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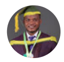
6 authors, including:


Kingsley Nwozor
University of Aberdeen


Chinedu Ibe
University of Nigeria


Kingsley Chiadikobi
Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria


Emmanuel Aniwetalu
Godfrey Okoye University

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PETROGRAPHIC AND PALYNOLOGICAL ANALYSES OF THE EZE-AKU GROUP IN AKPOHA AND ENVIRONS, SOUTHERN BENUE TROUGH, NIGERIA

O. N. Ikegwuonu[1], O. I. Chiaghanam[2], K. K. Nwozor[2], C. U. Ibe[3], K. C. Chiadikobi[2], and E. U. Aniwetalu[1]*

[1] Department of Physical & Geosciences, Godfrey Okoye University, Enugu, Nigeria
[2] Department of Geology, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria
[3] Departmentof Geology, University of Nigeria, Nsukka, Nigeria

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Abstract
Cretaceous sediments outcropped extensively in the Abakaliki sedimentary basin. Petrographic and palynological analyses of selected outcrop samples from Akpoha and environs were carried out, using the conventional method of acid macerationin order to re-establish the depositional history of the sediments in the area and their provenance, establish the age of sediments and reconstruct their paleoenvironments of deposition, and evaluate the hydrocarbon source rock potential. Lithological units encountered include sandstones, shales, mudstones, and limestone. Result from sandstone petrography shows that most of the sandstones in the area were mostly derived from the metamorphic /igneous basement sources, and were deposited in a very low energy environments where sediments are rapidly deposited with little reworking. Palynological investigation revealed a Late Cenomanian - Middle Turonian age for the sediments, with the following index sporomorph assemblage: *Cretacaeiporitesscabratus, Ephedripitesmulticostatus, Cretacaeiporitesmulleri, Monosulcites* sp., *Tricolporopollenites* sp. and *Tricolpites* sp. Palynomorphs of environmental value indicated that the sediments in the area were mostly deposited under openmarine condition, with minor terrigenous input. Kerogen examination features mostly the amorphous organic matter (AOM), followed by opaque debris, giving rise to type 11 / type 111 kerogen, which are generally over mature but have potential to generate oil or gas.

***Keywords**: Cretaceous; Palynomorph; Kerogen; Petrography; Paleoenvironment.*

1. Introduction

In an attempt to explore petroleum in the Anambra basin and Afikpo synclinorium by the shell D' Archy Petroleum Development Company of Nigeria (now known as Shell BP), which started in the year 1938, a lot of geological and geophysical surveys of southern Nigeria have been carried out. This led to the drilling of many test holes/wells which provided important information about the stratigraphy of southern Nigeria. Many previous research works have been undertaken on the regional scale within the Afikpo sub-basin. Simpson [1] was the first to describe the Eze-Aku Formation as comprised of hard grey to black shale, deposited in a shallow marine environment. Barber [2], Reyment [3], Murat [4], Nwachukwu [5] and Kogbe [6], established some paleontological evidence on the Turonian Eze-Aku Formation, indicated to be well developed and enriched by ammonites and other fauna such as ammonites and *Inoceramus* spp.

Reyment [3] described the Amasiri Sandstone facies exposed around Nkalagu market as the lateral equivalent of the Eze-Aku Formation and held that they might not require a separate status. He further remarked that the formation is mildly folded and the fossils are mainly Vascoceratids, pelecypods, gastropods, echinoids, fish-teeth decapod fragments, and plant fragments. Ofodile [7] established the existence of an unconformity between the Turonian Eze-

Aku Formation and the overlying Campano-Maastrichtian Nkporo Group in southern Nigeria. Petters [8] believed that the Eze-Aku and Awgu Formations are equivalent because they are indistinguishable in the field both in lithology and fauna. In the eastern flank of Abakaliki Anticlinorium, Banerjee [9-10] and Amajor [11] identified and described similar lithofacies, which were established on the western flank of the same Anticlinorium by Umeji, [12], who subdivided the Eze-Aku unit into several lithofacies, which include shales, sandstones, siltstones, and limestones. Umeji [12-13] described the ammonite paleoecology, sub-tidal shelf sedimentation and trace fossils from the Eze-Aku Formation, and assigned a shallow marine environment of deposition. She posited that at Nkalagu the Eze-Aku Group consists of a sequence of cross-bedded, medium-grained sandstone, grey bioturbated calcite-cemented siltstone, laminated dark shale, and bioclastic limestone. On the basis of palynomorphs, Ojoh [14] identified and established Cenomanian facies in Ezillo and Ohana areas as Ezillo Formation. Umeji [15] recorded the palynological evidence for the Turonian/ Campanian boundary between the Abakaliki and Anambra basin, as exposed at Leru. She remarked that the Turonian/Campanian boundary, within which reworked Turonian palynomorphs are mixed with the indigenous Campanian flora, marking the sequence boundary, and in the absence of the Coniacian-Santonian Awgu Shale, the Campanian Nkporo Shale oversteps onto the Turonian Eze-Aku Shale. *Igwe et al.*, [16] assigned a Late Cenomanian to Turonian age to the Eze-Aku Shale facies based on the planktonic foraminiferal assemblages of *Hedbergellids* and *Heterohellicids, Whitenella* and *Archeoglobérina blowi.* Igwe and Okoro [17] noted that there is underlying controversy over the status of Amasiri Sandstone (Eze-Aku Group) and the problem of misnaming of its type locality. They identified two component formations for the Eze-Aku Group in the basin: the late Cenomanian-early Turonian Eze-Aku Shale (transgressive phase) and the middle-late Turonian Amasiri Sandstone (regressive phase). The present study attempts to re-establish the depositional history of the sediments in the area and their provenance, establish the age of sediments and reconstruct their paleoenvironments of deposition, and evaluate the hydrocarbon source rock potential and the degree of thermal maturation, using the organic-walled microfossils.

2. Location and physiography

The study area is located along the Abakaliki-Afikpo Road, about 46 kilometer and 13 kilometers respectively, in Afikpo North local Government Area of Ebonyi State, in the southeastern Nigeria (Fig. 1). It lies between latitudes $5^0 56^1$ N and $6^0 00^1$ N and longitudes $7^0 56^1$ E and $8^0 00^1$ E, with an area extent of about 86 sqkm (Fig. 2 and Fig. 3). The study area is bounded on the north by Afikpo, on the south by Ndibe and on the west by Amasiri town. It covers areas such as Amata and Ekerekunta. The area has a road network and footpaths. The main road divides the area into roughly two equal parts. The major access route into the area is Abakaliki road and the Afikpo-Okigwe road (Fig. 3). The area is easily accessible through footpaths that start from the main road into the hinterland. Due to sparse vegetation, cultivated farmlands traversing the area are not difficult except in the swampy shaly terrains. The study area falls within the zone of 27^o-30^o of annual temperature [18]. The climate of this area is classified as a tropical wet and dry savannah climate.

