British Journal of Applied Science & Technology
3(4): 898-915, 2013

SCIENCEDOMAIN *international*
www.sciencedomain.org

Palynological and Paleoenvironmental Investigation of the Campanian-Lowermost Maastrichtian Asata/Nkporo Shale in the Anambra Basin, Southeastern Nigeria

A. O. Ola-Buraimo[1*] and I. M. Akaegbobi[2]

[1]*Department of Chemical and Geological Sciences, Al-Hikmah University, Ilorin, Nigeria.*
[2]*Department of Geology, University of Ibadan, Ibadan, Nigeria.*

Authors' contributions

This work was carried out in collaboration between authors. Author AOO designed the study, managed the analyses of study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author IMA managed the literature searches and approve the draft of the manuscript. The authors read and approved the final manuscript.

Research Article

Received 27th November 2012
Accepted 3rd March 2013
Published 1st June 2013

ABSTRACT

Ditch samples recovered from interval 2216 to 2716m of Nzam-1 well in the Anambra Basin, Nigeria were investigated for sedimentological, palynological age dating and paleoenvironment reconstruction. The stratigraphic successions in the well include intercalated gypsiferous shale, shale, sandy shale and shaly gypsum of varying gypsum content. Palynological zone of *Milfordia spp* acme zone was established. The zone is characterized by maximum development of *Milfordia spp., Longapertites sp* 3 and first uphole appearance of *Buttinia andeevi*. Other forms that mark the zone are regular occurrence of *Cupanieidites reticularis*, *Syncolporites subtilis, Cingulisporites ornatus, Trichotomosulcites sp. 1, Periretisyncolpites sp., Auriculiidites sp., Tricolpites gigantoreticulatus, Foveotriletes margaritae, Cupanieidites reticularis, Auriculiidites sp.* and *Constructipollenites ineffectus*. The top of the zone is marked by the final appearance of *Trichotomosulcites sp. 1, Milfordia jardinei*, *Cupanieidites reticularis* and relative increase in *Longapertites marginatus, Monocolpites marginatus, stephanocolporate pollen*. The interval is particularly marked by maximum development of *Milfordia spp.* depicting Campanian to Lowermost Maastrichtian age.

**Corresponding author: E-mail: rolaburaimo@yahoo.com;*

The paleoenvironment of deposition is marginal marine in nature defined by higher percentage of peridinaceans such as *Senegalinium spp.* and *Andalusiella spp.* over *Gonyaulacysta* forms. The relative position of the sea level and climatic condition is manifested on the lithofacies, characterized by the intercalation of shale and gypsum representing different times of transgression and lowstand phases.

Keywords: Lowermost maastrichtian; peridinacean; gonyaulacacean; gypsiferous shale Campanian; shale.

1. INTRODUCTION

The Anambra Basin of southern Nigeria was said to have evolved during the Santonian [1]. This assertion is strongly criticized as the definition of Anambra Basin includes all area or region in Nigeria that include the following states - Anambra, Enugu, Ebonyi, Delta, Kogi and part of Benue [2]. Recent study has revealed contrary data which shows that the basin contains pre Santonian sediments such as Asu-River Group, [3]; Eze Aku Formation [4] and Awgu Formations [5]. Most of the efforts of some researchers have been restricted to the southern part of the basin, most especially around Onitsha and Enugu area. One other limiting factor to some of the activities carried out in the basin is the biostratigraphic documentation of ammonite, brachiopods, and microforaminifera. Few works on the basin done by past researchers have been on outcrop samples or those taken from open mines which are likely to be contaminated.

[6] worked on Enugu shale otherwise known as Nkporo Formation and Iva Valley Shales (Mamu Formation) at Oyeama mines. His palynological result revealed Campanian-Maastrichtian age sediments. A further compared palynomorph assemblages from both the Enugu shale and Iva Valley Shale which shows similar miospores but different on the account that the Enugu Shale contains dinoflagellates which the latter lacks. He attributed the palynological content differences to gradual regression of the sea in the area.

This study was embarked upon to evaluate Asata/Nkporo Shale sequence from an exploratory well located in the northwestern part of the basin (Fig.1) on the basis of sedimentary and palynology in order to understand the stratigraphic sequence, age dating and determination of the paleoenvironment of deposition of the sediments. It is strongly believed that data obtained from ditch cutting samples would be more reliable and result oriented than those obtained from out crop or mines which may suffer contamination and weathering.

2. GEOLOGIC SETTING AND STRATIGRAPHY

Sedimentation history of the Anambra Basin is related to the Lower Benue Trough evolution which is usually linked to separation of the Gondwana during the Middle Cretaceous time [7]. The evolutionary trend of Anambra Basin is patterned by east to west shifting of the depocenters [2]. The initial area of active sedimentation was located in the Abakaliki Trough from Aptian to Santonian. However, recent studies have shown that the active sedimentation was not restricted to the Abakaliki Trough alone but also took place within the graben of the faulted block segments of the Anambra Basin [12]. The pre Santonian formations are the Asu River Group, Eze Aku and Awgu Formations.

