British Journal of Applied Science & Technology
14(3): 1-11, 2016, Article no.BJAST.20452
ISSN: 2231-0843, NLM ID: 101664541

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Appraisal of the Middle Cretaceous Sediments in Ubiaja-1 well Through the Use of Palynology in Anambra Basin, Southeastern Nigeria

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Authors' contributions

This work was carried out in collaboration among the authors. Author AOOB designed the study. Authors AOOB, MA and NAY managed the analyses of study and performed the statistical analysis. Author NAY managed the literature searches. Authors AOOB and MA wrote the protocol. Author AOOB wrote the first draft of the manuscript. The authors read and approved the draft of the manuscript.

Article Information

DOI: 10.9734/BJAST/2016/20452
Editor(s):
(1) Verlicchi Paola, Department of Engineering, University of Ferrara, Via Saragat 1, Ferrara, Italy.
Reviewers:
(1) Gabriela Civeira, Universidad de Moron, Argentina.
(2) Honglei Liu, Tianjin Academy of Environmental Sciences, China.
(3) Alexandre Marques da Silva, Sao Paulo State University, Brazil.
Complete Peer review History: http://sciencedomain.org/review-history/13145

Original Research Article

Received 28th July 2015
Accepted 28th August 2015
Published 3rd February 2016

ABSTRACT

Revelation of the presence of older sediments continues to evolve in the Anambra Basin through the biostratigraphy study of Ubiaja-1 well located in the Anambra Basin, Nigeria. The study is predicated with a view to determining the age of the oldest sediments, evidence of rework sediment and chronostratigraphy of the studied section. The method of analysis includes digestion, sieving, oxidation, floatation of residues and final mounting of them on glass slides for petrographic observation using binocular microscope. The lithostratigraphy of the formations varies from dark grey fissile shale and shaley siltstone at the base through heterolith facies of sand and shale, dark grey fissile shale at the middle section to sandstone and intercalated sand and shale of various proportions at the upper section of the interval. Three palynological zones were erected: *Triorites africaensis* assemblage zone 1 (2510-3130ft) characterized by co-occurrence of *Triorite africaensis*

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and *Lycopodiumsporites* sp dated Turonian age; belonging to Eze-Aku Formation; *Droseridites senonicus* assemblage zone 2 varying from interval 2052-2510ft, characterized by the co-occurrence of *Droseridites senonicus, Trifossapollenites sp* and the dominance of angiosperm pollen, dated Coniacian age and belongs to Awgu Formation. This is overlain by the *Milfordia spp.* acme zone 3, ranging from interval 1440 to 2050ft, marked by the appearance of *Milfordia jardinei, Milfordia sp* and paucity of palynomorphs. The interval is dated Campanian age and belongs stratigraphically to Nkporo Shale. The results show that sediments older than Santonian age, devoid of rework sediment and which ranges from Turonian to Campanian age are present in Anambra Basin. The paleoenvironment of deposition is mainly deltaic to marginal marine defined by the occurrence of *Andalusiella sp, Senegalinium sp* and *Criproperidinium sp.*

Keywords: Oldest sediment; biostratigraphic sequence; heterolith; Turonian; Coniacian; Campanian.

1. INTRODUCTION

The study area is located in the southern part of the Anambra Basin (Fig. 1). The search for hydrocarbon in Nigeria started in the Anambra Basin situated in the southeastern part of the country. The unsuccessful breakthrough in the early period prompted the search to be extended to southern basin referred to as Niger Delta in Nigeria. The discovery of oil and gas in the Niger delta discouraged intense continuous search for hydrocarbon in the Cretaceous sediments of the Anambra Basin. The origin of the Anambra Basin is similar to the way by which other sedimentary basins in Nigeria were formed due to the separation of the Africa and South America land masses known as Gondwana land [1]. The trough-like structure formed along the central part of the country led to the formation of the Anambra Basin.