3. Regional geologic setting and stratigraphy

The study area lies within the Afikpo Syncline, a depression formed in the eastern flank of the southeastern edge of the Benue Trough, as a result of Santonian tectonism and uplift of the Abakaliki Anticlinorium [19]) (Fig. 4). The area study is part of the Benue trough which is an elongated fault-bounded depression lying in the eastern and north-eastern direction containing deformed Cretaceous as well as the early Cenozoic sedimentary and volcanic rocks. Tectonism in southern Nigeria started in the early Cretaceous period, with the separation of Africa from South America and consequently the opening up of the Atlantic [5,20] (Fig. 4). Murat [4] noted the three major phases that gave rise to the formation of Abakaliki-Benue Trough, Anambra Basin and Niger Delta Basin (Fig. 4). The first phase occurred during Albian times and was characterized by trending faults resulting in the formation of the rift like Abakaliki-Benue Trough. The second phase commenced from upper Santonian to middle Eocene time. At the end of the Eocene, the third phase occurred given rise to the formation of Niger Delta Basin.

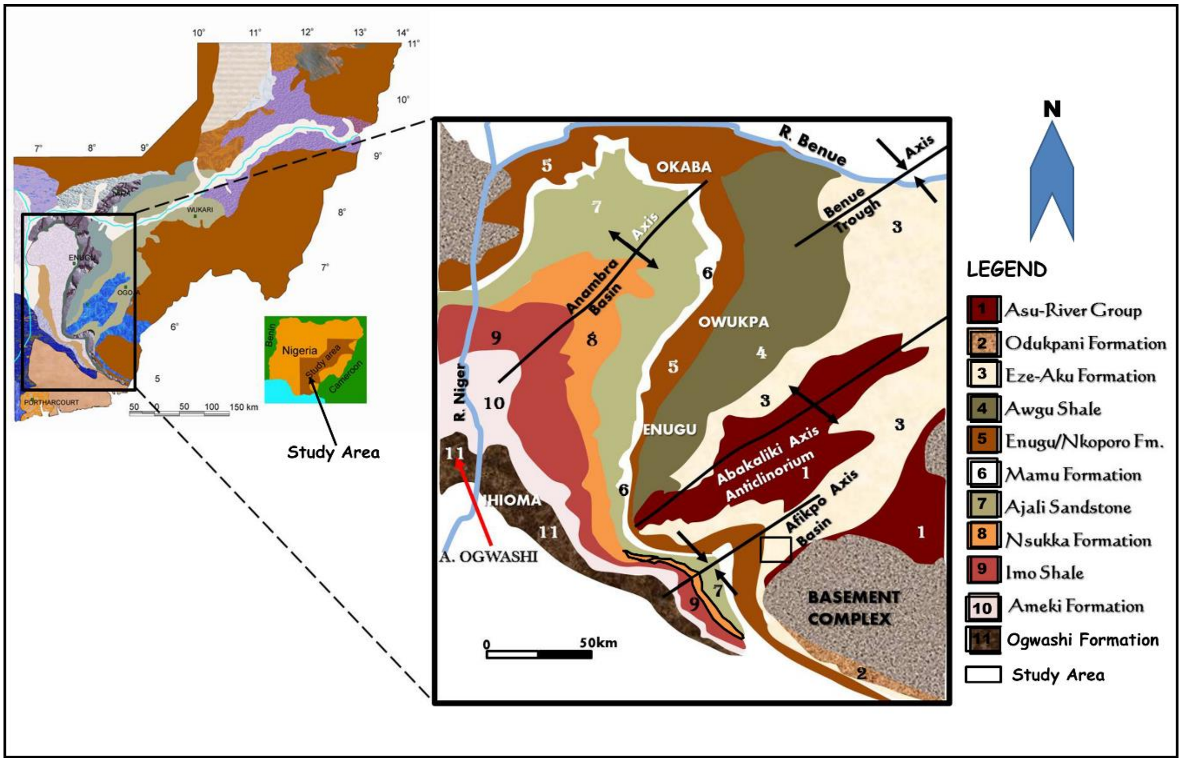

Fig. 1. Geological map southern Benue Trough showing location of study area (*modified from Ojo et al.* [38])

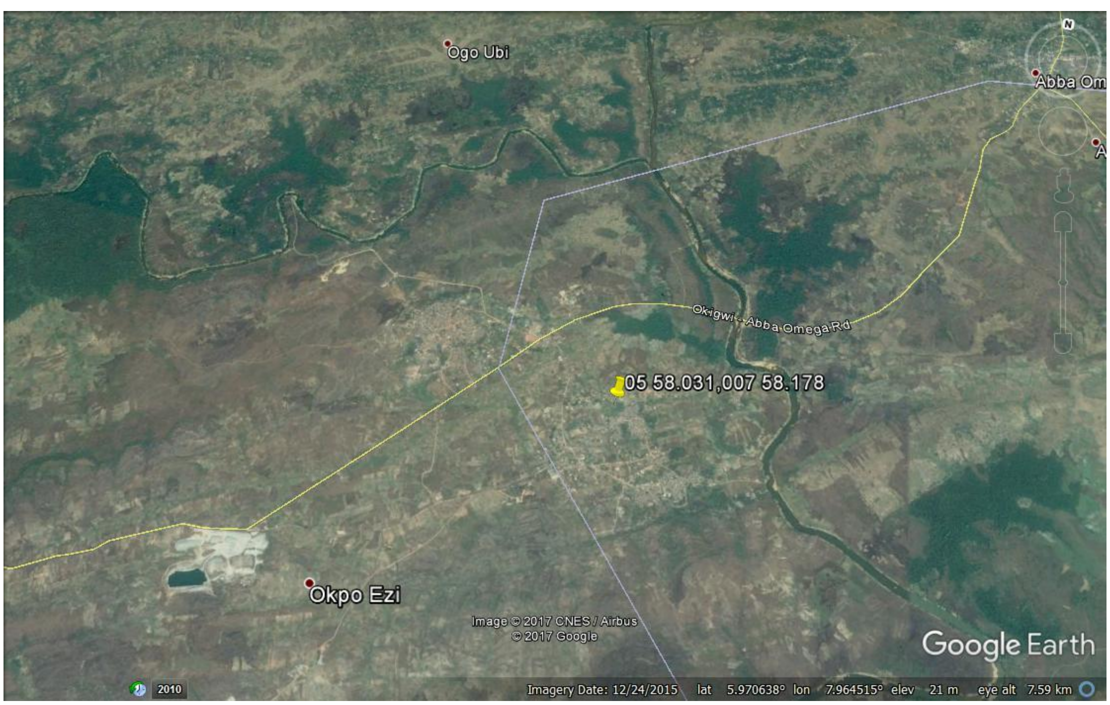

Fig. 2. Satellite imagery map showing the locations and access routes in the study area