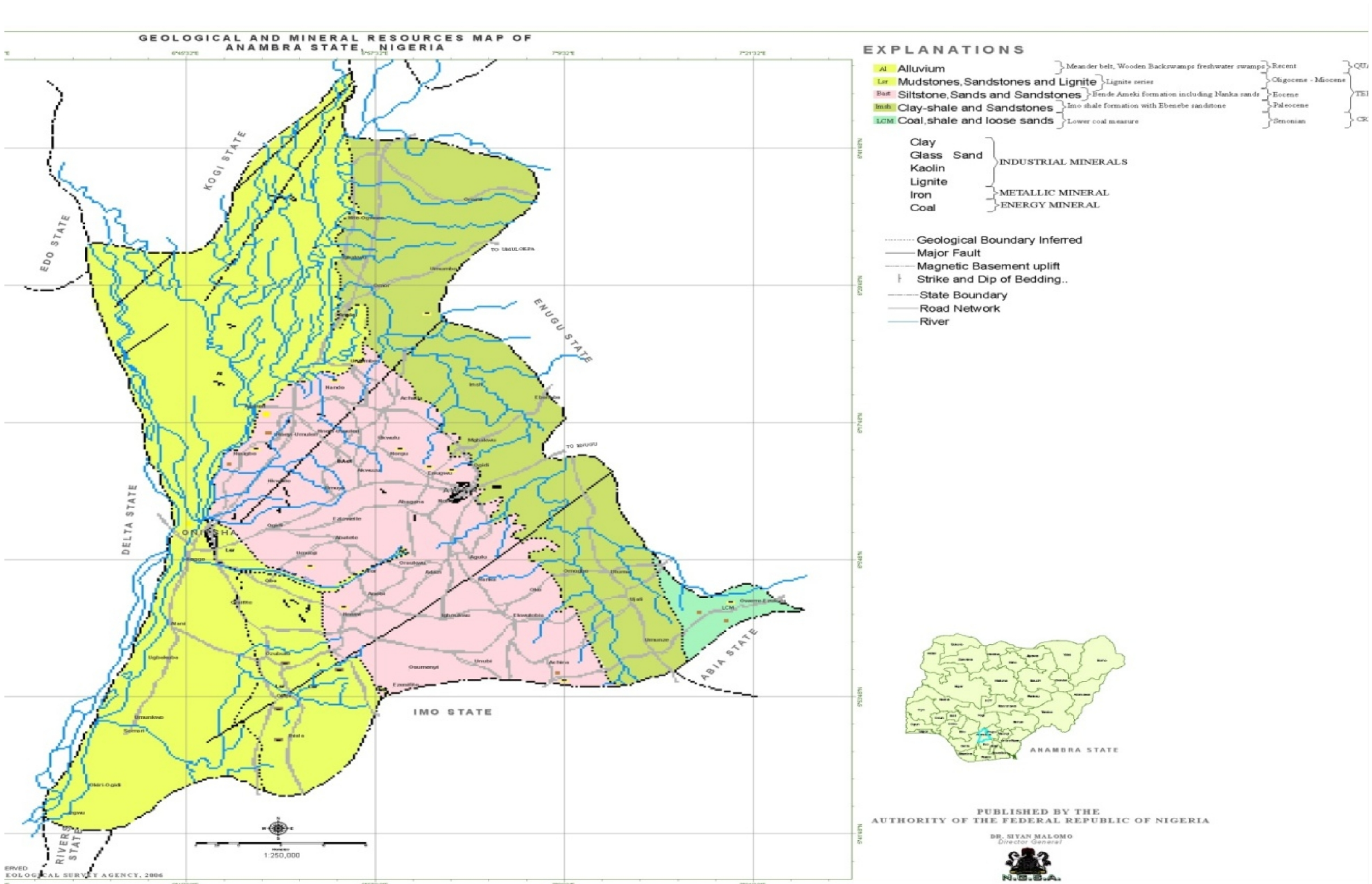


Fig 1. Geological map of Anambra state showing location of Nzam-1 well, with inset showing map of Nigeria with 36 states

However, [9] indicated that the Anambra Basin became active after the Santonian tectonic event. Anambra Platform started prograding by depositing deltaic facies. It later subsides and an east-west prograding system developed. The deltaic system became aborted during the Maastrichtian by the commencement of major marine transgression [2]. The Nkporo Shale and the overlying Lower Coal Measures were deposited towards the center of the basin.The deltaic system was aborted during the Maastichtian by the commencement of major marine transgression [2]. The Tertiary period was characterized by deposition of Imo Shale (Paleocene); Ameki (Eocene); Ogwashi-Asaba (Late Miocene-Pliocene [10] and finally overlain by Benin Formation (See Fig. 2).

Table 1. Correlation Chart for Early Cretaceous-Tertiary strata in southeastern Nigeria (After Nwajide, 1990)

AGE		ABAKALIKI-ANAMBRA BASIN	AFKPO BASIN
M.Y 30	Oligocene	Ogwashi-Asaba formation	Ogwashi-Asaba formation
54.9	Eocene	Ameki/Nanka formation/ Nsugbe sandstone(Ameki group)	Ameki formation
65	Paleocene	Imo formation Nsukka formation	Imo formation Nsukka formation
73	Maastrichtian	Ajali formation Mamu formation	Ajali formation Mamu formation
83	Campanian	Nkporo Oweli Formation/Enugu Shale	Nkporo shale/Afikpo sandstone
87.5	Santonian		Non-deposition/erosion
88.5	Coniacian	Agbani sandstone/ Awgu shale	
	Turonian	Eze Aku Group	Eze Aku Group (include Amasiri sandstone)
93 100	Cenomanian-Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Group	
PRECAMBRIAN		BASEMENT COMPLEX	

3. METHODOLOGY

Ditch cutting samples from exploratory well with depth range from 2216-2716m were used for both lithological description and palynological recovery content. Nineteen ditch cutting samples were obtained from the well at about 27.4m interval for palynological slides preparation. The first stage of the laboratory analysis was lithological sample description. The samples were described under the microscope by considering the colour, lithology, textural features of the grains, fossil content and post deposition diagenetic effects such as hematite.

The weighted samples of about 20gm were poured in well labeled in plastic containers. Dilute Hydrochloric acid (HCl) was added to the samples in order to remove the carbonate mineral present. This is followed by digestion of the samples in 60% grade Hydrofluoric acid (HF) stirring intermittently overnight for about twenty four hours (24hrs). The samples were later sieved with 5um mesh in order to remove the clay size particles that might obscure petrographic description. Other stages involved include non-oxidation of the samples and heavy liquid separation of the macerals before they were finally mounted on glass slides with Deepex (DPX) mountant.

Counts of the pollen, spores, dinoflagellates, algae, fungi and other stratigraphically important forms present were made to determine the relative frequency of each species in the sample; upon which diagnostic species photographs were taken with Coolpix P6000 digital camera.

4. RESULTS AND DISCUSSIONS

4.1 Lithostratigraphy

Current study from the well section through a thorough litho-description shows five lithologic units; from the base gypsiferous shale sequence (2716m-2420m), intercalated with shales, has an average gypsum/shale ratio percent of about 30:70% (See Fig. 2). The top of this unit 1 is marked by a thin gypsum layer (2420m).

