Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 20 Issue 6 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Palynology and Stratigraphy Relationship of the Facies Intertongueing between the Afikpo Sandstone and Nkporo Shale in the Cretaceous Anambara Basin, Southeastern Nigeria

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Keywords: nkporo group, intertongueing, afikpo sandstone, nkporo shale/afikpo sandstone, campanian-early maastrichtian and intercalation.

GJSFR-H Classification: FOR Code: 059999

Strictly as per the compliance and regulations of:

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Two palynological zones: *Milfordia spp* acme zone I characterized by relative high abundance of *Milfordia* spp. such as *Milfordia* sp. and *Milfordia jardinei*, dated Campanian and the overlying *Foveotriletes margaritae zone* II characterized by paucity *of Milfordia* spp. and co-occurrence of *Monocolpopollenites sphaeroidites, Syncolporites* sp., *Ephedripites* sp., and *Monosulcites* sp.; dated Early Maastrichtian age. The age dating and the stratigraphic lithofacies is equivalent to Nkporo Shale/Afikpo Sandstone known for Afikpo Basin stratigraphy but here reported newly in the Anambra Basin. This suggests lateral facies intertongueing of Afikpo Sandstone characterized by erosional surfaces, unconformable with Nkporo Shale, extended into Anambra Basin. The result reveals a new sandstone member in the Nkporo Formation or in another way makes Nkporo Formation to become Nkporo Group comprising of Nkporo Shale and Afikpo Sandstone.

Keywords: nkporo group, intertongueing, afikpo sandstone, nkporo shale/afikpo sandstone, campanian-early maastrichtian and intercalation.

I. Introduction

The full knowledge of the statigraphy of Anambra Basin is still a mirage considering the complexity of the lithofacies in both vertical and lateral relationship. The Ubiaja-1 well is located in the Anambra Basin, Delta State, Nigeria (Fig. 1). A considerable lower section of it had earlier been investigated by Ola-Buraimo *et al,* (2015). In this study the upper part of the well is being investigated to further elucidate the lithofacies sequence and to determine both the palynostratigraphy and paleo environment of deposition of the sediments. Detail investigation shows that there is much complexity attached to the understanding of the stacking patterns of contemporaneous sediments, thereby making it virtually difficult to emphatically say that the formations are composed of a particular sequence in one location compared to the other. A study of the Ubiaja-1 well revealed two important information in terms of age dating which varies from the oldest sediment of Eze-Aku Formation dated Turonian (Ola-Buraimo *et al,* 2015) and the uppermost part of this study which indicates Nkporo/Afikpo Formation which has never been reported for Anambra Basin but only for Afikpo Basin (Nwajide, 1990). A lithostratigraphic sequence of over 300ft shows that younger formations such as Mamu, Ajali, Nsukka, Imo, Ameki and Ogwashi-Asaba Formations are not present. This raises a lot of concern and why they are missing from the established sequence of Anambra Basin up to the near surface of the studied well.

Palynological study of this well has raised another dust in terms of what could have been responsible for the non-deposition or removal of such thick pile of sediments involving several formations. A conclusive statement cannot be made here but it could suggest another phase of tectonic activity that has not been noticed and reported in the Anambra Basin. After the Early Maastrichian deposition of the Afikpo Sandstone, it was followed by period of structural readjustment leading to tectonic activity whereby there was local upliftment of the Ubiaja syncline into a platform; that is from a graben into a horst compared to

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its adjacent structural blocks. However, this idea is at a premature stage because it lacks enough data probably due to inadequate sampling and poor marker palynomorph recovery which needs further investigation by collecting more samples from the area to corroborate results obtained from this study. However, a new Stratigraphy is suggested for the Nkporo Formation to become Nkporo Group comprising of Nkporo Shale and Afikpo Sandstone.

