of the depositional environment. Index palynomorphs and foraminifera formed bases for the dating of the sediments.

4. Results and Interpretation

4.1 Facies Description

Borehole 1

Four lithofacies identified from the base to the top of the borehole at Ibeagwa- Nike include; grayish fissile shale lithofacies, laminated grayish shale lithofacies, heterolithic (shale/fine sandstone) lithofacies and dark fissile shale lithofacies (Fig. 2). There is coarsening upward of succession from the basal shale lithofacies to the heterolithic lithofacies at the middle part of the borehole. The lithofacies and their fossil contents are described below;

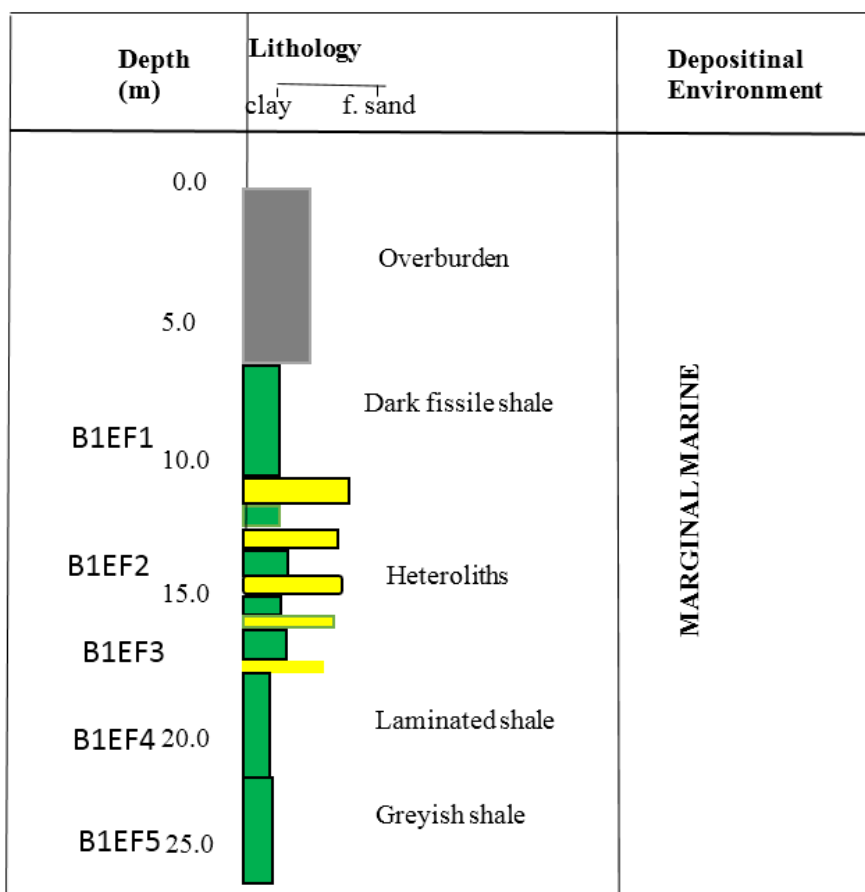


Fig. 2: The lithologic section across borehole one; B₁EF (Ibagwa-Nike)

Greyish Shale Lithofacies (A)

This is at the base between the intervals of 22 – 26 m depth and consists of very fissile grayish shale. Sample collected from the unit is labelled B₁EF₅. Palynomorphs recovered at this depth comprise of pollen and spores which show low abundance but moderate diversity. These include *Echitriporites trianguliformis*, *Zlavisporites blanensis*, *Rugulatisporites caperatus*, *Constructipollenites ineffectus*, *Longapertites sp.* and *Proteacidites longispinosum* (Table 2a). The only foraminifera at this depth is the *Ammotium nkalagun*.

The facies is interpreted to be deposited within coastal swamp to lagoonal setting.

Laminated Greyish Shale Lithofacies (B)

This lithofacies is overlain by the heterolithic lithofacies. It lies at a depth interval of about 18- 22 m and denoted as B₁EF₄. The lithofacies consists of laminated light grey shale with thin bands of whitish fine sandstone which constitute the laminae. *Ammobaculites* was the only genera recovered which also documented very low abundance and diversity.

The shale also recorded low abundance and diversity of pollen and spores assemblages notably; *Cyathidites australis*, *Echitriporite trianguliformis*, *Retitriporites sp.* among others. The depositional environment is interpreted as coastal swamp to lagoonal/estuarine setting.