The unit 2 varies from 2420-2295m characterized by mainly dark grey, fissile carbonaceous shale but with minor intercalated gypsum at the upper part of the interval. The lithologic sequence unit 3 is gypsiferous shale facies unit with a thin interbed of gypsum at 2173m; it ranges from 2295-2203m with a total thickness of 92m. The forth lithologic unit ranges from 2201-2182m (19m thick) characterized by dark fissile sandy shale interbedded with a dark gray fissile shale (Table 2). Sand particles vary in size from medium to pebble; rounded to subangular, moderately sorted. The grading sequence shows an uphole increase in sand content which depicts a prograding deposit of a deltaic setting.

The unit 5 ranges in depth from 7160-7100ft. It contains a dark grey to whitish fissile shaley gypsum; average gypsum content is over 75%. The gypsum distribution trend with depth shows an upward stratigraphic increase in gypsum content which may suggest a shoaling upward paleobathymetry (Table 2).

The Asata/Nkporo Formation to a school of thought is the oldest deposit in the Anambra Basin in which the authors have a contrary opinion. It was described to consist of dark shales and mudstone with occasional thin beds of sandy shale, sandstone, shaly limestone and coal (Umeji and Edet, 2008). However, current study shows that the formation contains various heterolith facies of shale and gypsum in different proportion; dark grey fissile shale and sandy shale units.

Table 2. Lithostratigraphy of the analyzed section (2216-2716m) of Well-N 1, Anambra Basin Southeastern Nigeria

Depth(m)	Litho-log	Description	Remark
2216	__Gp----- ____-- _Gp_-- __Gp_--_--- __--_Gp_- _-_----__-- __-GP_-_- GP_-GP__-	Dark grey, fissile shaly gypsum, average gypsum content is over75%	Uphole increase in gypsum content (Shoaling water body)
2182 **2201**	_-_-__---- GP--_--__-- Gp_-_-_--- __--___-_- _-__-_-- ___-__---	Dark grey, fissile sandy shale intercalated with dark grey fissile carbonaceous shale. Sand size varies from medium to pebble; rounded to subangular and moderately sorted.	Prograding in a deltaic setting
	__--_----__- -__----__- __-_-_-_--- __----_- Gp_----_---- --Gp--_-_-_- --_-_-_-_-_- -Gp--_Gp_- _-_-_-_-_-_- --__--_--- Gp_-_-_-_-- -Gp_-_--- _Gp_-_-__- -_-----_-_- __-_--Gp_- _-_--__--_--	Dark grey to whitish gypsiferous shale with a thin layer of interbedded gypsum	Marginal marine deposit
2295 **2420**	---Gp_-_-_- _-_-Gp_-_-- -_-_----___- --Gp_-_---_- _-_-_--_- _Gp_-_-_- ___-_-_-_- _-_-Gp_-_- _---_---_-_- ___-___--_- _-_-_-__--_- --__--Gp_--- _---_---_-_- _---__--_-_-	Maily dark grey, fissile shale sequence, but gypsiferous at the upper part and underlain by a thin gypsum layer	Relatively deeper marine deposit

2716	_-__--_-_-_- _-_-_-__-- __-___-__-- --__---__--- _---__-___- _-_-__-_--_- __-_-_-_- __-__-Gp Gp Gp- ____---_--- _---_---_- __--__-_--- Gp--_---__- _---_---__- _-Gp_---__- -_--------__-- _-_-_-_---_- --__--_-_-_- --_--Gp_-_- _--_---__-- __--_---__-- __-__Gp_- _-__-_-_-_- _-_-_-_-_-_- _-_-_-_------	Gypsiferous shale sequence with intercalated shale intervals. Gypsum/shale ratio is about 30:70	Contains higher percentage of shale to gypsum

4.2 Palynology

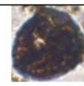
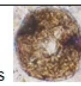
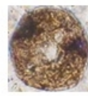
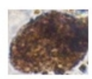
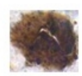
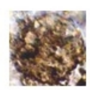
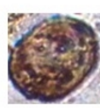
The base of the zone at 2716m is defined by the first appearance of *Longapertites sp 3* [11], continuous occurrence of *Zlivisporites blanensis*, stephanocolporate pollen, *Verrucatosporites sp, Monocolpites sp* and *Cyathiditess sp*. At the near base of the interval is the appearance of new forms such as *Milfordia spp*, *Syncolporites subtil*, *Cingulatisporites ornatus* and *Monocolpites marginatus*. The top of the zone is characterized by the disappearance of *Milfordia spp*, and *Cupanieidites reticularis* (See Fig. 4). Within this zone, there is a variety of *Milfordia* taxa showing a continuous occurrence along with *Cupanieidites reticularis.* They are both restricted within the zone.

The top of the zone is marked by the disappearance of *Cupanieidites reticularis, Tricolpites gigantoreticulatus* [12], *Retitricolpite gageonnetii* [13], *Milfordia jardine* and appearance of Stephanocolporate pollen.

Maastrichtian markers that have their offshoot within this zone include *Buttinia andreevi*, *Retidiporites magdalenensis*, *Periretisyncolporites sp.*, *Proxapertites cursus* and *Cingulatisporites ornatus*. However, some forms became extinct within this zone such as *Milfordia spp., Cupanieidites reticularis, Triorites africaensis, Ephedripites multicostatus, Auriculiidites reticularis,* and *Cicatricosisporites sp.* Other miospores present within the interval are *Constantinisporites jacquei, Tricolporopollenites sp.* (S. 152 of [12], *Ulmoideipites sp.*, Tricolpate pollen, *Monoporites sp., Leiotriletes sp, Inaperturopollenites sp.*, *Verrucosisporites sp, Gemmatricolpites sp., Laevigatosporites sp.,* and dinoflagellate cysts. The *Milfordia spp* acme zone is equivalent to *Longapertites sp. 3* Assemblage Zone of [11]. This zone is well represented in Nzam – 1 well, Anambra Basin, Nigeria.