It is generally believed in some quarters that the Anambra Basin contains exclusively of post Santonian sediments. This theory stems from the fact that sedimentation started in the Middle-Cretaceous from the Abakaliki Trough during which the Anambra Basin was a high; as a result there was no sedimentation [2,3]. However, during the Santonian period was a tectonic activity which reversed the situation whereby the Anambra Basin now become a trough and the Abakaliki becomes anticlinorium; this was associated with sedimentational axis reversal whereby there was erosion of earlier deposited sediments in the Abakaliki anticlinorium deposited in the Anambra Basin [4]. This theory of the evolution of the basin sounds good but lack biotratigraphic evidence to support the assertion. Biostratigraphically, such sediments should contain both older and younger fossils deposited together after the Santonian tectonic event.

Recent works on the retrieved ditch cutting samples from exploration wells have proved otherwise for some parts of the basin investigated so far [5,6]. It is ironical that most of the geological researches by the earlier workers were concentrated on the southern part of the basin most especially in the southern Onisha-Portharcourt axis. [5] dated the oldest sediment in the Anambra Basin to be Albian-Lower Cenomanian for the Asu River Group. Overlying this formation is the Eze-Aku Formation dated Upper Cenomanian –Turonian [7]; subsequently overlain by Awgu Formation dated Coniacian age [8]. The evidences of these pre-Santonian sediments are well documented in Nzm-1 and Umuna-1 wells located in the Anambra Basin, Nigeria [9].

As stated earlier there has not been enough evidence to support sediment rework in the Anambra Basin from the experience of the first author. All samples obtained from the basin including both subsurface and outcrop samples; none of them suggests reworking of the older sediments along with younger sediments in the samples of Nkporo Shale studied by [6,9] or from Mamu Shale and Coal deposits by [10]. The only sedimentary facies associated with evidence of reworking in Anambra Basin is the Ogwashi/ Asaba Formation where Oligocene forms were seen in association with Late Miocene/ Pliocene palynomorph forms [11]. Therefore, it is imperative to deviate from the psyche of widespread tectonic upliftment and redeposition in the basin to the idea of a basin associated with deep fault blocks which contain within horsts and grabens in which sediments of various ages were deposited depending on the location. Palynology as a tool was employed to elucidate these problems. However, palynology is an aspect of biostratigraphy is a scientific study of pollen, spores, dinoflagellates, algae and other

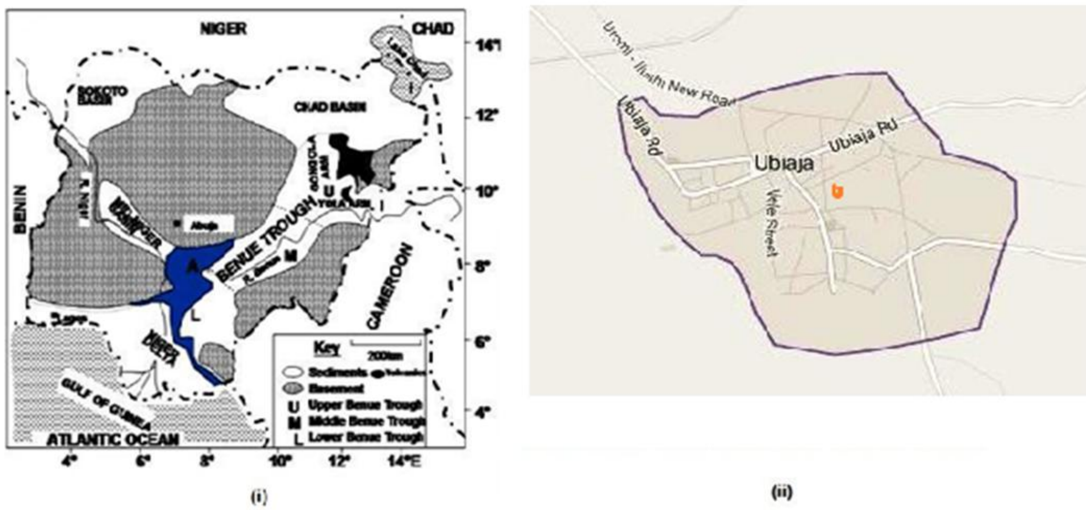

Fig. 1. (i) Generalized geological map of Nigeria showing Anambra Basin [12; blue color-A]; (ii) location map of the Ubiaja -1 well in Anambra Basin