Heterolithic lithofacies (C)

The lithofacies lies below the dark fissile shale facies at the depth interval of between 10 -18 m. The two samples

collected within the interval are labelled B₁EF₂ and B₁EF₃. It consists of laminated grayish shale interbedded with thin beds of whitish fine sandstone. The unit becomes sandier upwards (Fig. 2). Foraminifera recovered from the heteroliths comprises of only *Ammobaculites* which documented very low abundance and diversity of species. Two species of the genera recovered include *Ammobaculite bauchiensis* and *Ammobaculites amabensis* (Table 3).

Palynological analysis yielded very low abundance but high diversity of pollen and spores among which are *Cingulatisporites ornatus*, *Monocolpites marginatus*, *Echitriporites trianguliformis*, *Constructipollenites ineffectus*, *Rugulatisporites caperatus*, *Monocolpites annulatus*, *Psilatricolporites sp.*, *Auriculiidites sp.*, *Retimonocolpites sp.*, *Gleicheniidites sp.*, etc (Table 2 and Fig. 4). Coastal swamp and marshes to estuarine/lagoonal depositional setting is assigned to the sediment.

Dark Fissile Shale Lithofacies (D)

This lithofacies is at the topmost part of the borehole at a depth intervals of between 6 – 10 m and denoted by B₁EF₁. It consists of dark fissile shale. Palynomorphs recovered from the intervals are only pollen and spores of plants which documented low abundance but high diversity. *Proteacidites longispinosus*, *Acrostichum aureum*, *Psilatricolporites sp.*, *Polypodiaceoisporites sp.*, *Retidiporites magdalenensis*, *Gemmamonoporites sp.*, *Retitricolporites sp.*, *Ephedripites sp.*, *Foveolatus margaritae*, *Echitriporites trianguliformis*, *Cyathidites australis*, *Laevigatosporites sp.*, among others were recovered (Table 2a).

Coastal swamp depositional setting is assigned to the facies.

Borehole 2

The borehole is located at Liberty Estate, Enugu. The lithofacies of the borehole consist of the basal laminated shale lithofacies followed upwards by greyish shale lithofacies and dark fissile shale lithofacies at the topmost part of the borehole (Fig. 3).

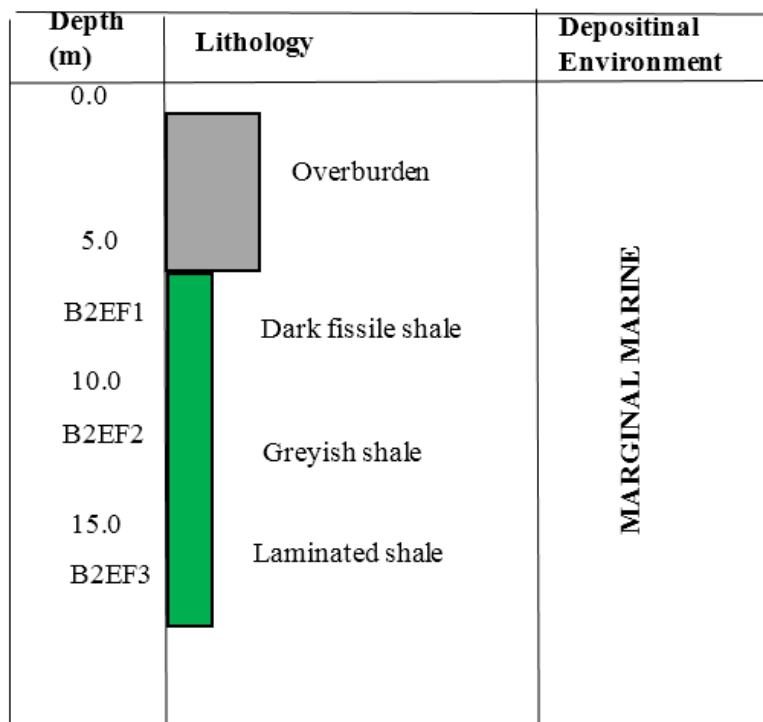


Fig. 3: The lithologic section across borehole two, B₂EF (Liberty Estate)

Greyish Shale Lithofacies (A)

This lithofacies underlies the dark fissile shale lithofacies and is found between the intervals of 10- 14 m depth. It is represented as B₂EF₂. Palynomorphs recovered from this lithofacies include: *Tricolporopollenites sp.*, *Echitriporites trianguliformis*, *Cingulatisporites ornatus*, *Rugulatisporites caperatus* and *Proteacidites longispinosus*. It documented high abundance of arenaceous benthic foraminifera which is predominated by the species of *Ammobaculites* (about 96%). They include *Ammobaculite bauchiensis*, *A. jessenses*, *A. bennensis* and *A. stratheanensis*. Other genera recorded are *Haplophragmoides sp.* and *Saccamina sp.* (Table 3). The depositional environment is interpreted to show range from coastal swamp to lagoonal./estuarine.