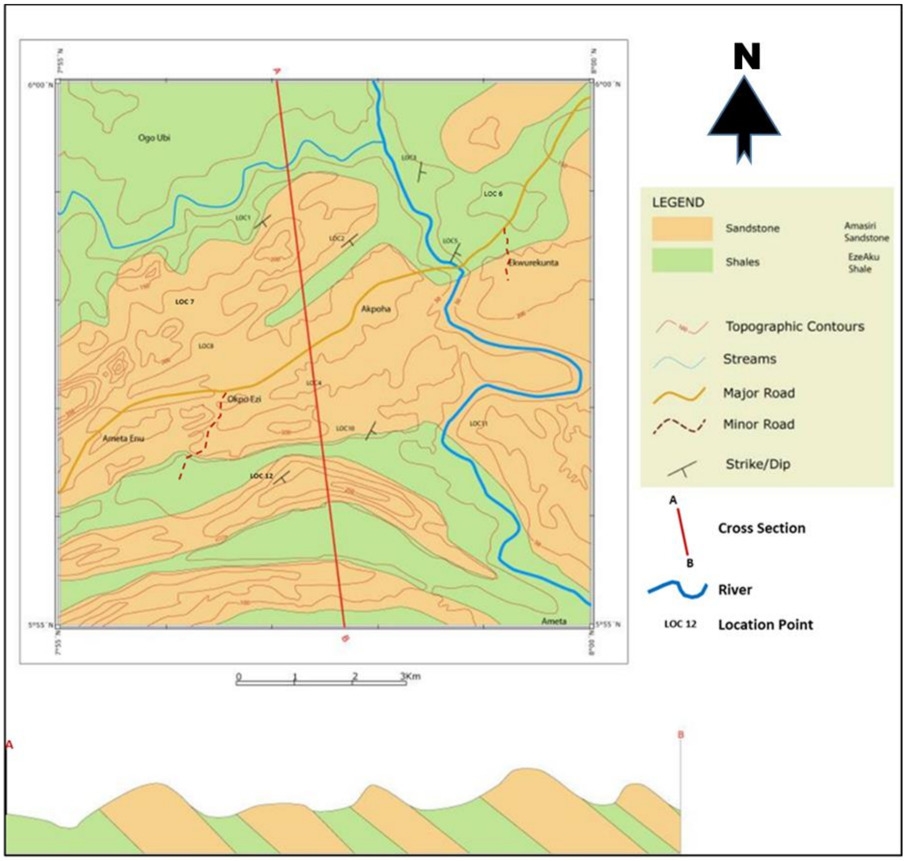

Fig. 3. Geologic map showing the cross-section of the study area

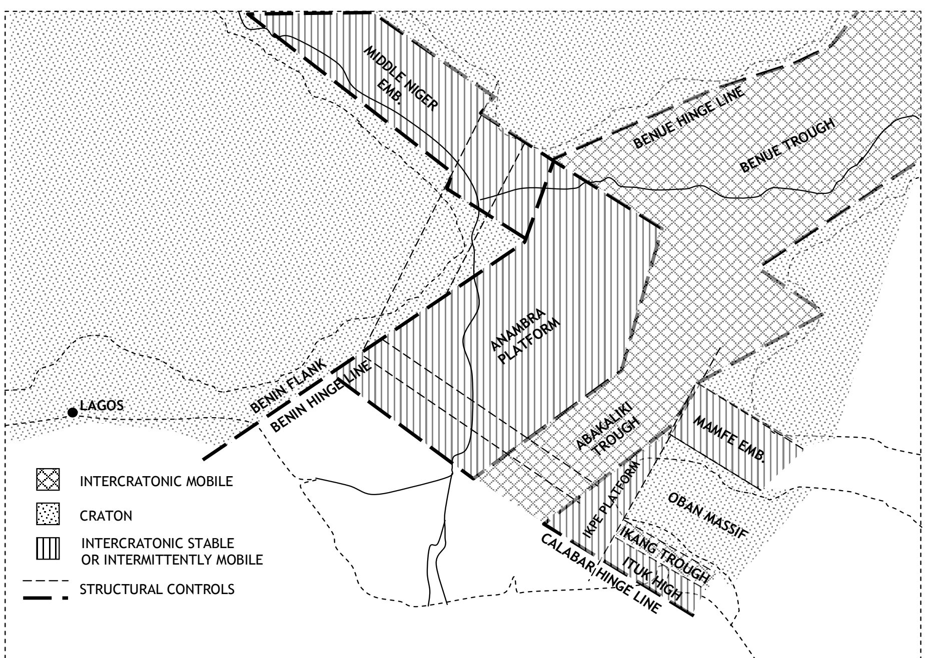

Fig. 4. Albian-Santonian Tectonic Framework for the Benue Trough (*after Murat* [19])

The sedimentation and stratigraphy of the southern Nigerian sedimentary were controlled by four transgressive-regressive cycles, which resulted from the eustatic and isostatic rise and fall of sea levels and global tectonics (Table 1). The oldest sediments belong to the Upper Cretaceous during Albian period represented by the deposits of the Asu River Group. The Asu River Group unconformably overlies the basement rock. The Asu River Group consists of shale, sandstone and limestone beds, with a maximum thickness of about 6,000 m containing ammonites. During the Cenomanian, the regressing Sea resulted in the deposition of Odukpani Group in the Calabar Flank and Agala Formation in the Abakaiki Basin. This was followed by an extensive Turonian marine transgression, which deposited the Eze-Aku Shale, Amasiri Sandstone and Nkalagu limestone. The Turonian transgression extended into the Coniacian, with the deposition of Awgu Group in the western part of the Abakaliki Anticlinorium, whereas in part, the resultant Santonian tectonic event truncated the deposition Awgu Group, given rise to an Angular unconformity. The Uplift of the Abakaliki Anticlinorium gave rise to the contemporaneous subsidence of Anambra Basin and Afikpo sub-basin to the West and East of the Anticlinorium respectively (Table 1).