important fossils or material present to determine the chronostratigraphy, relative age dating for the geologic purposes, evidence of sediment rework, detection of unconformity, sequence stratigraphy, climatic changes, organic richness, kerogen type, source rock thermal maturity and other important uses as set objectives of the researcher. Thus, this prompted the need to carry out further studies through the appraisal of Ubiaja-1 well in Anambra Basin in order to determine whether oldest sediments present in the Ubiaja-1 well are older or younger than Santonian age as generally ambiguously known with the evolution of Anambra Basin; in pursuant of this to determine evidence of rework sediments based on the co-occurrence of older and younger fossils that were supposedly transported from the Abakaliki Anticlinorium and redoposited in the Anambra Basin. Finally to generate a chronostratigraphy framework for the studied interval so as to serve as reference well and used for future correlation with other wells in the region.

2. GEOLOGIC SETTING AND STRATIGRAPHY

The Anambra Basin is one of the Cretaceous sedimentary basins of Nigeria, bounded on the southwestern flank by the Niger Delta hinge line, northwest by the Benue flank and southeast by the Abakaliki fold belt. The basin lies between latitudes 5.0°N and 8.0°N and longitudes 6.3°E and 8.0°E. To a school of thought the Anambra Basin is the lower section of the Benue Trough, an intracratonic basin, trending NE-SW, folded and aborted rift basin that runs obliquely across Nigeria.

Therefore, its origin was linked to the tectonic processes that accompanied the separation of the African and South American plates in the Early Cretaceous [1,2]. The structural evolution of the Anambra Basin has been described by others [13-17]. Prior to the tectonic event, the Anambra Basin was a platform that was only thinly covered by sediments. The folding of the Anticlinorium laterally shifted the depositional axis into the Anambra platform which then began to accumulate sediments shed largely from the Abakaliki Anticlinorium [1,18,19]. The Anambra basin-fill comprises over 2500 m of sediments that accumulated during the Campanian-Paleocene period. The lithostratigraphic framework for the Early Cretaceous- Paleocene strata in southeastern Nigeria has been summarized by [20; Table. 1).

The sequence of depositional events have been suggested by various authors including [21-23] suggest a progressive deepening of the basin from lower coastal plain and shoreline deltas to shoreline and shallow marine deposits. The resulting stratigraphic succession comprises of the Nkporo Group, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Formation and Ameki Group (Table 1). The detailed stratigraphic description of these formations is available in several publications [24-26]. The rich coal deposits of Middle – Early Maastrichtian ages suggest brackish marshes during their deposition [10].

Table 1. Correlation chart for early cretaceous strata in southeastern Nigeria [20]

Age		Abakaliki-Anambra basin	Afikpo basin
30 M.Y	Oligocne	Ogwashi-Asaba formation	Ogwashi-Asaba formation
54.9	Eocene	Ameki/Nanka formation Nsuegbe 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 87.5	Campanian	Nkporo Oweli formation/Enugu shale	Nkporo Shale/Afikpo sandstone
	Santonian		Non-deposition/erosion
88.5	Coniacian	Agbani sandstone/Awgu shale	Non-deposition/erosion
93	Turonian	Eze Aku Group	Eze Aku group (include Amasiri Sandstone)
100	Cenonian-Albian	Asu River group	Asu River group
119	Aptian Berremian Hauterivian	Unnamed group	
Precambriam		Basement complex	

This study's idea on the sedimentation and resultant stratigraghy of the Anambra Basin runs contrary the earlier conception that Anambra Basin contains exclusively of post Santonian sediments. Recent studies have revealed that pre-Santonian sediments that are as old as Albian in age are present in the basin [5]. As a result of this, pre Santonian formational sequence have been dated using palynological tool. The Asu-River Group is the oldes facies, dated Albian to Lower Cenomanian [5]. This is overlain by Eze-Aku Formation dated Upper Cenomanian to Turonian age [7]; further overlain by Awgu Formation, dated Coniacian in age [8].