Laminated Shale Lithofacies (B)

This unit is at the base between the depth intervals of 14-18 m and denoted as B₂EF₃. It is made up of laminated shale which is grayish in color. The palynomorphs recovered from this unit consist of *Monosulcites sp.*, *Cingulatisporites ornatus*, *Cyathidites sp.*, *Psilatricolporites sp.*, *Laevigatosporites sp.* and *Foveotriteles*

margaritae. Micropaleontological analysis yielded low abundance of benthic foraminifera which are of arenaceous type. The assemblage is also predominated by species of *Ammobaculites*. However, *Haplophragmoides sp.* and *Trochamina sp.* were also recovered.

Coastal swamp to lagoonal/estuarine environments is assigned.

Dark Fissile Shale Lithofacies (D)

This lithofacies is between the intervals of 6 -10 m depth and at the topmost part of the borehole. Sample collected from the shale is labelled B₂EF₁. It consists of dark shale which is very fissile (Fig. 3). The palynomorphs recovered from the facies are only pollen and spores with low abundance. *Foveotrilletes margaritae*, *Cyathidites sp.*, *Milfordia sp.*, and *Echitriporites trianguliformis* were recovered along with the bacteria *Botryococcus braunii* (Table 2b),

There is general absence of foraminiferal assemblages. Coastal swamp depositional setting is assigned to the facies.

Table 2a: Chart of pollen and spore assemblages recovered from the borehole at Ibagwa-Nike (B₁EF)

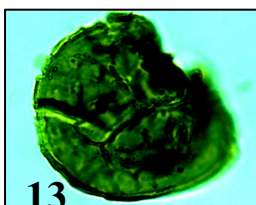
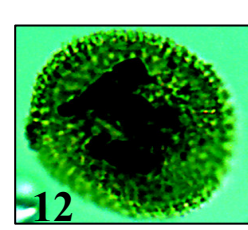
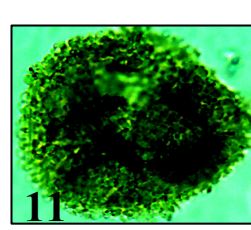
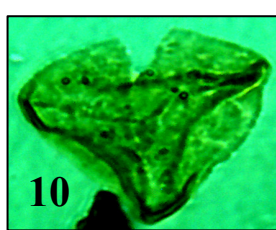
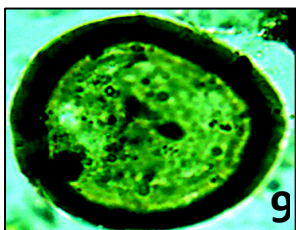
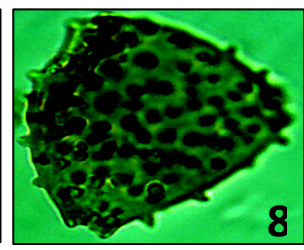
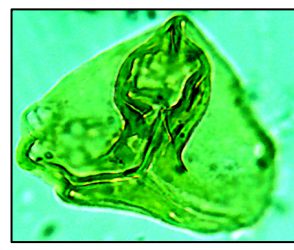
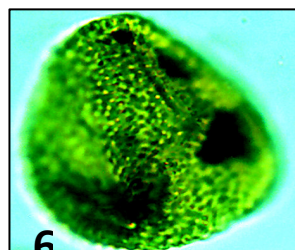
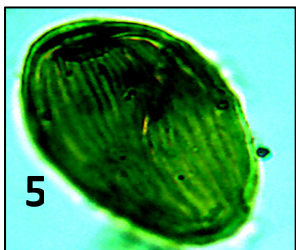
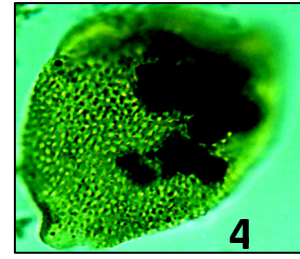
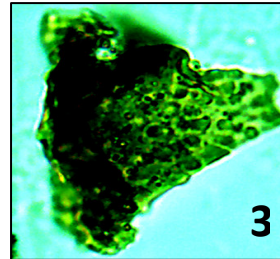
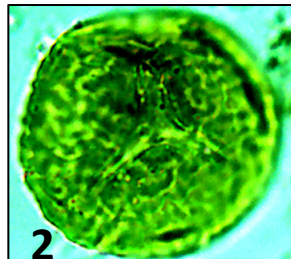
Depth (m)	Taxa	POLLENS										SPORES										SPECIES AMOUNT					
		<i>Constrictipollenites ineffectus</i>	<i>Droseridites senoniensis</i>	<i>Echitriporites trianguliformis</i>	<i>Inaperturate pollen</i>	<i>Longeperrites sp.</i>	<i>Monocolpites marginatus</i>	<i>Monoporites annulatus</i>	<i>Monosulcites sp.</i>	<i>Psitricolporites sp.</i>	<i>Psitricolporites sp.</i>	<i>Acrostichum aureum</i>	<i>Auriculidites sp.</i>	<i>Cingulatisporites ornatus</i>	<i>Cyathidites anstralis</i>	<i>Cyathidites sp.</i>	<i>Cyathidites minor</i>	<i>Gleichenidites sp.</i>	<i>Laevigatosporites sp.</i>	<i>Polyodiaceosporites sp.</i>	<i>Rugulatisporites caperatus</i>		<i>Retidiporites magdalenensis</i>	<i>Ferrucosporites sp.</i>	<i>Zlivisporites bicarvensis</i>		
22-26	B ₁ EF ₃	1		2		1				1																	8
18-22	B ₁ EF ₄			1										1	1					1							5
14-18	B ₁ EF ₃								1	1			3							1			1				7
10-14	B ₁ EF ₂	1	1	1	1		2			1		1	2			1				1							12
6-10	B ₁ EF ₁			1							2				3		1		1			1					11
	Total	2	1	5	1	1	2	1	1	3	2	2	1	5	1	3	1	1	3	3	3	1	1	1	1	1	43