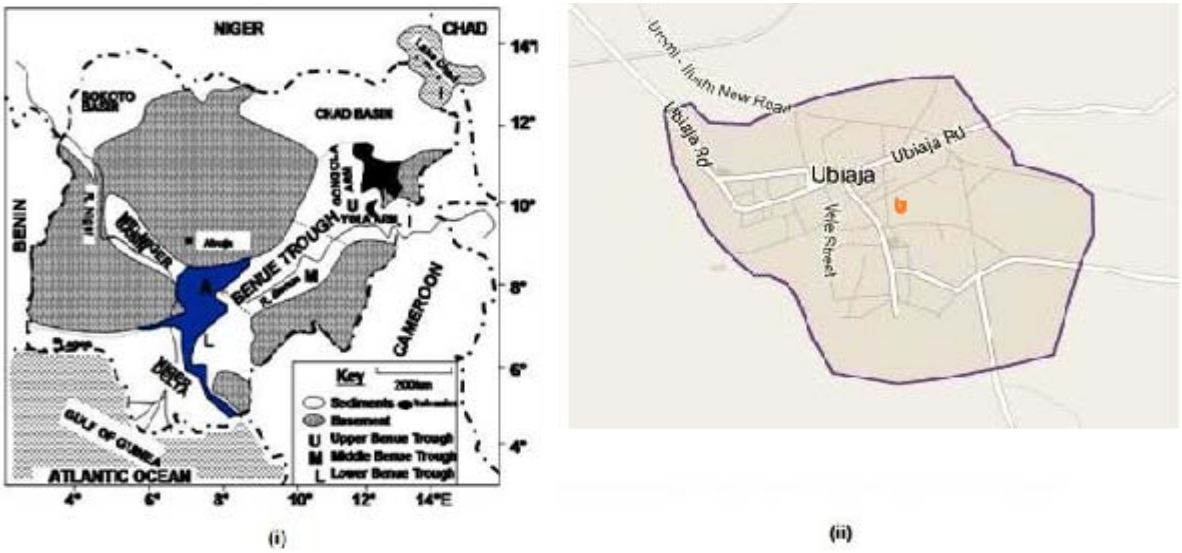


Fig. 1: (i) Generalized geological map of Nigeria showing Anambra Basin [Whiteman, 1982; blue color-A]; (ii) location map of the Ubiaja -1 well in Anambra Basin (Adopted from Ola-Buraimo *et al.,* 2015)

II. Geologic Setting

The Anambra Basin is believed to be the lower section of the Benue Trough, an intracratonic basin, trending NE-SW, folded and aborted rift basin that runs obliquely across Nigeria. Its origin was linked to the tectonic process that accompanied the separation of the African and South American plates in the Early Cretaceous (Murat, 1972; Burke *et al.,* 1972). Structurally, the evolution of the Anambra Basin has been described by some researcher (Nwachukwu, 1972; Ojoh, 1988; Popoff, 1990; Fairhead and Binks, 1991; Obi *et al.,* 2001; Obi and Okogbue, 2004). Prior to the tectonic event, the Anambra Basin was considered to be a platform; that was thinly covered by sediments while the Abakaliki Synclinorium was an axis of active sedimentation. Recently, understanding the stratigraphy of the Anambra Basin has shown that this assertion might not be widely applicable to the whole basin rather a local aspect of it. This is because oldest sediments of Albian to Upper Cenomanian age (Ola-Buraimo and Akaegbobi, 2013b) within the basin at a great depth has proved that when there was active sedimentation in the Abakaliki Synclinarium, the same active sediment deposition was also taking place in some other parts of the Anambra Basin.

There is an old school of thought which believes that the folding of the Abakaliki Anticlinorium led to lateral shifting of the depositional axis into the Anambra Basin which began to accumulate sediments shed largely from the Abakaliki Anticlinorium (Murat, 1972; Hoque and Nwajide, 1985; Amajor, 1987). Also, this explanation given for the post Santonian deposition of sediments in the Anambra Basin lacks logical reasoning and simple geological law of superposition. Firstly, pre-Santonian sediments which include Asu River Group, dated Albian to Lower Cenomanian (Ola-Buraimo and Akaegbobi, 2013b); Eze-Aku Formation, dated Upper Cenomanian-Turonian (Ola-Buraimo, 2013a); and Awgu Formation, dated Coniacian (Ola-Buraimo, 2013c) have been found present in the Anambra Basin. Secondly, the sediments claimed to have been shed from Abakaliki Anticlinorium to Anambra Basin after Santonian tectonics suppose to have been deposited in reverse order of the youngest sediment (Awgu) being eroded first from the top and deposited, followed by Eze-Aku and Asu River at the top. However, this is not the case.