Table 1. Regional stratigraphy of southern Nigerian sedimentary basins. (*after Murat* [39])

Age	Group/Formation	Sedimentary cycle
Pliocene	Benin Formation	
Oligo-Miocene	Ogwasi Formation	Niger-Delta Basin (Third sedimentary cycle)
Eocene	Ameki Formation	
Paleocene	Imo Shale	
	Nsukka Formation	
Maastrichtian	Ajali Sandstone	
	Mamu Formation	Anambra-Afikpo Basin (Second sedimentary cycle)
Campanian	Nkporo/Enugu Shale, Afikpo Sandstone, Owelli Sandstones	
	HIATUS	
Coniacian-Santonian	Awgu Group	
Cenomanian-Turonian	Eze-Aku Group	Abakaliki-Benue Basin (First sedimentary cycle)
	Odukpani Group	
Albian	Asu-River Group (Abakaliki Shale)	

4. Materials and methods

The materials for this study were collected through systematic logging of various outcrop sections in the area from base to top. A total of 11 selected field samples, distributed as follow, were studied: Eze-Aku Formation (7 samples) and Amasiri sandstone (4 samples) Fig. 3.

The method of the study included lithologic logging, laboratory processing, and transmitted light microscopy. Four (4) sandstone samples were subjected to petrographic study in order to examine the textural and mineralogical compositions. Each sample was first to cut into the slab and then sawed to obtain a slice of approximately 1/8 inch thick. It was then cemented on a glass slide with Canada balsam, pressing the slice at an oblique angle against the glass slide to eliminate air bubbles. The slice is then ground on a rotating lap with IF silicon carbide until the standard thickness of 0.03 mm diameter was obtained when the cover glass was cemented firmly to the section. The thin slide was then subjected to detailed microscopic study.

Seven (7) outcrop samples of shale, mudstone and limestone were selected from the locations 1, 2, 8 and 12 (Fig. 3) and subjected to palynological sample processing for their palynomorph contents. The sample preparation was carried out using the conventional method of maceration technique for recovering acid-insoluble organic-walled microfossils from sediments. Each sample was thoroughly cleaned to remove the field contaminants. 10 g of each sample was weighed out in a standard weighing balance and gently crushed with agate mortal and piston. The crushed sample was digested for 30 minutes in 40 % hydrochloric acid to remove traces of carbonate and 72 hours in 48 % hydrofluoric acid for removal of silicates. The digested sample was diluted with distilled water and sieve-washed through 10 microns nylon mesh. The sieve-washed 10 g residues equivalent was partitioned into two parts, 5 g each, for oxidation and for kerogen assessment. The 5 g residues extract were oxidized for 30 minutes in 70 % HNO_3 and 5 minutes in Schulze solution to render the fossils translucent for transmitted light microscopy. The acid-free oxidized residues were rinsed in 2 % KOH solution to neutralize the remaining traces of acid; swirled to remove the resistant coarse mineral particles and undigested organic matter. The swirled residues were collected on the sieve and stained with Safranin – O to increase the depth of contrast for microscopic study and photography.

Aliquots were dispersed with polyvinyl alcohol, dried on cover-slips and mounted in petro-poxy resin. One slide was made from each sample and microfossils were searched, counted and recorded. Light photomicrographs were taken with a Leica lll binocular microscope.

4.1. Kerogen

The simple classification mentioned in Tyson [21], Ibrahim *et al.* [22]) and Chiaghanam *et al.* [23] for rapid assessment of hydrocarbon potentialities may be used as follows:
1- Kerogen type I (highly oil-prone material): It includes alginitic material derived from chlorococcale algae, prasinophyte algae, cyanobacteria and some of the bacteria. Resins are the only significant terrestrially derived components belonging to this group.
2- Kerogen type II (oil-prone material): It includes amorphous organic matter, but sporopollenin palynomorphs, cuticle, and non-cellular membraneous debris are also included.
3- Kerogen type III (gas-prone material): Orange or brown, translucent, phytoclasts or structureless materials. Woody fragments are typical.
4- Kerogen type IV (inert material): Opaque to semi-opaque, black, or very dark brown particles, representing oxidized or carbonized phytoclasts.

Five (5) outcrop samples of shale and mudstones from the Locations 1, 2, 8 and 12, were selected and subjected to palynological sample processing for their particulate organic matter (POM) contents. Sample preparation was carried out using the conventional method of acid maceration for recovering acid insoluble organic-walled microfossils from sediments. Each calcite-free sample was digested for 72 hours in 40% hydrofluoric acid for removal of silicate. The extracts were sieve-washed through 10 microns nylon mesh. The sieve-washed residues were mounted on the cover-slip and then on the glass slide using petro-poxy resin mountant.

Five (5) kerogen slides were made, one for each, of the examined samples. Each slide was examined using the transmitted light microscopy at X10 and X40 magnifications in order to make a qualitative as well as a quantitative analysis of particulate organic matter (POM), determine the palynofacies associations and kerogen types, examine spores /pollen colouration, estimate the Thermal Alteration Index (TAI), Vitrinite Reflectance (Ro %), as well as the degree of organic thermal maturation. Each slide was counted for its (POM) contents, in which the first 200 particles were counted in terms of *abundant* (>35 %), *frequent* (16-35 %), *common* (5-15 %) and *rare* (>5 %).

5. Results

5.1. Petrography: Classification of sandstones

Numerous classifications of sandstones have been proposed by different workers, but sandstones can best be classified within the Ternary scheme proposed by Folk [24]. The major components, i.e., the framework elements, namely: quartz (Q), feldspars (F) and rock fragments (RF) are placed at the poles of a composition triangle (Fig. 5). In this classification, the Q pole consists of both monocrystalline and polycrystalline quartz grains, the F pole includes all types of feldspars, and the RF pole incorporates both rock fragments and micas. Since mica is fairly represented in the samples and may have some genetic significance, it is considered expedient to place it in the RF pole (Tabs. 2, 3, and Fig. 6).