Some of the miospores reported in this zone have been described in the Campanian-Maastrichtian sediments of Africa, South America and India. They have also been reported in the works of [14], [15], [16], [17,18]; [12]. *Cupanieidites reticularis* and *Cingulatisporites* *ornatus* have been reported by [19,20]; [21,22,23]; [24,25,26]; [27,28]; [29;30]; [31,32]; [33], [34], [35,36,37,38,39]; [40], [41], [42], and [[43].

Table 3. Trend of appearance and evolutionary changes in Milfordia taxa

Lithology	Litholog	Formation	Marker fossil range	Age
2216m	Gp		 Cupaniiditesreticularis  M. jardiniei	
2271			 M. Sp2A  Buttinia andreevi	Lowermost Maastrichtian
2304	Gp		 Milfordia jardiniei  M sp2A	
2411	Gp	Nkporo	 Milfordia sp Z	Campanian
			M. sp, M. Sp 3, M. Sp2D, M sp 4	
2521	Gp		   	
2548			 Milfordia sp 2B  M. jardiniei	
2603	Gp		 Milfordia sp 2A	
2716	Gp, Gp		 Milfordiasp  Long. sp 3	

The *Milfordia spp* acme zone is similar to other zones observed in Senegal and Cote d' Ivoire; equivalent in part to sequence IV-II of [12]]; palynomorph assemblages from Campanian sediments of Egypt described by [44], [40]; Upper Senonian sediment described from Brazil, [24,25,26]; Upper Cretaceous dinoflagellate assemblage reported from Cauvery Basin.

The presence of *Buttinia andreevi* and *Auriculiidites sp* in the Upper part of the interval, appearing first in the stratigraphic column conform with the observations of [12], [45], and [25] dating the sediments Campanian – Lower Maastrichtian age.

[46] established a Late Campanian for the Nkporo Shale on the basis of exclusive planktonic foraminiferal assemblages of *Globotruncana fornicate* (Plumer), *Rugoglobigerina rugosa* (Plummer), *Heterohelix pulchra* (Brotzen) *and H. globulosa* (Ehrenberg). However, ammonite fauna including *Libycoceras crossense* [47]; *L. afikpoense* [48] and *Sphenoidiscus lobatus* assigned a Late Campanian age. Therefore, the interval 2216-2716m of the *Milfordia sp* acme zone is here conveniently dated Campanian to Lowermost Maastrichtian age.

The paleoenvironment of deposition is characterized by organic wall organisms such as *Senegalinium spp*, *Andalusiella spp*, *Spinidium sp 1, Cribroperidium sp* [49], *Spiniferites sp*, *Oligosphaeridium and Dinogymnium sp*. The preponderance of peridinacean over the short spine dinocyst is suggestive of marginal marine environment for the stratigraphic interval studied [50], [51], [52].

4.3 Formation of Gypsum

The origin of the gypsum is of interest because it is in high concentration to shale facies. The gypsum ($CaSO_4.2H_2O$) is an evaporate deposit. Large deposits of gypsum are derived from marine brines [53,54]. Though evaporate minerals could as well appear in veins, cavities and even atoll cliff roofs, but this is most unlikely to be applicable to gypsum found in Ananmbra Basin, Nigeria. Thus, most occurrences of silistone are formed by the crystallization of salts from concentrated hydrous solutions (brines). Factors that control formation of such deposits include climate, hydrographic conditions (e.g. currents and density of brines and water), the chemistry of invading solutions, and the basin geometry.

Evaporites generally have reported to form in arid regions (playas) of desert basins, in sabkha along the hot coastal regions and in extremely restricted to isolated marine basins along dry coastlines which is suggested for the Anambra Basin during the Campanian – Maastrichtian period of gypsum formation. [55] gave conditions necessary for evaporates formation to include a water-balance deficit; that is the rate of evaporation must exceed periodical inflow of water into the basin. In essence this condition requires a constraint whereby the entrance to a basin is topographically or geographically restricted so that evaporation exceeds water inflow due to combination of topograhic and climatological or hydrographic factors.

On the other hand a hinterland basin like Anambra Basin is more likely to experience high evaporation greater than rate of inflow of fluid. It is argued in other quarters that irrespective of the shape of the basin, less saline, lower density water that enters the basin will begin to spread across the top of the ambient fluid. The inflow fluid at the surface will undergo evaporation and consequent density increase. As salinity and density increase, the fluid precipitates evaporate minerals in restricted basin; sink to levels that preclude their escape from the basin [56].

It is further advanced that in continental basins, evaporation occurs at a distance from the mouth of streams that contribute less saline water to the basin. All these possibilities of evaporate formation could account for gypsum formation in the basin. However, the most favorable concept that fits into the formation of gypsum in Anambra Basin is probably a situation where the basin is restricted from inflow of both fresh and marine waters into the basin as a result of topography high, climate (hot temperature) and hydrographic condition (Fig. 2).

The Anambra Basin is bounded to the west by the Benin Hinge line and to the west of it is the Okitipupa Ridge [57]. It is suggested that probably during Campanian-Maastrichtian period the Okitipupa Ridge which was supposedly submerged was raised isostactically in such a way that it formed a topographically or geographic restriction to the basin whereby inflow of water into the basin was reduced (Fig. 2). These in combination with hot tropical climate and probably hydrographic factors led to high evaporation of the brine water and subsequent precipitation and crystallization of gypsum mineral. This was found intercalated with shale beds due to transgression and tectonic adjustment otherwise referred to as dynamic topography.