Thirdly, Stratigraphy rule applies that in reworked sediment like that suggested for Anambra Basin (Murat, 1972; Hoque and Nwajide, 1985) should contain both older and younger fossils, where the younger fossil takes precedent over the older fossil in dating the formation. Ola-Buraimo *et al,* (2015) reported that all pre Santonian formations dated palynologically did not show any evidence of reworking which should have shown admixture of older and younger fossils. Such reworked sediment was only reported in the Neogene Ogwashi-Asaba Formation (Ola-Buraimo and Akaegbobi, 2012).

The lithostratigraphic framework for the Early Cretaceous-Oligocene strata in the southeastern Nigeria

has been summarized by Nwajide, (1990; Table 1). Various authors including Arua, (1986); Anyanwu and Arua, (1990); Fayose and Ola, (1990) have suggested a progressive deepening of the basin from lower coastal plain and shoreline deltas to shoreline and marginal marine deposits. The resulting post Santonian stratigraphy succession comprising of Nkporo Group, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Formation, Ameki Formation and Ogwasi-Asaba Formation is presented in Table 1. The detailed stratigraphic descriptions of the formations have been reported by many authors (Petter, 1978; Ladipo, 1985; Agagu *et al.,* 1986; Reijers, 1996; Ola-Buraimo and Akaegbobi, 2012, 2013b).

Table 1: Correlation chart for early cretaceous strata in southeastern Nigeria (Modified after Nwajide, 1990)

Age	Abakaliki-Anambra Basin		Afikpo Basin
30M.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
		Nkporo Oweli Formation/Enugu Shale	Nkporo Shale/Afikpo Sandstone
83	Campanian		
87.5	Santonian	Non-deposition/erosional	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	

III. Materials and Methods

Detailed lithostratigraphy description was carried out on fifty two samples under the microscope in the laboratory. The lithological description followed international standard by considering the type of facies, colour, textural parameters such as grain size, roundness, and sorting. Other important features noted are fossil contents, post depositional effect (diagenesis) and presence of calcite or authigenic minerals such as glauconite or pyrite.

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. Fifteen samples were selected and taken at irregular interval because some of the intervals are missing. Therefore, 10 g of the samples were soaked overnight in Hydrofluoric acid (HF), and stirred intermittently for effective digestion.

To completely remove the fluoro-silicate compounds that usually form from the reaction with HF, the content was again treated with warm 10 % HCl and finally completely neutralized with distilled water. Sieving process with 5µm mesh was undertaken 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 2.1g/cc. The collected residue was mounted on glass slides with DPX. The preparation method was in accordance with standard methods (Traverse, 1988; Wood *et al.,* 1996). Important forms including pollen and spores photographs were taken with Nikon Koolpix P6000 digital camera.

IV. Results and Discussion

a) Lithology Description

i. *Lithostratigraphy of Ubiaja-1 Well*

The lithostratigraphy analysis result shows that there are nine lithofacies units delineated and they occur

at different intervals within the analyzed section. Details of the lithofacies units are given below.

ii. *Lithofacies unit 1: Conglomeratic sandtone*

This lighofacies unit occurs thinly between facies, it is whitish to pinkish in colour, grain size varies from fine to small pebbles, angular to rounded and poorly sorted. It has a thickness of 15 ft (600-615 ft); characterized by fining upward sequence and erosional base (unconformity) of a typical continental deposit. It is suggested to have been deposited by river system under high energy condition (Table 2).

iii. *Lithofacie Unit 2: Granulestone*

This lithofacies occurs at the uppermost part of the section with an interval range of 40-75 ft. The granulestone is reddish in colour, grain size ranges from medium to pebble; roundness varies from angular to rounded, and it is poorly sorted. The granulestone is friable and ferruginised in nature, it has a total thickness of 35ft.The facies shows fining upward sequence; unconformable relation with underlying facies typical of fluviatile deposit (Table 2).

iv. *Lithofacie unit 3: Pebbly sandstone*

The pebbly sandstone facies is whitish to pinkish in colour, grain size varies from fine to small pebbles, angular to rounded, poorly sorted in nature and more pebbly in content. It is suggested to have been deposited by high energy current in a continent environment associated with erosional base.