3. MATERIALS AND METHODS

3.1 Litho-description

Laboratory lithological description involved observation of color of sample, textural characteristics such as grain size, roundness in term of angularity of grains, sorting and other important parameters such as fossil content, presence of accessory minerals, degree of diagenesis and the effect of dilute hydrochloric acid on the sediments [27].

3.2 Materials and Palynological Preparation

The materials used for the palynological analysis are mortar and pestle, weighing balance, sample plastic cups, pipettes, 5 micron sieves, centrifuge, fume cupboard, Branson sonifer 250, distilled water, test tubes, glass slide and cover slip, hydrochloric acid (HCl), hydrofluoric acid (HF), filter paper, glycerine ($C_3H_8O_3$), 250 ml polypropylene beakers, Nitric acid (HNO_3), Zinc Bromide ($ZnBr_2$), TPX (a mounting medium), Potassium hydroxide (KOH) and personal protective wears such as safety gloves, glasses and coverall. The samples retrieved from the Ubiaja-1 well range from 1460-3130 ft; weighed to about 20 gm, soaked overnight in Hydrofluoric acid (HF), and stirred intermittently for effective digestion. This is followed by sieving process with 5 µm mesh in order to remove clay particles present, enhance collection of the debris and to achieve clean slide making. The retrieved debris of the samples was mildly oxidized, followed by heavy mineral liquid separation of the macerals using Zinc bromide ($ZnBr_2$) at 2.1 g/cc. The collected residue was mounted on glass slides with DPX. The preparation method was in accordance with standard methods [28-30].

Pollen, spores, dinoflagellates, fungal spores, microforaminiferal wall linings and other stratigraphically significant forms present were determined for each sample in terms of abundance and diversity; and were interpreted by comparison with established works. However, diagnostic species photographs were taken with Nikon Koolpix P6000 digital camera (Table 3 and Plate 1).

4. RESULTS AND DISCUSSION

4.1 Litho-description

Six lithologic units were differentiated from the analyzed section, ranging from 1440-3130 ft. The lithofacies units were determined on the basis of textural characteristics, colour, facies type and post depositional effect on the sediments [27]. The lithofacies units are described in detail below:

4.2 Lithofacies Unit 1: Shale

This lithofacies form the bulk of sediment present in the analyzed section. The shale is light to dark in colour and mostly fissile but rarely bulky in nature. The intervals of occurrence are in the upper part- 1440-1445 ft, 1529-1530 ft, 1600-1615 ft, 1625-1820 ft; in the middle part- 1875-1915 ft, 2018-2052 ft, 2245-2275 ft, 2310-2420ft and in the lower part- 2507-2510 ft, 2663, 2668-3310 ft. The shale sequence is compared with the works of [7,8,6]; thus suggested to have been deposited in marine environment (Table 2).

4.3 Lithofacies Unit 2: Sandy Shale

This is a heterolith facies consisting of sand and shale. It is a light grey sandy shale where the sand size is coarse and slightly ferruginized. The sand/shale proportion varies from 25/85 to 45/55% where the sand grains vary in size from fine to coarse, angular to rounded and well sorted. It is suggested that the facies may have been deposited in a near shore environment or a deltaic setting [7,8,6]. The lithofacies unit occurred at intervals 1450 ft, 1621-1625 ft, 2285-2390 ft, 2497 ft, 2658 ft, and 2665 ft (Table 2).