Table 2. Summary of framework elements of the sandstone

Unit	Quartz (%)		Feldpar (%)	Rock fragment (%)	Matrix (%)	Total (%)
	Polycrystalline	Monocrystalline				
AM/L1/04	14.3	20.3	9	4.3	55	100
AKP/L7/01	15	19	5.5	15.5	45	100
AM/L2/04	22	20	13	25	20	100
AM/L3/02	15	20	15	5	45	100

Table 3. Frequencies of Quartz, Feldspar, Mica and Rock fragment in the sandstones with matrix more or less than 15%

Sample	Quartz		Feldspar		Mica+Rock Fragment	
	Value	Recalculated*	Value	Recalculated*	Value	Recalculated*
AM/L1/04	34.6	72	09	18.75	4.3	09
AKP/L7/01	34	62	5.5	10	15.5	28
AM/L2/03	42	52	13	23	25	31
AM/L3/02	35	63	15	27	05	09

**(recalculated to 100% from table above F Frequencies of Quartz, Feldspar, Mica and Rock fragment in the sandstones with matrix more or less than 15% recalculated to 100% from table*

Table 4. The absolute occurrence and distribution of the palynomorph counts in the examined samples

PALYNOMORPHS SPECIES Sample→	AM/L1/01	AM/L1/02	AM/L2/01	AM/L2/02	AKP/L8/01	OKP/L12/01	LST
TERRESTRIAL SPECIES							
Spores							
Laevigatosporites ovatus	7	4	3	5	4	3	2
Leiotriletes adriennis	2	0	1	0	0	0	0
Cyathidites minor	0	2	0	0	2	1	0
Pollen							
Ephedripites multicostatus	2	0	1	1	3	1	0
Cretacaeiporites scabratus	3	1	4	2	I	2	0
Cretacaeiporites mulleri	1	3	1	0	1	3	0
Tricolpites sp. S427	4	0	2	2	0	0	0
Cretacaeiporites krutzschi	0	2	1	0	0	3	0
Tricolporopopollenites sp	2	0	3	0	1	0	0
MARINE SPECIES:							
Dinogymnium euclaensis	2	1	2	0	1	4	2
Oligosphaeridiums pp.	4	2	2	3	0	3	1
Leiosphaeridea sp.	0	0	1	0	2	0	0
Spiniferites ramosus	5	7	2	0	2	5	3
Cyclonephelium spp	0	1	0	2	1	4	0
Trichodinium c.f. casaneum	2	0	2	4	2	0	1
Baliacashaera compta	0	1	1	0	1	3	0
Scuticabolus lapidaris	4	2	3	0	2	0	0
Pediastrum sp.	2	1	1	0	0	2	0
Substilisphaera spp.	4	2	1	2	1	0	0
Foraminifers test lining	0	2	2	0	2	1	3

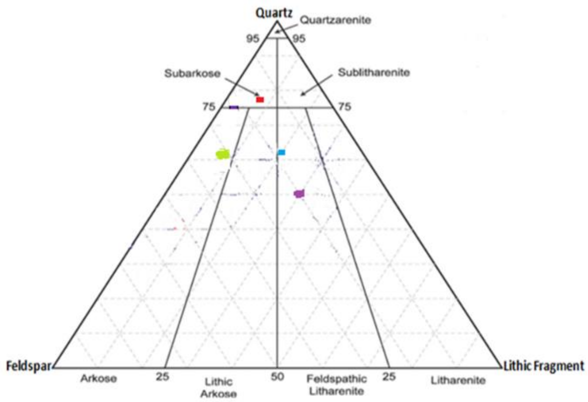

Fig. 5. Plots of AM/L1/04 (red), AKP/L7/01 (blue), AM/L2/03 (purple) and AM/L3/02 (green) sandstones from this study on a compositional triangle for sandstone classification *(after Folk [24])*

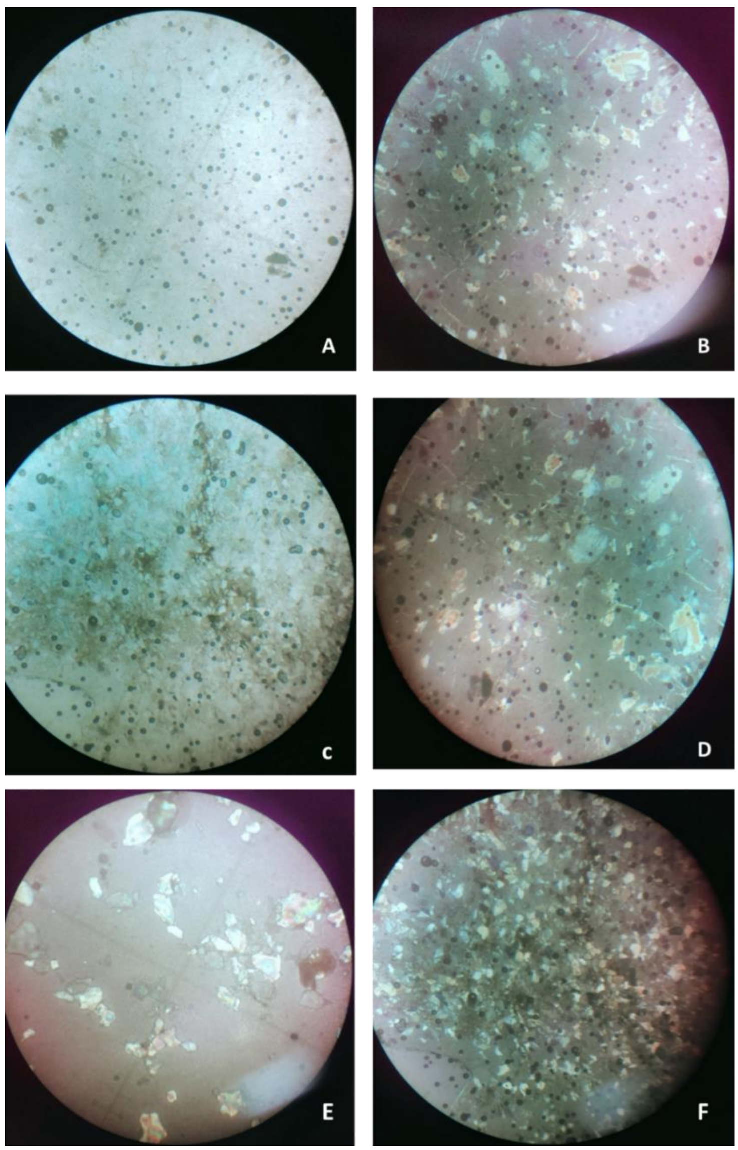

Fig. 6. Micrographs of sandstone petrography: (A) AM/L1/04 plane polarized light, (B) AM/L1/04 cross polarized light, (c) AKP/L7/01 plane polarized light, (D) AKP/L7/01 cross polarized light, (E) AM/L2/03 plane polarized light, and (F) AM/L2/03 cross polarized light