v. *Lithofacies Unit 4: Sandstone*

The sandstone occurs at different levels. Generally, they are whitish to reddish in colour at the upper part (75 to 110 ft). It is coarse grained and poorly sorted, whereas at the middle part of the section, the grain size is medium, moderately to poorly sorted. The lithofacies occurs at intervals 75 to 110 ft, 645 to 795ft, 815 to 845 ft, 855 to 865 ft, 915 to 930 ft. They are suggested to have been deposited in continental setting and unconformably overlying shale at the lower section of the studied interval (Table 2).

vi. *Lithofacies unit 5: Claystone*

The claystone facies is restricted to the upper part of well section. It varies in colour from light brown to white, sometimes ferrugenized. It varies in interval from 146 to 172 ft with total thickness 26ft. The presence of the whitish claystone (kaolinite) shows the extent of leaching and chemical transformation of double lattice clay into single lattice type.

vii. *Lithofacies unit 6: Mudstone*

The mudstone directly underlies the clay deposit in the upper part of section, though it also occurs at the lower part of the well section. It is reddish to greyish coloured facies which has add-mixture of clay and sand particles; varies from fine to small pebble. The mudstone facies occur at various intervals such as 172-390 ft, 960-1045 ft. it is suggested that the mudstone was deposited in a continental setting (Table 2). The grayish colour of the mudstone is indicative of carbonaceous content.

viii. *Lithfacies unit 7: Sandy Shale*

This lithofacies is light grey in colour and heterolith in nature, It is a light grey sandy shale which has sand/shale ratio (s/sh) = 45:55%, the sand size varies from fine to small pebble, fine to rounded and poorly sorted. It varies in interval from 890 to 900ft with a total thickness of 10ft, deposited in prograding deltaic environment.

ix. *Lithofacies unit 8: Shaley sand*

The shaley sand occurred at interval 850 to 870ft. It is a dark grey facies, heterolith in nature with sand/shale contents ratio (s/sh) = 55:45%. It is suggested to have been deposited within prograding deltaic system..

x. *Lithofacies 9: Shale*

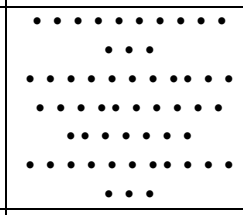
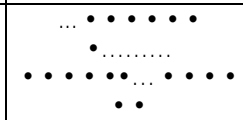
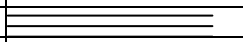
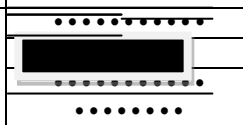
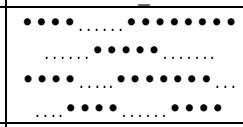
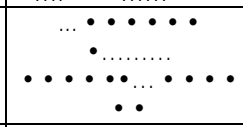
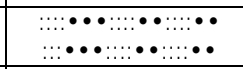
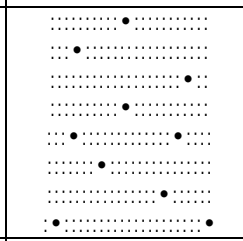
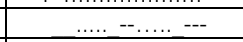
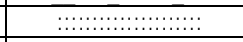
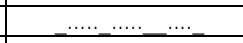
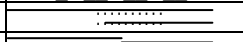
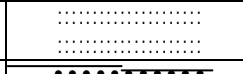
This lithofacies is light grey to dark grey in colour, fissile and slightly ferrugenized. It occurs at various intervals 1000-1005 ft, 875-885 ft, 1020-1025 ft, 1370-1765 ft. It occupies smaller part of the section and it is suggested to have been deposited in anoxic marginal marine environment.

The lithogical sequence in the studied stratigraphic interval is not similar to other established stratigraphic sequence for Nkporo Shale (Edet and Nyong, 1984; Nwajide, 1990; Ola-Buraimo and Akaegbobi, 2013). It is strongly believed that the thick sandstone facies of Campanian to Early Maastrichtian age encountered in this studied stratigraphic section in the Ubiaja -1 well is a lateral extension of an intertongueing facies of Afikpo Sandstone from Afikpo Basin into Anambra Basin. The base of the Afikpo Sandstone in the well cannot be precisely placed but it is tentavely placed at 1165ft at the base of the interval where it first occurred in the available sample interval in the well section. It is characterized by fine to pebble sized particles, whitish to pinkish in colour, angular to rounded, moderately to poorly sorted at various intervals, fining upward sequence, and unconformably overlying the Nkporo Shale (Table 2).