Table 2b: Chart of palynomorph assemblages recovered from the borehole at Liberty Estate (B₂EF)

Depth (m)	Taxa	POLLEN						SPORES						DINOFLAGELLATES	SPECIES AMOUNT												
		<i>Echitriporites trianguliformis</i>	<i>Milfordia sp.</i>	<i>Monosulcites sp.</i>	<i>Proteacidites longispinus</i>	<i>Psitricolporites sp.</i>	<i>Tricolporopollenites sp.</i>	<i>Cyathidites sp.</i>	<i>Foveotrilletes margaritae</i>	<i>Cingulatisporites ornatus</i>	<i>Laevigatosporites sp.</i>	<i>Rugulatisporites caperatus</i>	<i>Leoisphaeridia sp.</i>														
14-18	B ₂ EF ₃			3		1			3	1	1	1															10
10-14	B ₂ EF ₂				1		1									1						1					5
6-10	B ₂ EF ₁	1	1						2	1																	5
	TOTAL	1	1	3	1	1	1		5	2	2	1	1		1						1						20

Table 3: The chart of Foraminifera recovered from the studied sections

Taxa Sample Name	<i>Ammobaculites bauchensis</i>	<i>Ammobaculites sp.</i>	<i>Ammobaculite amabensis</i>	Shell fragment	<i>Ammonium nkalagum</i>	<i>Ammobaculites jessensis</i>	<i>Haplophragmoides spp.</i>	<i>Ammobaculites strathearnensis</i>	<i>Saccammina sp.</i>	<i>Ammobaculites beuensis</i>	<i>Trochammina spp.</i>	SPECIES AMOUNT
B ₁ EF ₅	-	-	-	-	1	-	-	-	-	-	-	1
B ₁ EF ₄	-	1	-	1	-	-	-	-	-	-	-	2
B ₁ EF ₃	-	1	1	-	-	-	-	-	-	-	-	2
B ₁ EF ₂	1	-	-	-	-	-	-	-	-	-	-	1
B ₁ EF ₁	-	-	-	-	-	-	-	-	-	-	-	0
B ₂ EF ₃	8	-	-	-	-	1	2	-	-	-	1	12
B ₂ EF ₂	27	119	-	-	-	6	6	2	1	4	-	165
B ₂ EF ₁	-	-	-	-	-	-	-	-	-	-	-	0
TOTAL	36	121	1	1	1	7	8	2	1	4	1	183



1. *Echitriporites trianguliformis* Van Hoeken- Klinkenberg, 1964
2. *Rugulatisporites caperatus* Van Hoeken- Klinkenberg, 1964

3. *Proteacidites longispinosus*
4. *Retidiporites magdalenensis* Germeraad et al., 1968
5. *Ephedripites* sp.
6. *Foveotrilete margaritae* Germeraad et al., 1968
7. *Cyathidites* sp;
8. ?*Proteacidites longispinosus*
9. *Cingulatisporites ornatus* Van Hoeken- Klinkenberg, 1964
10. *Gleicheniidites*
11. ? *Gemmatripurites ogwashiensis*
12. *Constructipollenite ineffectus* Van Hoeken- Klinkenberg, 1964
13. *Zliviporites blanensis* Pacltova, 1961

Fig. 4: Pollen and spore assemblages from the Enugu Formation

4.2 Age of the Enugu Formation

The relative age assigned to the formation is based on the index palynomorphs (Table 4) as well as foraminifera recovered from the analyzed samples.