5.2. Palynological result

Table 4 shows the absolute occurrence and distributions of palynomorph counts present in the given examined samples from the locations 1, 2, 8 and 12. The shale and mudstone samples yielded moderately rich palynomorph assemblages while the limestone sample recorded very few palynomorph counts. The sandstones were barren of palynomorphs. The species of marine origin such as Dinoflagellate cysts were the most abundant and diverse. The terrigenous species recorded more pollen and spores while freshwater algal spores yielded low counts (Table 4).

Table 5. Summary of % frequency distributions of the total particulate organic matter (POM) present in the examined samples

Sample NO.	Phytoclasts	AOM	Opaques	Palynomorphs
AM/L1/01	15 %	50 %	30 %	5 %
AM/L1/02	8 %	62 %	24 %	6 %
AM/L2/01	20 %	55 %	25 %	0 %
AKP/L8/01	5 %	65 %	28 %	2 %
OKP/L12/01	10 %	52 %	33 %	5 %

Table 6. Summary of the kerogen assessment and interpretation

Sample No	Palynofacies association	S/P colour	TAI	Vitrinite reflectance (R%)	Thermal maturation	Kerogen type	Source rock potential
AM/L1/01	Mostly dark AOM followed by opaque debris	Very dark brown-dark	+3 to -4	1.3= - 2.0%	Over mature	Type II/III	Oil –gas prone
AM/L1/02	Mostly dark AOM followed by opaque debris				Over mature	Type II	Oil prone
AM/L2/01	Mostly dark AOM followed by opaque debris				Over mature	Type II/III	Oil –gas prone
AM/L2/02	Mostly dark AOM followed by opaque debris				Over mature	Type II	Oil –prone
AKP/L8/01	Mostly dark AOM followed by opaque debris				Over mature	Type II/III	Oil –gas prone

Table 7. Summary of palynomorphs % frequency distribution and their paleoenvironmental inferences

Sample no.	Palynomorphs % frequency			Paleo-salinity	Paleoenvironments of deposition
	Spores	Pollen	Marine Species		
AM/L1/01	**21 %**	**27 %**	**52 %**	Brackish – Normal marine	Marginal - Open marine (probably shallow shelf)
AM/L1/02	**19 %**	**19 %**	**62 %**	Normal marine	Open marine (probably open shelf)
AM/L2/01	**11 %**	**33 %**	**56 %**	Brackish – Normal marine	Marginal – Open marine (probably shallow shelf)
AM/L2/02	**24 %**	**24 %**	**52 %**	Brackish – Normal marine	Marginal – Open marine (probably shallow shelf)
AKP/L8/01	**22 %**	**22 %**	**56 %**	Brackish – Normal marine	Marginal – Open marine (probably shallow shelf)
OKP/L2/01	**11 %**	**26 %**	**63 %**	Normal marine	Open marine (probably Open shelf)

5.2.1. Amachi River Section (AM/LI/01 and AM/L1/02)

The samples from this location documented more marine (52-62 %) of the total palynomorph counts over terrestrial (36-48 %) species (Tabs. 4 and 7). Freshwater species were poorly recovered.

Terrestrial species: Among the sporomorph group were spores, pollen, and algal spores. The spores include *Leiotriletes adriennis, Laevigatosporites ovatus,* and *Cyathidites minor*. The pollen is *Ephedripites multicostatus*, *Cretacaeiporites scabratus*, *Cretacaeiporites mulleri*, *Tricolpites sp.* S 427, *Cretacaeiporites krutzschi* and *Tricolporopopollenites sp*.

Marine species: The group of marine species includes dinoflagellate cysts, acritarchs, prasinophytes and foraminifer inner test lining. The dinoflagellate cysts encountered included both gonyaulacacean and peridinecean species. They include *Dinogymniumeuclaensis, Spiniferites* spp*., Oligosphaeridium* sp, *Operculodinium centrocarpum,* and *Substilisphaera* sp.