4.4 Lithofacies Unit 3: Sandstone

The sandstone unit moderately occurred within the studied interval. The sandstone unit is usually whitish to pinkish in colour; grain size varies from fine to very coarse, angular to rounded and moderately sorted. The energy of transportation is suggested to be moderate and deposited in a continental to shoreface settings [7,8,6]. It occurred at1549 ft, 1574-1584 ft, 1840 ft, 1974-1981 ft, 2015 ft, 2202 ft, 2407-2479 ft (Table 2).

4.5 Lithofacies Unit 4: Claystone

The claystone is the smallest facies in terms of thickness. It is intercalated within sandstone units. The claystone is light brown in colour with minor sand clast. It is found at depth1464 ft.

4.6 Lithofacies Unit 5: Shaley Sand

This is another heterolith facies consisting of shale and sand. The sand is more predominant than shale. The sandstone is pinkish to reddish in colour and grain size varies from fine to very coarse, angular to rounded, moderately sorted. The lithofacies is suggested to be deposited in a near shore environment when compared with the similar work of [7,8]. The intervals of occurrence are 2477-2487 ft, 2578-2588 ft. It has a total thickness of 20ft (Table 2).

4.7 Lithofacies Unit 6: Shaley Siltstone

This lithofacies varies in depth from 2548-2578 ft (Table 2). It is a light grey shaley siltstone. It is characterized by silt size grains with minor clasts, slightly, ferrouginized in nature. The silt/shale ratio is 60:40%. It is suggested to have been deposited in a relatively deeper marine environment probably within the lower shoreface [7]. It has a total thickness of about 30 ft. It could serve as excellent reservoir because of its high porosity and shale interbeds as seal.

4.8 Biozonation

The miospore recovery is generally poor and fairly moderate at few intervals; poorly preserved in nature. However, distinctive forms present were used for palynozonation. Three palynological zones are erected after the works of [31-35,6]. The details and basis of establishing the zones are given bellow:

Interval: 2510-2778ft
Zone: *Triorites africaensis* Assemblage Zone 1
Age: Turonian

Characteristics: The base of the interval is marked by the appearance of *Lycopodiumsporites sp, Classopollis sp,* and *Inaperturopollenites sp*. The interval is characterized by co-occurrence of *Trioritesafricaensis, Monocolpites sp, Monosulcites sp,* and *Cyathidites sp.* The top of the interval is defined by relative increase in palynomorph recovery (see Table 3). The top is associated with *Trifosapollenites rugosa, Tetradites sp, Monosulcites sp* and a number of dinoflagellates such as *Cribroperidinium sp, Andalusiella sp, and Senegalinium sp* (Table 3). Some of the forms contained in the interval are comparable with those reported by [7]. The interval is shaley in nature and stratigraphically equivalent to the upper part of Eze-Aku Formation.

Interval: 2052-2510 ft
Zone: *Droseridites senonicus* Assemblage Zone 2
Age: Coniacian

Characteristics: The base of the zone coincides with the top of the underlying older *Triorites africaensis* zone. The interval is characterized by paucity of palynomorphs. It is marked by the occurrence *Tricolpites sp, Monosulcites sp,* and *Tricolporopollenites sp;* while the top is marked by the appearance of *Droseridites senonicus, Monoporites sp,* and *Classopollis sp.* The 8 6 eticulates 6 ic feature of this zone is the dominance of angiosperm pollen [3] and co-occurrence of marker form *Droseridites senonicus.* The interval is conveniently dated Coniacian age. Stratigraphically, the interval is equivalent to Awgu Shale and it is sitting unconformably on the younger Campanian sediments (see Table 3).