The index palynomorphs recovered include late Campanian markers such as;

1. *Auriculiidites* sp. (Okoro et al., 2012; Ola-Buraimo and Akaegbobi, 2013)
2. *Ephedripites* sp. (Adebayo et al., 2015)
3. *Monocolpites marginatus*, (Umeji, 2006; Okoro et al., 2012; Chiaghanam et al., 2013; Aja and Igwe, 2015)
4. *Milfordia* sp: (Ola-Buraimo and Akaegbobi, 2013; Adebayo et al., 2015)
5. *Rugulatisporites caperatus* (Okoro et al., 2012)

The early Maastrichtian markers are as follow;

1. *Cingulatisporites ornatus*, (Soronnadi-Ononiwu et al., 2012; Chiaghanam et al., 2013; Ola-Buraimo and Akaegbobi, 2013)
2. *Constructipollenites ineffectus* (Soronnadi-Ononiwu et al., 2012; Chiaghanam et al., 2013)
3. *Cyathidites minor* (Nwojiji et al., 2012)
4. *Echitrisporites triaguliformis*, (Soronnadi-Ononiwu et al., 2012)
5. *Foveotriletes marginatus* (Okoro et al., 2012),
6. *Laevigatosporites* sp. (Lawal and Moullade, 1986; Umeji, 2006; Chiaghanam et al., 2013; Onuigbo et al., 2012a; Okoro et al., 2012; Aja and Igwe, 2015)
7. *Longapertites marginatus* (Lawal and Moullade, 1986; Umeji, 2006; Okoro et al., 2012; Chiaghanam et al., 2013; Aja and Igwe, 2015)
8. *Retidiporites magdalenensis*, (Soronnadi-Ononiwu et al.; 2012; Chiaghanam et al., 2013; Ola-Buraimo and Akaegbobi, 2013)

Late Campanian- Early Maastrichtian markers

1. *Constructipollenites ineffectus*, (Nwojiji et al., 2013; Aja and Igwe, 2015)
2. *Gleicheniidites* sp. (Aja and Igwe, 2015)
3. *Laevigatosporites*, (Onuigbo et al., 2012a)
4. *Longapertites* sp. (Aja and Igwe, 2015)
5. *Monocolpites marginatus* (Nwojiji et al., 2013; Aja and Igwe, 2015)
6. *Proteacidites longispinosus*, (Onuigbo et al., 2012a; Aja and Igwe, 2015)
7. *Psilatricolporites* sp. (Onuigbo et al., 2012a)
8. *Retitricolpites* sp. (Onuigbo et al., 2012)
9. *Zlivisporites blanensis* (Onuigbo et al., 2012a; Okoro et al., 2012),

Index Foraminifera

The foraminiferal assemblages consisting of *Ammobaculites* sp, *Ammotium nkalagum*, *Saccamina* spp., *Trochammina* sp. and *Haplophragmoides* sp. have been assigned Late Campanian to Early Maastrichtian age by Peters, (1979), Omoboriowo et al., (2012) and Aja and Igwe, (2015).

The presence of the above recovered index palynomorphs and foraminifera have been used to propose Late Campanian – Early Maastrichtian for the Enugu Formation (Table 4).

Table 4: The chart of age range of the palynomorphs

AGE	TAXA
MAASTRICHTIAN	<i>Auriculidites</i> sp.
	<i>Ephepites</i> sp.
	<i>Leiosphaeridia</i> sp.
	<i>Monocolpites marginatus</i>
	<i>Milfordia</i> sp.
	<i>Rugulatisporites caperatus</i>
	<i>Cingulatisporites ornatus</i>
	<i>Cyathidites minor</i>
	<i>Echtrispites trianguliformis</i>
	<i>Retidiporites magdalensis</i>
	<i>Foveotriletes marginatus</i>
	<i>Laevigatosporites</i> sp.
	<i>Longaperites marginatus</i>
	<i>Gleichenidites</i> sp.
<i>Constructipollenites ineffectus</i>	
CAMPANIAN	<i>Proteacidites longispinosus</i>
	<i>Psilatricolporites</i> sp.
	<i>Retitricolpites</i> sp.
	<i>Zitvisporis blauenensis</i>