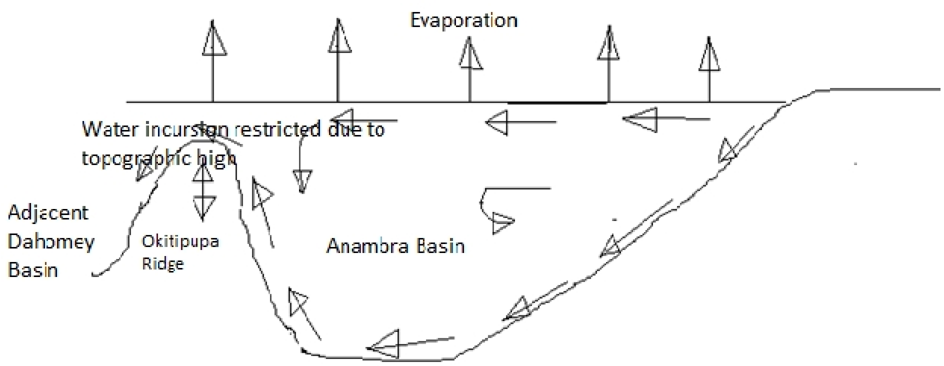


Fig. 2. Cross section of the relationship of the Okitipupa Ridge to the Anambra Basin forming topographic high along with other factors responsible for gypsum crystallization

5. CONCLUSION

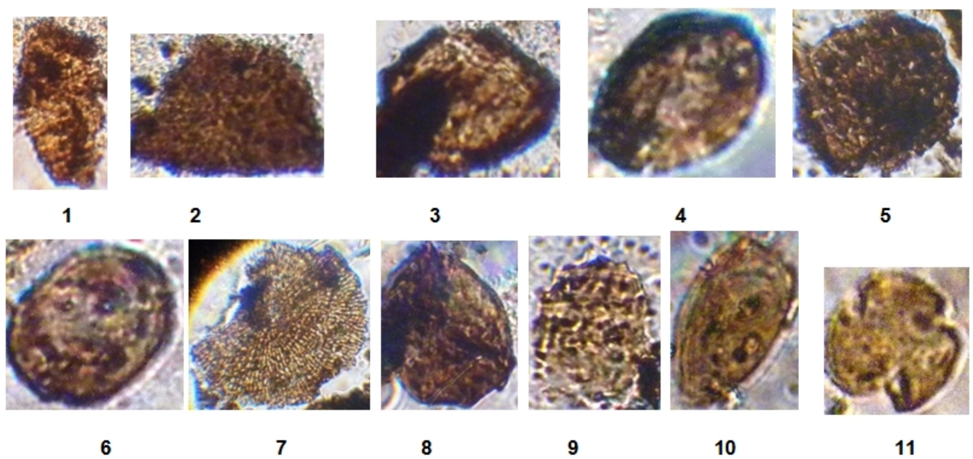
This study reveals that Asata/Nkporo Shale is a post Santonian sediment deposit in the Anambra Basin, Nigeria. One of the main characteristic features in this study is the stratigraphic succession that indicated different lithofacies relationship which varies from base gypsiferous shale, intercalated with dark grey fissile shale. The upper shale sequence is sandy and pebbly in nature suggesting a prograding deltaic setting. The uppermost lithofacies has over 75% gypsum content which increases upward and suggestive of shoaling paleobathymetry. Therefore, compared to earlier studies, the studied section of the well shows that the Asata/Nkporo Shale is not entirely shaley but contains some gypsum and sand grains of various sizes.

Palynological inferences show maximum development of Milfordia taxa within the interval (2216-2716m); characterized by lowermost appearance of *Longapertites sp 3* [11], while the upper part of the interval is defined by the first uphole appearance of *Buttinea andereevi*, last appearance of *Cupanieidites reticularis* and *Milfordia jardinei*. Thus, the studied interval is dated Campanian to Lowermost Maastrichtian age and the paleoenvironment of deposition is generally marginal marine setting.

ACKNOWLEDGEMENT

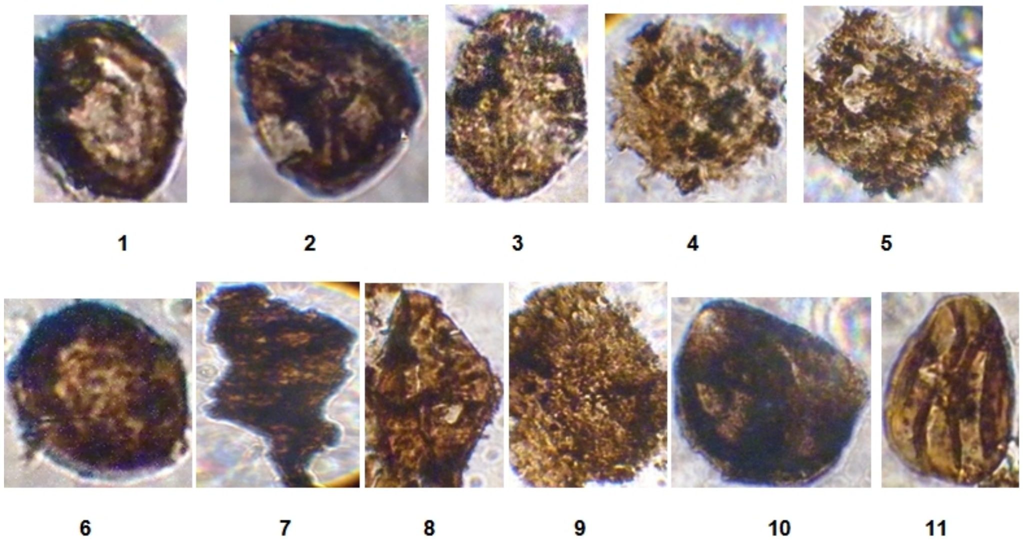
The authors are grateful to Palystrat Limited for consistent assistance in sponsoring researches and providing research tools and materials for this study. We as well appreciate the kindness of Geological Survey Agency of Nigeria, Kaduna for providing the ditch cutting samples and granting permission for publication of the results obtained. The author appreciates constructive criticism and corrections of the reviewers.