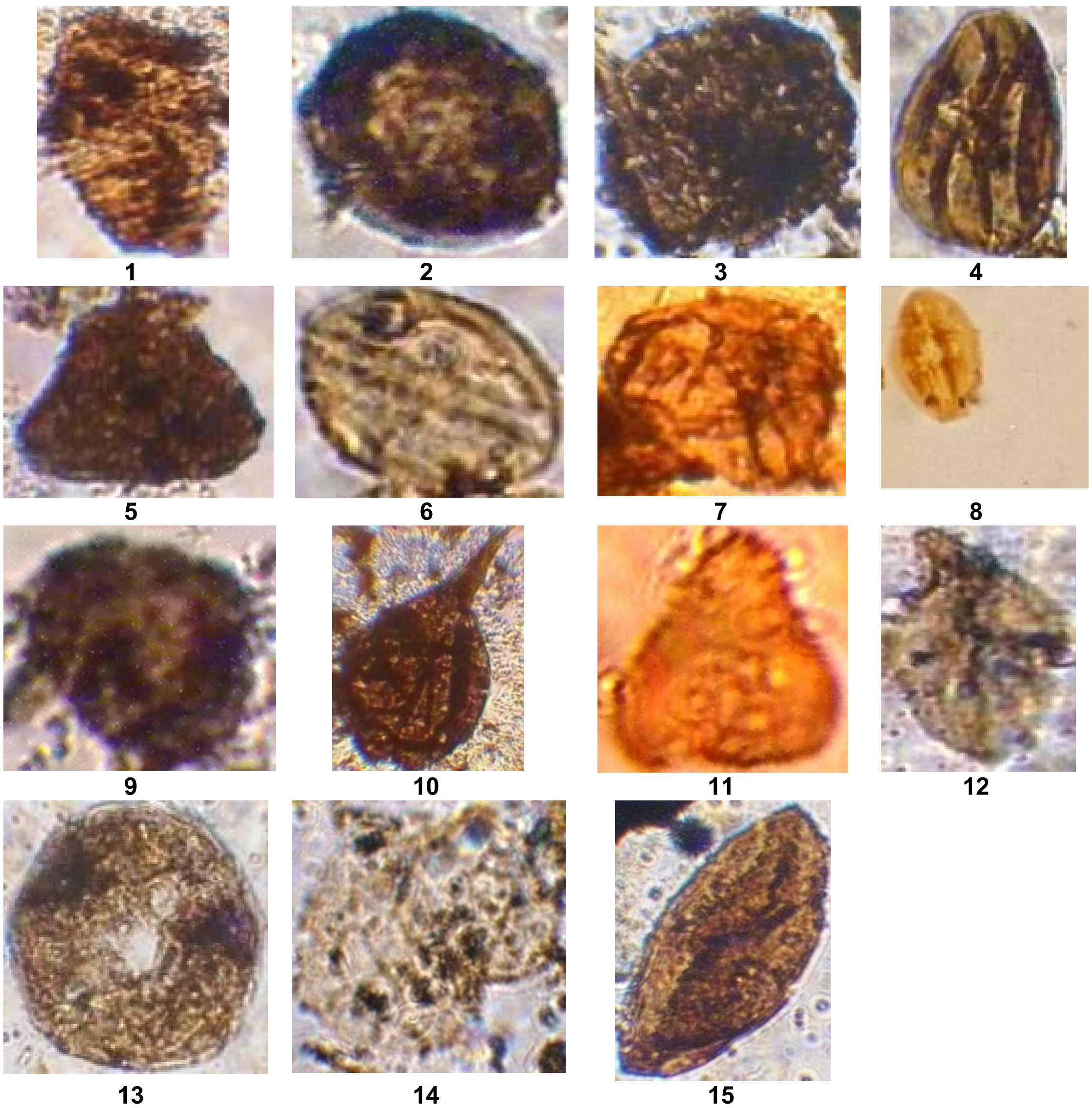

Plate 1. Monographs of important palynomorphs

1-Monosulcites sp, 2,3- Milfordia sp, 4-Tricolpites sp, 5-Triorites africaensis, 6-Monocolpites sp, 7-Zlivisporites blanensis, 8-Tricolporopollenites sp, 9-Classopollis brasiliensis. 10-Andalusiella polymorpha, 11-Triorites africaensis, 12-Auriculiidites reticularis, 13-Milfordia jardinie, 14-Senegalinium sp, 15-Monosulcites sp