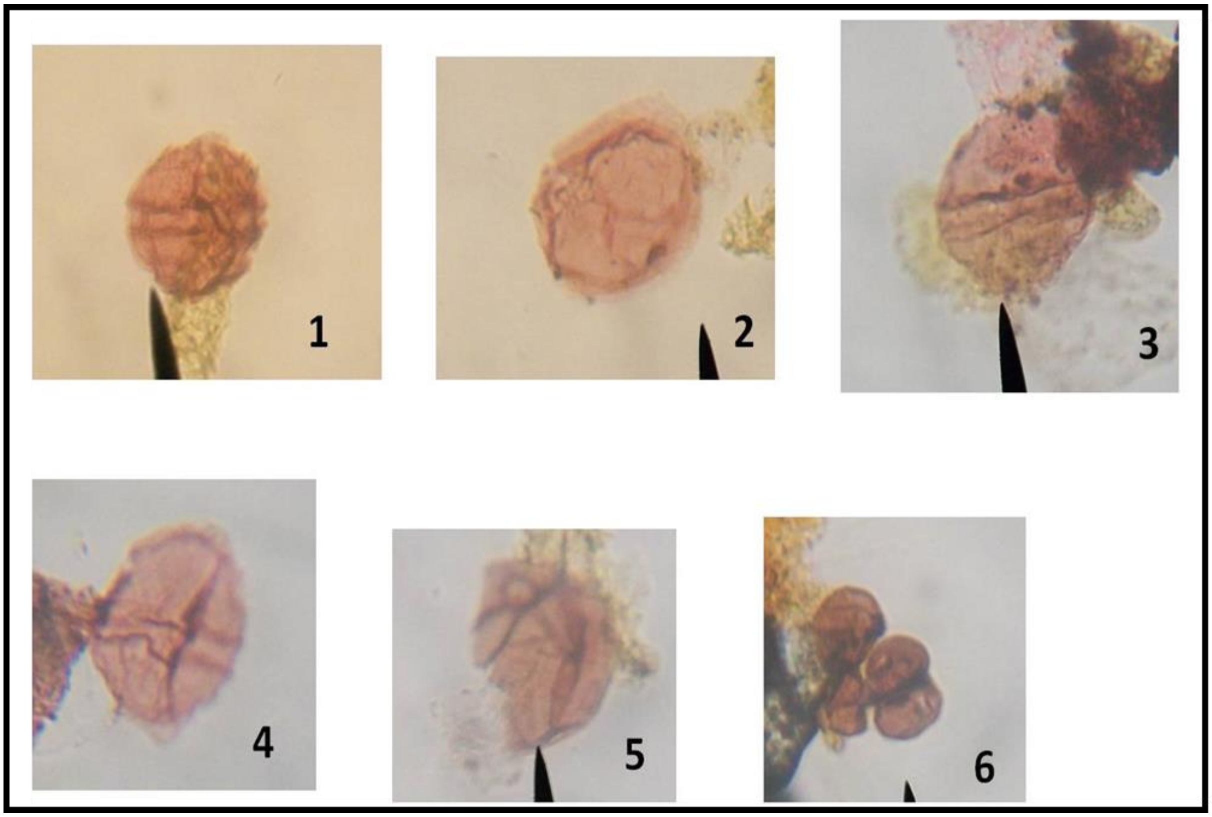

Fig. 7. Micrographs of some Late Cenomanian to Turonian dinoflagellate cysts and forams test lining from the study area, magnification (X 40)

1. *Substilisphaera senegalensis*
2. *Substilisphaera hyaline*
3. *Pterodinium cingulatum*
4. *Substilisphaera* sp.
5. *Baltiacasphaera compta*
6. *Forams inner test lining*

5.2.2. Amachi Quarry Section (AM/L2/01 and AM/L2/02):

The shales and mudstone samples from this location produced more marine (51-52 %) than the terrigenous (44-48 %) species (Table 4&7). The pollen predominate over spores. The fresh water *Pediastrum* sp. and foraminifer inner lining were occasionally encountered.

Terrestrial species: The recovered spores included only two species of fresh water ferns, *Laevigatosporites ovatus* and *Leiotriletes adriennis*. Among the pollen are*Cretacaeiporitesmulleri,Tricolporopollenites* ssp., *Ephedripites multicostatus*, *Cretacaeiporites scabratus*, *Cretacaeiporites mulleri* and *Tricolpites sp.* S 427.

Marine species: The dinoflagellate cysts and the acritarchs *Scuticabolus lapidaris,* forams inner lining and *Leiosphaeridia* spp. were recorded. Thedinoflagellate cysts predominate over other marine species. The gonyaulacacean (open marine species) predominate over peridinecean(near-shore brackish water) species. They include *Spiniferites ramosus, Oligosphaeridium*spp, *Operculodinium centrocarpum, Substilisphaera* spp*., Dinogymnium euclaensis, Cyclonephelium*spp*., Trichodinium c.f. casaneum,* and *Baltiacaphaera compta* (Table 4and Fig. 7)

5.2.3. Locations 8 and 12 (AKP/L08/01 and OKP/L12/01):

Thissamples recorded both marine and terrigenous palynomorphs. The marine species (56-63 %) predominate over terrigeneous (37-44 %) of the total palynomorph counts. The pollen were recorded more than the spores (Table 4&7). Fresh water species were also encountered.

Terrestrial species: The fern spores are *Laevigatosporitesovatus*and*Cyathidites minor*. Among the pollen included *Tricolporopollenites* sp*., Cretacaeiporites scabratus*, *Cretacaeiporites mulleri*, *Ephedripites multicostatus* and *Cretacaeiporites krutzschi*.

Marine species: Dinoflagellate cysts species encountered include *Trichodinium*c.f.*casaneum, Dinogymnium euclaensis, Spiniferites* spp*., Oligosphaeridium* spp, *Operculodinium centrocarpum, Cyclonephelium* spp*.,* and *Baltiacaphaera compta*.

The limestone (LST) yielded very low palynomorph counts. The terrigenous species encountered included one single grain of fern spore *Laevigatosporites ovatus* while pollen were absent. Few species of marine origin such as *Dinogymnium euclaensis, Trichodinium c.f. casaneum* and *Oligosphaeridium* spp., and foraminifers test lining were recorded while fresh water algae was not observed (Table 4).

5.3. Kerogen results

Table 5, shows the summaryofthe percentage frequency distributions of the total particulate organic matter (POM) present in the given examined samples. Almost all the samples in the area (from location 1 - 12) have similar palynofacies associations, constituted mostly of dark AOM followed by opaque debris (Table 6). The estimated spores/pollen colouration generally ranged from very dark brown to dark, which are overmature, and correspond to +3 to -4 TAI, 1.3 - 2.0 Vitrinite Reflectance (Ro %) in the standard colour chart. The kerogen types are generally type II/III (Table 6).

6. Interpretation and discussion

6.1. Provenance and depositional environment

The major objective of sandstone petrography of a unit is to decipher the paleogeographic setting which controlled the derivation, transportation, and deposition of the detritus. This involves the identification of the provenance, the mode of transportation and the kind of depositional environment.

A brief discussion of the results of the study is aimed at relating these results to depositional processes and possible identification of environments of deposition. The roundness of sand grains is slightly modified in a single cycle. The studied samples are characterized by subrounded and subangular grains which indicate a first cycle deposit since rounded quartz sands generally indicate recycling. However, as long distances of transport or reworking may not effectively round clastic quartz grains. It may nevertheless be noted that organic acids cause the dissolution of corners of clastic grains in soils and weathering profiles and so effects some rounding. Form, like size, is also often inherited [26]. Abrasion is thought to play little or no part in determining form. The preponderance of prismatic, elongate feldspars and highly strained polycrystalline quartz grains in the samples is indicative of derivation from mostly gneissic sources. Bokman [27] has shown that granitic quartz has a greater tendency towards equality as compared to metamorphic quartz. Equant and very equant quartz grains, indicative of granitic sources are rare in the studied sandstone units.