All magnification at X400 PLATE 1



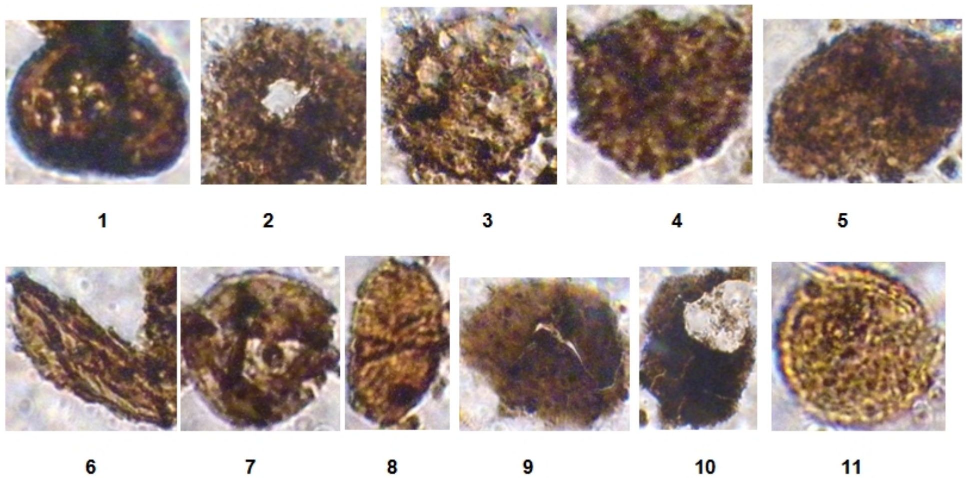
1 *Monosulcites sp*
2 *Longapertites sp 3* Lawal, 1982.
3 Stephanocolporate pollen
4 *Monocolpopollenites sphaeroidites*
5 *Milfordia sp. 3* Lawal, 1982.
6 *Milfordia sp.*
7 *Trichothyrites sp* (microthyriaceous fungal fruiting body) Ruta et al, 2007.
8 *Andalusiella laevigata* Malloy, 1972.
9 *Dinogymnium sp*
10 *Longapertites sp 3* Lawal and Moullade, 1986.
11 *Tricolpites sp 1* Jardine & Magloire, 1965.

All magnification at X400 PLATE 2



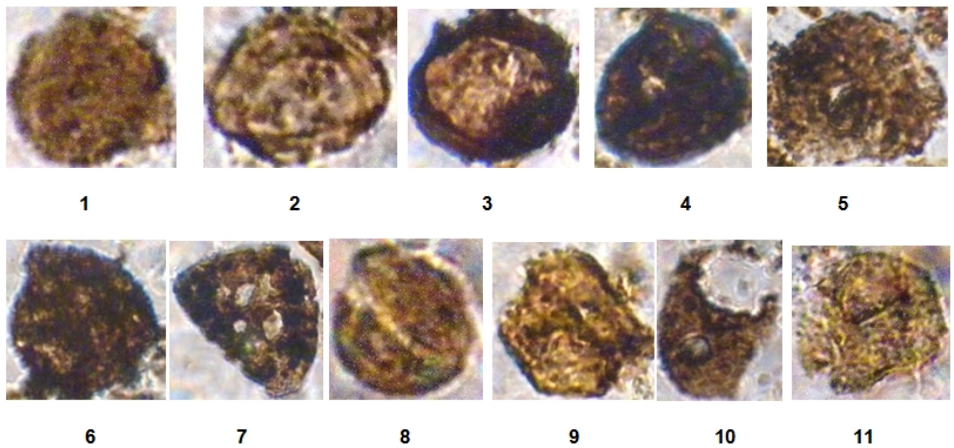
1 *Cupanieidites reticularis* Cookson and Pike, 1954.
2 *Cyathidites sp.*
3 *Retimonocolpites sp.*
4 *Homotryblium sp. A* Oloto, 1987.
5 *Pheloddinium bolonienae* Riegel, 1974.
6 *Milfordia sp 3* Lawal, 1982.
7 *Botryococcus brunii*
8 *Auriculiidites sp 1* Lawal, 1982
9 Dinocyst
10 *Phelodinium belonienae* Riegel, 1974.
11 *Tricolpites sp 2* Jardine & Magloire, 1965.

All magnification at X400 PLATE 3



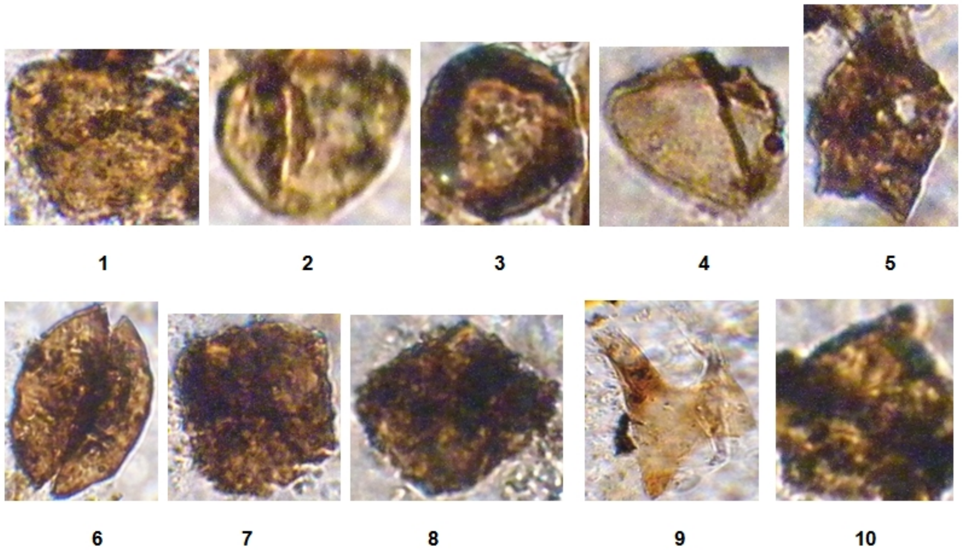
1 *Milfordia sp. 2A*
2 *Milfordia sp. 2B*
3 *Milfordia jardinei* Hochuli, 1979.
4 *Cf Zlivisporites blanensis*
5 *Milfordia sp.*
6 *Ephedripites sp.*
7 *Araucariacites australis* Cookson, 1947.
8 *Psilatricolporites diversus*
9 *Milfordia sp. 2D*
10 Forma Y
11 *Cicatricosisporites sp*

All magnification at X400 PLATE 4



1 *Retidiporites magdalenensis* Van der Hammen & Garcia, 1965.
2 *Milfordia sp. Z*
3 *Milfordia sp. 2A*
4 *Cupanieidites reticularis* Cookson & Pike, 1954.
5 *Milfordia sp 3* Lawal, 1982.
6 *Milfordia sp*
7 *Milfordia sp 4*
8 Stephanocolporate in Kuyl, Muller & Waterbolk, 1955
9 *Phelodinium bolonienae*
10 Forma Y
11 *Cf Cupanieidites reticularis*

All magnification at X400 PLATE 5



1 *Syncolporites ifeensis* Jan du Chene, 1977.
2 *Cupanieidites reticularis* Cookson and Pike, 1954
3 *Milfordia sp. 2A*
4 *Cf Graminidites sp.*
5 *Senegalinium sp.*
6 *Monosulcites sp.*
7- *Phelodinium bolonienae*
9 *Deflandre sp.*
10 *Senegalinium sp. 8* Lawal, 1982.