Table 2. Litho-log of interval 1440-3130ft, indicating delineated lithology, equivalent formations and paleoenvironment of deposition

Depth	Litho-log	Lithology	Formation	Description	Paleoenvironment
1440	_-_-_-_--_-__-_-_-_---_-	Light grey fissile shale		Light grey fissile shale	
	………………………………………..........	Sandstone		Fine to very coarse sandstone, moderately sorted	
1480	_--_-_--_-_-_----_-_----_-_---_-__-_- _--_--_-_--_--_-_--_-_-_-_-……_-_- …._--_--……_-_--………_--_---	Light grey fissile shale			
1549	………_-_--……_-_-_--_-_-_-_-_-_- _-------_-_-_-_-_--_-_---_-_-_-_-_-_-	Intercalated sand and shale			
1584	_-_-----_-_-_-_-_-----_-_-----_-_-_--- _----_---_-_--_-------_-_-__-_-_-_----_- _-_-_-_-__-_--_---_-_-----_-_--_--_--- -_-----_-----_-_-_-_-_---_-_-_-_-_--_- _-_-_---_--------- …………………………………………. _-_-_-……._---_--……_-_--_-	Shale	Nkporo	Dark grey fissile shale with different degrees of ferruginisation	Deltaic To Marine
2420	……._--__--…….._-_-_---_-_---_--- _-_-_-_-_-_-_----_--_-_-_-_-_-_-_-_-_-	Sandstone and heterolith	Awgu		
2490	_-__-_-_-_-__-_--_-_-_-__-_-__------- ---_-_----_-_---------…….._-_---- _……._-----…._-_-__-_-……._---_-- ---------_-_--_-_-_-_--_-_-_-_-_-_-_--	Shale			
2575	-_---_-----_----_---_--------_---_--_--- _----_---_---_---_---_----_----_----_----	Heterolith sand and shale		Heterolith of sand and shale in different proportion	Marginal marine
2665	_----_----_----_----_---_--_-_-_---_-__- _-_-__-_-----_---__---_----_-----_---- _----_------_------__---______-----__--- _----_----__-----_-----_-----_----__--- __---__----__----__---__----__----__-- --__----_----_----__---_----_---_---_--- -__--_---__---__--__---_---_---__--	Shale			
3130	__-----_---_--_--_--_-----		Eze-Aku	Dark grey fissile shale	

Table 3. Distribution chart, palynozones, characteristics, age and paleoenvironment

DEPTH	LITHO-LOG	FORMATION	ZLIVISPORITES BLANENSIS	MILFORDIA JARDINIE	LEIOTRILETES SP	TRICOLPOROPOLLENITES SP	AURICULIIDITES RETICULATUS	AURICULIIDITES SP	MONOPORITES SP	INAPERTUROPOLLENITES SP	MILFORDIA SP	DROSERIDITES SENONICUS	CLASSOPOLLIS SP	MONOSULCITES SP	TRICOLPITES SP	TRIFOSSAPOLLENITES RUGOSA	TETRADITES SP	TRIORITES AFRICAENSIS	MONOCOLPITES SP	LYCOPODIUMSPORITES SP	SENEGALINIUM SP	ANDALUSIELLA SP	CRIBROPERIDINIUM SP	BOTRYOCOCCUS BRAUNII	PALYNOMORPH ABUNDANCE	PALYNOMORPH DIVERSITY	PALYNOZONE	CHARACTERISTICS	AGE	PALEOENVIRONMENT
1440		Nkporo Shale																			1			1	2	2	*Milfordia spp* zone	Based on the co-occurrence of *Milfordia jardinie* and *Auriculiidites reticulatus*	EARLY CAMPANIAN	MARGINAL MARINE
1529			1																						1	1				
1610-1615				1																					1	1				
1730-1735							BARREN																							
1795-1800																								2	2	1				
1875					2																1	1		4	9	6				
1974-1981				1		2	1	1	1	1	1										2			6	18	10				
2052		Awgu Shale				1			1			1	1											2	6	5	*Droseridites senonicus* Assemblage zone	Based on the occurrence of *Droseridites senonicus*	CONIACIAN TO ?SANTONIAN	
2245						1																		1	4	3				
2330														1	1						1			1	4	3				
2420																								1	1	1				
2510		Eze-Aku				1				1				1		2	1				1	1	1	5	16	10	*Triorites africaensis* Assemblage zone	Based on the oc-occurrence of *Triorites africaensis* and *Trifossapollenites rugosa*	TURONIAN	
2638					1					1				1				1	3					4	13	7				
2698																				1				7	8	2				
2778										1			1							3				1	8	6				