5. Discussion

5.1 Depositional Environment

The greyish shale lithofacies at the basal part of borehole 1 (22- 26 m depth interval) documented very low abundance of single species of the genera *Ammotium*. *Ammotium* is referred to as a genera typical of estuarine environment (Scott et al., 2004). It is an infauna deposit feeder restricted to shallow brackish water of tidal marshes, brackish lagoons and estuaries and enclosed brackish shelf sea (Murray, 1991). The high abundance and diversity of the arenaceous benthic forms which include *Ammobaculites* (constitutes almost 96% of the genera present), *Haplophragmoides* and *Saccamina* recorded by this lithofacies in borehole 2 at 10- 14 m depth intervals are also suggestive of estuarine condition (Aseez et al., 1974). High diversity and abundance of arenaceous species occur in estuaries in region of high nutrient availability due to organic matter input from the terrestrial environment. This is evidenced from the occurrence of fungal spores, *Botryococcus braunii*, and *Milfordia* sp. Marginal marine are usually areas of high organic productivity and relatively high environmental variability.

The thin sand laminae within the laminated shale lithofacies at the depth intervals of 18- 22 m in borehole one indicate shallowing/progradation of the sea. The low abundance and diversity of *Ammobaculites* as well as trilete spores and angiosperm pollen recorded by the lithofacies is also attributed to lagoonal/estuarine condition and the development of fresh water swamp and marshes as the sea progrades. The association of only arenaceous foraminifera notably *Ammobaculites*, *Haplophragmoides* and *Trochamina* seen in the lithofacies in borehole 2 at 14- 18 m depth interval suggests marginal marine condition (estuaries and hyposaline lagoons) characterized by low temperature, rapid sedimentation and stagnant bottom conditions (Nagy et al., 1988). Such association is also attributed to restricted low oxygen bottom water condition (Gebhardt, 1988; Scott et al., 2004; Nwojiji et al., 2014). This could be as a result of increasing input of organic matter from the fluvial system. Arenaceous foraminifera tolerate conditions of high fresh water flux (high sediment and organic matter flux) and associated lowered oxygen availability which are characteristics of marginal marine environments. The low diversity and the dominance of the three genera also confirm marginal marine condition. The co- occurrence of the three arenaceous benthic foraminifera with the pteridophytic spores and angiosperm pollen suggest a marginal marine setting that ranges from coastal swamp and marshes to estuaries/lagoonal settings.

The heterolithic lithofacies at the depth interval of 10- 18 m in borehole 1, consisting of shale interbedded with thin beds of fine sandstone which becomes sandier upwards suggests paralic condition. The coarsening upwards of succession exhibited by the lithofacies from the basal greyish shale lithofacies to the laminated shale lithofacies and the overlying heterolithic lithofacies also suggests shallowing of the sea. The occurrence of only *Ammobaculites* which exhibit low abundance and diversity may possibly be attributed to stressful condition due

to low water salinity and rapid sedimentation with increased influx of sand and organic matter from the continental environment. It has been noted that *Ammobaculites* tolerate water salinity variations from 0.5‰ to 23‰ (Aseez et al., 1974) and are well developed in brackish water with moderate temperature such as coastal plain estuaries or lagoons (Scott et al., 2004) and tolerate low oxygen level. It however, show extreme dominance in estuaries with salinity range of 1- 15‰ (Ellison and Nichols, 1970; Ellison, 1972). The co-occurrence of the *Ammobaculite* sp. with the Pteridophytic spores and angiosperm pollen in this lithofacies is suggestive of environmental setting that ranges from fresh water swamp and marshes to coastal plain estuaries/lagoons.

The dark fissile shale lithofacies at the top of the two boreholes exhibit the same characteristics of general absence of foraminifera. Palynomorphs comprising of pteridophytic spores (*Cyathidites minor*, *Foveotrite margaritae* and *laevigatosporites*) together with angiosperm dominated by tricolporate (*Psilatricolporites* sp., and *Retitricolporites* sp.), diporate (*Retidiporite magdalenensis*) and monocolpate (*Echitriporite trianguliformis*) pollen group are suggestive of occurrence in fresh water swamp and marshes.

The dominance of the terrestrial pollen and spores over the marine species and general absence of the marine species documented by the lithofacies are indications of the withdrawal of the sea. The terrigenous species commonly increase during regressions.