COMPETING INTEREST

Authors have declared that no competing interests exist.

REFERENCES

1 Murat RC. Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in southern Nigeria. In: Dessavagie TFJ and Whiteman AJ (Editors), African Geology, Ibadan University Press, Ibadan. 1972;251-266.
2 Akaegbobi IM. The Crabs eye view of the organic sedimentological evolution of the Anambra Basin Nigeria: Hydrocarbon source potential and economic implications. Faculty of Science Lecture, University of Ibadan, Ibadan. 2005;42.
3 Ola-Buraimo AO, Akaegbobi IM. Palynological evidence of the oldest (Albian) sediment in Nzam-1 well, Anambra Basin, sourhestern Nigeria; 2013 (unpublished).
4 Ola-Buraimo AO. Palynological stratigraphy of the Upper Cenomanian-Turonian Eze-Aku Formation in Anabra Basin, southeastern Nigeria. 2013;30(1):54-67.
5 Ola-Buraimo AO. Biostratigraphy and Paleoenvironment of the Coniacian Awgu Formation in Nzam-well, Anambra Basin, southeastern Nigeria; 2013 Unpublished).

6 Mebradu S. Palynofacies of Enugu/Ivia valley shales, Anambra state, Nigeria. Journal of Mining and Geology. 1990;26(1):13-20.

7 Nwachukwu SO. The tectonic evolution of the southern portion of the Benue Trough, Goelogical Magzine. 1972;109(5):411-419.

8 Ola-Buraimo AO. Palynozonation and chronostratigraphy of the Albian to Pliocene sediments of the Nzam-1 and Umuna-1 wells, Anambra Basin, southeastern Nigeria; 2012 (Unpublished thesis).

9 Reyment RA. Aspect of the geology of Nigeria. Ibadan University Press. 1965;145.

10 Ola-Buraimo AO, IM Akaegbobi. Neogene dinoflagellate cyst assemblages of the Late Miocene-Pliocene Ogwasi-Asaba sediment in Umuna-1 well, Anambra Basin, southeastern Nigeria. Journal of Petroleum and Gas Exploration Research. 2012;2(6):115-124.

11 Lawal O, Moullade M. Palynological biostratigraphy of sthe Creteceous sediments in the upper Benue Basin, N.E. Nigeria. Revue micropaleontology. 1986;29(1):61-83.

12 Jardine S, Magloire I. Palynologie et stratigraphic du Cretace des Basins du Senegal et de Cote d' Ivoire ler Coll. Memoire du. Bureau Recherches Geologiques et Minieres. 1965;32:187- 245.

13 Boltenhagen E. Pollen et spore Senoniens du Gabon. Cahier Micropaleontology. 1976;3:3-21.

14 Van der Hammen T. El desarrolla de la flora Colombiana en los periodos geologieos 1, Maestrichtiano basia Terciaro mas inferior. Bulletin Geologico (Bogata). 1954;2(1):49-106.

15 Van der Hammen T, Wijmstra TA. A palynological study of the Tertiary and Upper Cretaceous of British Guians. Leidese Geologische Mededelingen ;30:209-231.

16 Pacltova B. Nektererostlinne mikrofosilieze sladkovodnich ulozenin svrehni Kridy (Senon) vjihoceskych panvich, Sborn. Ustr. Ust. Geol. Od. Pal. 1961;26:47-102.

17 Van Hoeken-Klinkenberg PMJ. A palynological investigation of some Upper Cretaceous sediments in Nigeria. Pollen et Spores. 1964;6(1):209-231.

18 Van Hoeken-klinberg, P.M.J. Maastrichtian, Paleocene, and Eocene pollen and spores from Nigeria. Leidese Goelogische Mededelingen. 1966;38:37-48.

19 Boltenhergen E. spores et pollen du Cretace superior du Gabon. Pollen et Spores. 1967;ix(2):335-355.

20 Boltenhagen E. Pollen et spore Senoniens du Gabon. Cahier Micropaleontology. 1976;3:3-21.

21 Sole de Porta N. Algunos generous nuevos de pollen procedenies de la Formacion Guaduss (Maaastrichtiense). Paleocena de Colombia. Rev. Espanion Micropal. 1971;4(2):225-250.

22 Sole de Porta N. Contribucion a la palinologia delnive de Lutites y Arenas (Campaniniense) en Guataqui (Valledel Magdalena, Colombia). Rev. Espanion Micropaleontology.1972a;4(2):225-250.

23 Sole de Porta N. Palinologia de la Formacion Cameroun (Maastrichtiense) en el valle medio ded Magilalens. Colombia Studia Geologica.1972b;4:103-112.

24 Herngreen GFW. Some new pollen grains from the Upper Senonian of Brazil. Pollen et Spores. 1972;14(1):97-112.

25 Herngreen GFW. An Upper Senonian pollen assemblage of borehole 3-PIA - 10-AL, state of Alagoas, Brazil. Pollen et Spores.1975a;17(1):93-140.

26 Herngreen GFW. Palynology of Middle and Upper Cretaceous strata in Brazil. Meded. Rijks. Geol. Dienst NS.1975;26(3):39-91.

27 Jain KP. Morphologic reinterpretation of some dinogymnium species with remarks on palaeogeographic and stratigraphic distribution of the genus. Palaeobotanist. 1975;24(2):132-139.