DISTRIBUTION CHART OF IMPORTANT PALYNOMORPHS IN ORDER OF APPEARANCE, LITHOLOGY, FORMATION, PALYNOZONE, AGE AND PALEOENVIRONMENT OF DEPOSITION OF SEDIMENTS OF INTERVAL 1440-2778FT OF UBIAJA- 1 WELL, ANAMBRA BASIN, SOUTHEASTERN NIGERIA.

Interval: 1440-2052 ft
Zone: *Milfordia spp* Zone
Age: Campanian

Characteristics: The base of the interval is marked by the relative increase in palynomorph recovery. This is further characterized by the co-occurrence of *Milfordia jardinie, Milfordia sp,Auriculiidites 9 eticulates, Auriculiidites sp 1* and *Tricolporopollenites sp.* Other forms present are *Zlivisporites blanensis* and *Senegalinium sp* (see Table 3). The palynomorph recovery in this interval is similar in part to those recovered from Asata/Nkporo Shale in Anambra Basin [6]. Therefore, the interval is dated Campanian age and also belongs to Nkporo Formation of the Anambra Basin, Nigeria [9].

The research study has shown through the checklist presented and microphotographs (Plate 1) that there is no evidence of rework fossils that may suggest mixture of older and younger sediments during transportation from the Abakaliki Anticlinorium to the Anambra Basin during the Santonian tectonic period. Furthermore, the chronostratigraphy of the study ranges from Turonian through Coniacian to Campanian belonging to Eze-Aku, Awgu and Nkporo Formations respectively. The inference shows that the results obtained negate the general assertion that older sediments greater than Santonian age (Albian-Coniacian) are restricted to Abakaliki Anticlinorium and that only younger sediment less than Santonian age (Campanian-Recent) are contained in Anambra Basin. Therefore, sedimentation is suggested to be primarily controlled by deep faults associated with horsts and grabens of varying sediment thicknesses and ages dependent on factors of weathering, transportation, tectonics and eustatic sea level changes. These differ from sedimentation reversal that is orchestrated and asserted being responsible for sedimentation in Anambra Basin where redeposition took place from the Abakaliki Anticlinorium into the Anambra Basin.

5. CONCLUSIONS

Six different lithofacies units such as shaley sand,shale, sandstone, claystone, shaley sand and shaley siltstone were delineated at various levels intercalating one another. The sandstone and claystones were suggested to be deposited in continental environment while the other facies present were deposited within the shoreface settings. Three palynozones ranging from Turonian –Campanian age belonging to Eze-Aku, Awgu and Nkporo Formations were established. However, there is no evidence of sediment rework that may suggest redeposition of sediment from Abakaliki to Anambra Basin which is not apparent in this study. This, further lend credence to the idea that Anambra Basin contains Pre-Santonian sediments of Middle Cretaceous age. It is suggested that further study using microfominifera should be used to corroborate the conclusion drawn on this study.

ACKNOWLEDGEMENT

The authors are grateful to Palystrat Limited for provision of materials, to Nigerian Geological Survey for providing samples and to the anonymous reviewers for their constructive suggestions and corrections.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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