6. Conclusion

Enugu Formation from the study of the two boreholes was deposited in a marginal marine setting which ranges from coastal swamp and marshes to estuarine/lagoonal. Lithofacies analysis of borehole 1 shows a coarsening upwards of lithofacies succession from the basal shale lithofacies to sand laminated shale lithofacies and heterolithic lithofacies. The succession is overlain by a shale lithofacies that consists entirely of terrestrially derived pollen and spores and generally lack marine species. This is an attribute of a prograding sea.

Late Campanian to early Maastrichtian age is proposed for the sediments based on the index palynomorphs and foraminifera recovered.

References

- Adebayo, O.F., Ola- Buramimo, A.O. Madukwu, H.Y., and Aturamu, A.O., 2015. Palynological and Sequence Stratigraphy Characterization of the Early-Late Campanian Nkporo Shale, Orekepeke-Imiegba area, Anambra Basin. *European Journal of Basic and Applied Sciences*, vol. 2, no1, pp. 1- 17
- Aja, A.U. and Igwe, E.O., 2015. Aspects of Biostratigraphic Analysis of Sediments of the Late Cretaceous Nkporo Formation in Amangwu-Edda, Afikpo Sub-Basin, Southeastern Nigeria, *International Journal of Life Science and Engineering*, vol. 1, no. 1, pp. 7-14
- Akaegbobi, I.M., and Schmitt, M., 1998. Organic Facies, Hydrocarbon Source Potential and Reconstruction of the Depositional Paleoenvironment of the Campano- Maastrichtian Nkporo Shale in the Cretaceous Anambra Basin. *NAPE Bulletin*, vol. 13, pp. 1- 19
- Akaegbobi, I.M, and Boboye, A.O., 1999. Textural Structural Features and Microssil Assemblage Relationship as a delineating Criteria for the Stratigraphic Boundary between Mamu Formation and Nkporo Shale within the Anambra Basin, Nigeria. *NAPE Bulletin*, vol. 14, no. 2, pp. 193- 207
- Asseez, L.O., Fayose, E.O., and Omatsola, M.E., 1974. Ecology of the Ogun River estuary, Nigeria. *Paleogeography, Paleoclimatology, Paleocology*, vol. 16, pp. 243- 260
- Chiaghanam, O.I., Nwozor, K.K., Chiadikobi, C., Omoboriowo, A.O., Soronadi- Ononiwu, C.G, Onuba, L.N and Ofoma, A.E., 2013. Lithofacies, Palynology and Paleoenvironmental Study of Early Campanian to Mid-Maastrichtian Deposits of Udi and Environs in the Anambra Basin, South Eastern Nigeria”, *International Journal of Science and Technology*, vol. 2, no. 6, pp. 453-470
- Ellison, R.L., 1972. *Ammobaculites*, foraminiferal proprietor of Chesapeake Bay estuaries. *Geological Society of America Memoir*, vol. 133, pp. 131- 151, 1972,
- Ellison R.L., and Nichols, M.M., 1970. Estuarine foraminifera from the Rappahannock River, Virginia: Cushman Found. *Foraminiferal Research*, 21, 1- 17
- Gebhardt, H., 1998. Paleocology and paleogeographic significance, *Journal of Foraminiferal Research*, vol. 28, pp. 76- 89
- Hoque, M. and Ezepue, M.C., 1977. Petrology and Paleography of the Ajali Sandstone. *Journal of Sedimentary Petrology*, 46, 579- 594
- Lawal, O., and Moullade, M., 1986. Palynology and biostratigraphy of Cretaceous sediments in the Upper 1 Basin, N.E Nigeria. *Revue De Micropal*, vol. 9, no. 1, pp. 6
- Mode, A.W., and Onuoha, K.M., 2001. Organic Matter Evaluation of the Nkporo Shale, Anambra Basin, from wireline logs. *Global Journal of Applied Science*, vol. 7, pp. 103- 107
- Murat, R.C., 1972. Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in southern Nigeria. (Ed, A.J. Whiteman), *African Geology*, University of Ibadan press, Nigeria, pp. 251- 266