28 Jain KP. An Upper Cretaceous dinoflagellate assemblage from Vriddhachallam area, Cauvey Basin, south Inolia. Palaeobatanist. 1976;25:146-160.

29 Elsik WC. A new sporomorph genus from Eastern Peru. Pollen et Spore. 1964;8,(3):553-564.

30 Jan Du Chene RE. Some new pollen species of the Upper Maastricthtian Tar Sand, Abeokuta Formation. Southern Nigeria. Reveu. Espania Micropaleontologie. 1977;IX(2):191-201.

31 Jan Du Chene RE, I De Klaz, Archibony EE. Biostratigraphic study of the borehole Ojo 1, S.W, Nigeria, with special emphasis on the Cretaceous microflora. Revue. Micropaleontologie. 1978a;2(3):123-139.

32 Jan Du Chene RE Onyike MS and Sowunmi MA. 1978b. Some new Eocene pollen of the Ogwashi Asaba Formation, Southeastern Nigeria. Revue Espania Micropaleonlogie. 1974;X(2):285-322.

33 Salard-Cheboldaeff M. Palynologie Maestrichtienne et Tertiare du Cameroon. Etude qualitative et repartition vertical des principales especes. Revue Paleaeobotany Palynology. 1979;28(¾):365-387.

34 Baksi SK, Debi U. Palynology of the Upper Cretaceous of the Bengal Basin, India. Revue Paleobotany Palynology. 1987;31(3/4):335-365.

35 Salami MB. Some Late Cretaceous and Early Tertiary pteridophytic spores from the southern Nigeria sedimentary Basin. Revue Espania Micropaleontologie. 1983;15(2):257-272.

36 Salami MB. Late Cretaceous and Early Tertiary palynofacies of southwestern Nigeria. Revue Espania Micropaleontologie. 1984;16:415-423.

37 Salami MB. Upper Senonian and Early Tertiarypollen grians from the Southern Nigeria Sedimentary Basin. Revue Espania Micropaleontologie. 1985;17(1):5-26.

38 Salami MB. Some dinoflagellate cysts and acritatchs from the Late Cretaceous and Paleogene sediments of the Benin (ex Dahomey) Embayment in southwestern Nigeria. Ife Journal of Science. 1986;1(1):11-21.

39 Salami MB. Petrography and palynology of the Upper Maastrichtian Abeokuta Formation of southwestern Nigeria. Ife Journal of Science. 1988;22(1-2):127-142.

40 Schrank E. Paleozoic and Mesozoic palynomorphs from northeast Africa (Egypt and Sudan) with special reference to Late Cretaceous pollen and dinoflagellates. Berlin Goewiss Abh (A). 1987;75(1):249-310.

41 Oloto IN 1987. Maastrichtian dinoflagellate cyst assemblage from the Nkporo shale on the Benin Flank of the Niger Delta. Review of Palaeobotany and Palynology. 1987;57:173-186.

42 Edet JJ, Nyong EE. Depositional environments, sea level history and paleogeography of the Late Campanian - Maastrichtian on the Calabar Flank, SE Nigeria. Paleogeography, Paleoclimatolology, Palaeoecology. 1994;102:161-175.

43 Umeji OP. Palynological evidence for the Turonian/Campanian boundary between the Abakaliki and the Anambra basins, as exposed at Leru along the Enugu-Portharcourt express, southeastern Nigeria. Journal of Mining and Geology; 2006.

44 Sultan IZ. Maastrichtian plant microfossils from the El Mahamid area, Nile Valley, Southern Egypt. Revue Micropaleontology. 1985;28(3):213-222.

45 Petrosyants MA, Trofimov DM. Caracteristique sporopollinique des formations du Cretace superieur de la syneclise du Niger-Mali (Sahara meridional). Byul. Mosk. Ova. Ispyl. Prir. Otd. Geol. 1971;76(6):75-85 (in Russian).

46 Nyong EE, Ramanathan R. A record of oxygen deficient paleoenvironment in the Cretaceous of the Calabar Flank, S. E. Nigeria. Journal Afrcan Earth Scieince. 1985;3(4):455-460.

47 Zaborski PMP. Lower Cenomanian (Mid-Cretaceous) ammonites from southeastern Nigeria. Journal African Earth Sciences. 1982;5(4):371-380.
48 Reyment RA. The Cretaceous ammonoiden of southern Nigeria and southern Cameroons. Bull. Geological Survey Nigeria. 1955;25:1-112.
49 Lawal O. Biostratigraphie palynologique es paleoenvirunmens des formationsCretacee de la Haute- Benoue, Nigeria mord-oriental. These-3-cycle, Univ. Nice. 1982;218.
50 Harland R. Dinoflagellate cyst and acritarchs from the Bear paw Formation (Upper Campanian) of southern Alberta, Canada. Paleontology. 1973;16(4):665-706.
51 Ogala JE Ola-Buraimo AO, Akaegbobi IM. Palynological investigation of the Middle-Upper Maastrichtian Mamu Coal facies in Anambra Basin, Nigeria. World Applied Sciences Jour. 2009;7(12):1566-1575.
52 Ola-Buraimo AO, Adeleye M. Palynological characterization of the Late Maastrichtian Ute Coal measure deposit, Southwestern Nigeria. Science Focus. 2010;15(2):276-287.
53 Sonnenfed P. Brines and evaporates Academic Press, London. 1984;624.
54 Sonnenfed P. Evaporites as source rocks of oil and gas. Jour. Petroleum Geology. 1985;8:253-271.
55 Logan. MacLeod Evaporates Basin of Australia. 1987. In, Applied sedimentology. Academic Press, Harcout Brace Jovanovich, Publishers; 1988
56 Selly RC. Applied sedimentology. Academic Press, Harcout Brace Jovanovich, Publishers; 1988.
57 Omatsola ME, Adegoke OS. Tectonic Evolution and Cretaceous Stratigraphy of the Dahomey Basin. Journal of Mining and Geology. 1981;18(1):130-137.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=226&id=5&aid=1441