Contacts between sand grains are normally the point type at a deposition; the other types are modifications of this initial fabric. The ubiquity of line and concavo-convex types in the studied samples show that a considerable amount of condensation has occurred in the sandstone [28]. According to Pettijohn [28], condensation is the process of bringing the grains closer together, resulting in more extended contacts. Taylor [29] attributed the modification of point contact to solid flow and pressure solution of quartz grains. The overgrowths on the quartz grains are normally produced as diagenetic features. Young [30] attributed segmented undulosity to the mode of response of quartz to stress and in general the undulose extinction to the differences in orientation of the c- axis in various parts of a crystal formed either as a response to bending gliding or progressive misorientation of various parts of a quartz crystal developed by parallel walls of dislocation.

6.1.1. Provenance

The term provenance includes all the factors relating to the production of sediment [28]. Most often it refers to geology, relief, climate, and location of the source region.

6.1.1.1. Composition of source rocks

The clastic grains that provide most information in this regard are quartz, feldspars and rock fragments.

Quartz: Quartz grains usually bear clues as to their source. According to Blatt et al, (1980), quartz grains derived from gneissic rocks are polycrystalline and are commonly composed of more than five crystals. The polycrystalline grains dominate in the AKP/L7/01 and AM/L3/02 sandstone units (Table 2) and consist of five to seven crystals, having sutured boundaries indicating a metamorphic source rock (Fig. 6).The samples representing all the lithologic units showed a higher proportion of undulose quartz grains. The significance of this with respect to the provenance is not very clear since no real difference exists in the degree of undulosity in quartz from igneous and metamorphic rocks [30-31]. Folk [32] however thinks strong undulosity is a characteristic feature of quartz grains from gneisses and schist.

Feldspar: Potash and sodic feldspars which were observed in the studied samples may equally be derived from gneissic and granitic sources. K-feldspars are associated with gneissic sources and plagioclase with granitic sources. The feldspar grains may have been derived from polygenetic sources since the two types of feldspars were represented in the samples (Table 2&3). The major fact that emerges from the analysis is that the source area is a basement complex containing perhaps all these rock types in various proportions with the metamorphic rock type appearing to dominate the region.

6.1.1.2. Climate and relief of the source area

The key indicator of paleoclimate is thought to be detrital feldspar [28]. The presence of large quantities of feldspars in sandstone implies a very arid or cold climate in the source region. Conversely, a very humid or wet climate is postulated for the absence of detrital feldspars. Such a rigorous climatic theory was questioned by Krynine [35] who argued that the presence or absence of detrital feldspar in sandstone depends not only on a suitable climate but also on the time through which the processes of decomposition operate.

The proportion of feldspar in the AM/L1/04, AKP/L7/01, AM/L2/03 and AM/L3/02 sandstone units (9%, 5.5%, 13%, and 15% respectively) (Table 3), does not appear considerable, though diagenesis might have reduced the original content of the feldspar grains of all the studied samples representing the three lithologic units and are on the average finer and rounder than the quartz grains. All the feldspars are also generally weathered. These factors would place the source region of the sandstone under study in a tectonically active zone, characterized by a rugged to moderate relief and a humid and warm climate.

From the foregoing, the provenance is most likely the metamorphic Precambrian Basement Complex of southeastern Nigeria in the Oban and Bamenda massifs/cratons located at the eastern border of the rift, towards the eastern border of the study area (Fig. 4).

6.1.2. Depositional environment

A depositional environment is a geographically restricted complex that can be described in geomorphic terms (e.g. marine environment, shelf environment) etc. The depositional environment of the sandstone units are discussed as deciphered from primary sedimentary structures and lithologic characteristics. However, the observed parallel lamination of the sandstone unit in the field is strong indication of low energy environment of deposition. The presence of mica in the sandstones (Table 2&3) indicates deposition in low energy environment where sediments are rapidly deposited with little reworking.

6.2. Age determination/Correlations

The designation of age to the examined samples was based on selected key age marker palynomorphassemblageencountered.The samples in the study area were dated **Late Cenomanian** to **Middle Turonian** based on the following index sporomorph assemblage: *Cretacaeiporites scabratus, Ephedripites multicostatus, Cretacaeiporites mulleri, Monosulcites sp.,Tricolporopollenites* sp.,and *Tricolpites sp.* S427.This assemblage is typical of the **Turonian** of Herngreen [34], Lawal and Moullade [35], and Abubakar *et al*. [36], in the Upper Benue Basins, Nigeria. *Cretacaeiporites scabratus* Herngreen, 1975, made its earliest appearance in the Upper Cenomanian [36-37]. Other important dinocysts assemblage present are *Cyclonephelium cf. membraniphorum, Spiniferites ramosus, Batiacasphaera compta.* The presence of *Substilisphaera hyaline* and *Substilisphaera senegalensis* species (Table 4, Fig. 7), which are typical of Late Cenomanian, as well as *Dinogymnium euclaensis,*which first appeared in the **Turonian** [35-37], strongly confirmed the above designated age for the samples. Meanwhile, the absence of *Droseridites senonicus* (an index pollen of Coniacian-Santonian) in the examined samples overruled Coniacian age [35-37].

6.3. Paleoenvironments of deposition

Table 7, shows the summary of palynomorphs percentage frequency distribution and their paleoenvironmental inferences. The obtained values of 38-40 % marine influence, as was reported by Umeji [37] in the formation, indicate nearshore marine condition, with terrigenous input (usually spores and pollen) as much as 60 %. Here, on the contrary, the obtained values of 52-62 % marine influence (Table 7), with terrestrial input as low as 40 %, is indicative of open marine environment of deposition. This, therefore, has showed that almost all the examined samples from the Eze-Aku Formation in the area were probably laid down during the period of transgressive Turonian Sea, which later gave way for the deposition of the overlying Amasiri Sandstone by the regressive Turonian Sea. Moreover, the occurrence of marine association of *Scuticabolus* spp. and *Subtilisphaera* spp.**,** with structureless organic matter also gave credence to open marine depositional setting.

7. Summary and conclusion

The geology of Akpoha and environs has been undertaken. The result from the petrographic analysis shows that most of the sandstone where deposited in a very low energy environment where sediments are rapidly deposited with little reworking. The palynological result indicates Late Cenomanian to Early Turonian age for the sediments in the study area. Environmentally significant palynomorphs indicate that most of the sediments were deposited in an open marine environment, with minor terrestrial input. The results from kerogen analysis indicated that most of the samples were generally overmature characterized mostly by dark amorphous organic matter followed by opaque black debris, and have the potential to generate mainly oil and or gas.

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To whom correspondence should be addressed: Dr. O. N. Ikegwuonu, Department of Physical & Geosciences, Godfrey Okoye University, Enugu, Nigeria