- Murray, J.W., 1991. Ecology and paleoecology of benthic foraminifera. Longman Scientific and Technical, Harlow, pp. 297
- Nagy, J., Lofaldli, M., and Backstrom, S.A., 1988. Aspects of foraminiferal distribution and depositional conditions in middle Jurassic to Early Cretaceous shale in Eastern Spitspergen. In: F. Rogl and F.M. Gradstein (eds.), Proceedings of the second workshop on agglutinated foraminifera, Geol. B.A, vol. 41, pp. 287- 300
- Nwachukwu, S.O., 1972. The Tectonic Evolution of the Southern portion of the Benue Trough, Nigeria. Geology Magazine, vol. 109, 411-419
- Nwajide, C.S., 2005. Anambra Basin of Nigeria: synoptic basin analysis as a basis for evaluating its hydrocarbon prospectivity. In: Okogbue, C.O. ed., Hydrocarbon Basin. (Ed, Reijers, T.J.A. Selected chapters on Geology), SPDC., pp. 133- 147
- Nwajide, C.S., 2013. Geology of Nigeria's sedimentary basins. CSS Bookshop ltd, Lagos, Nigeria, pp. 311- 326, 2013
- Nwajide, C.S., and Reijers, T.J.A., 1996. The Geology of the Southern Anambra Basin. In: T.J.A. Reijers ed., Selected chapter in Geology, SPDC publication, pp. 133-148
- Nwojiji, C.N., Osterloff, P., Okoro, A.U., and Ndulue, G., 2014. Foraminiferal Stratigraphy and Paleocological Interpretation of Sediments Penetrated by Kolmani River -1 Well, Gongola Basin, Nigeria. Journal of Geosciences and Geomatics, vol. 2, no. 3, pp. 85-93,
- Ola-Buraimo, A.O., and Akaegbobi, I.M., 2013. Palynological and Paleoenvironmental Investigation of the Campanian-Lowermost Maastrichtian Asata/Nkporo Shale in the Anambra Basin, Southeastern Nigeria. Journal of Applied Science & Technology, vol. 3, no. 4, pp. 898-915
- Okoro, A.U., Nwojiji, C.N., Osegbo, F.N., and Ndubueze, V.O., 2012. Palynological analysis of late Cretaceous sediments of the Nkporo Formation in the Afikpo sub-basin, Southeastern Nigeria. Asian Transactions on Science & Technology, vol. 2, no. 3, pp. 35-46
- Omoboriowo, A.O., Soronadi-Ononiwu, C.G., Awodogan, O.L., 2012. Biostratigraphy of a Section along Port Harcourt to Enugu Express Way, Exposed at Agbogugu, Anambra Basin, Nigeria. Advances in Applied Science Research, vol. 3, no. 1, pp. 384-392
- Onuigbo, E.N., Okoro, A.U., and Etu- Efeotor, J.O., 1012a. Lithofacies, Palynology and Facies Association: Keys to Paleogeographical Interpretation of the Enugu and the Mamu Formations of Southeastern Nigeria", Journal of Environment and Earth Science, vol. 2, no. 5, pp. 1-23,
- Onuigbo, E.N., Etu-Efeotor, J.O., and Okoro, A.U., 1012b. Palynology, paleoenvironment and sequence stratigraphy of the Campanian- Maastrichtian deposits in the Anambra Basin, South eastern Nigeria. European Journal of Scientific Research, vol. 78, no. 3, pp. 333-348
- Onuigbo, E.N., and A.U., Okoro, A.U., 2013. Ichnology of the Enugu Formation: Implications for Campanian sea movements in southeastern Nigeria. Asian Journal of Earth Sciences, vol. 7, no. 2, pp. 40- 50
- Onuigbo, E.N., Okoro, A.U., Etu- Efeotor, J.O., Akpunonu, E.O., and Okeke, H.C., 2015. Paleocology of Enugu and Mamu Formations in the Anambra Basin, southeastern Nigeria. Advances in Applied Science Research, vol. 6, no. 4, pp. 23- 39
- Petters. S.W., 1979. Paralic Arenaceous Foraminifera from the Upper Cretaceous of the Benue Trough, Nigeria. Acta Paleont. Polonica, vol. 24, no. 4, pp. 451-471
- Reyment, R.A., 1965. Aspects of the geology of Nigeria. Ibadan University Press, Nigeria, pp. 36- 43
- Short, K.C., and A.J. Stauble, A.J., Outline of geology of Niger Delta. AAPG Bull., vol. 51, pp. 761- 779
- Scott, D.B., Modioli, F.S., and Schafer, C.T., 2004. Monitoring in coastal environments using foraminifera and Thecamoebian indicators", Cambridge University Press, UK, pp. 173
- Soronadi- Ononiwu, C.G., Omoboriowo, A.O., and Chukwujekwe, N.V., 2012. Palynological and paleoenvironmental studies of the Mamu Formation, Enugu Area, Anambra Basin, Nigeria International Journal of Pure and Applied Science and Technology, vol. 10, no. 2, pp. 1-11
- Umeji, O.P., 2006. Palynological evidence for the Turonian/Campanian Boundary between the Abakaliki and Anambra Basin", Journal of Mining and Geology, vol. 42, no. 2, pp. 141-155