A greater proportion of the Afikpo Sandstone is mainly sandy with some claystone and mudstone intercalations at the upper part of the interval, suggestive of deposition in continental environment. However, interval associated with intercalation of sand and shale or heterolith facies is indicative of prograding deltaic setting (see Table 2). The continental Afikpo Sandstone is unconformably overlying the marginal marine Nkporo Shale. The sandstone could serve as a good reservoir rock for the Nkporo shale source rock. Within the sandstone section is the intercalated shale which could serve as excellent seal or cap rock at the top (Table 2). The result reveals a new sandstone member in the Nkporo Formation or in another way

suggests Nkporo Formation to become Nkporo Group comprising of Nkporo Shale and Afikpo Sandstone.

Table 2: Lithostratigraphy, Palynological Zones and Paleoenvironment of the Studied Interval

Depth (Ft)	Litho-log	Description	Formation	Zone	Age	Paleo-environment
40		Granulestone	Afikpo Sandstone	*Foveotriletes margaritae* Assemblage Zone II	Early Maastrichtian	Continental To Deltaic
75		Coarse sandstone				
146		Claystone				
172		Mudstone No Data Mudstone				
555		Heterolith sand and shale				
600		Conglomeratic sandstone				
690		Coarse sandstone				
775		Pebbly sandstone				
780		Medium grained sandstone but pebbly in nature				
850		Shaly sand		*Milfordia spp* Acme Zone I	Campanian	
865		Sandstone				
870		Shaly sand				
885		Shale				
900		Sandy clay				
		Mudstone				
915		Sandstone				
960		Mudstone				
1165		Sandstone				
1370		NO DATA				
1425		Shale	**Nkporo Shale**			Marginal Marine

V. Biozonation

Palynological analysis was carried out yielded palynological contents such as pollen, spores, dinoflagellates , algae, and fungal spore. The interval yielded poor to moderate amount of palynomorphs which are fairly preserved. However, diagnostic forms present were used for palynozonation exercise. Two palynological zones were erected after the works of Jardine and Magloire, (1965); Lawal, (1982); Lawal and Moullade, (1986); Ola-Buraimo, (2012); Ola-Buraimo and Akaegbobi, (2013b). The details and basis of establishing the zones are given bellow.

Interval: 870-1425 ft

Zone: *Milfordia* spp. Acme Zone

Age: Campanian

Characteristics: The base of the interval is marked by the appearance of *Milfordia* sp., *Proxapertites cursus, Tricolpites* sp.*,* and *Inaperturopollenites* sp. Depth 1330 ft is characterized by the occurrence of *Milfordia* sp.*, Syncolporites marginatus* and *Tricolpites* sp. There is a continuous occurrence of *Milfordia* spp. in the interval with relative maximum development within the interval. Other forms that occurred within the interval include *Inaperturopollenites* sp, *Proxapertites cursus, Tricolpites* sp., *Syncolporites marginatus, Verrucatosporites usmensis, Zlivisporites blanensis, Milfordia jardinei, Cyathidites* sp. and *Laevigatosporites* sp. The top of the interval is marked by the top quantitative occurrence of *Milfordia* sp. The fossil assemblage observed here is similar to palynological report on *Milfordia* spp acme zone 3 reported on Tuma-1 well, Bornu Basin, Nigeria (Ola-Buraimo, 2012), also similar to assemblages reported on Nkporo Shale in Anambra Basin, southeastern Nigeria(Ola-Buraimo and Akaegbobi, 2013b). The interval is dated Campanian age and stratigraphically belongs to Nkporo Formation in Anambra Basin, southeastern Nigeria (see Tables 1 and 2).

Interval: 40-870 ft

Zone: *Foveotriletes margaritae* Assemblage Zone II

Age: Early Maastrichtian

Characteristics: The base of the interval coincides with the top of the underlying zone I marked by the quantitative top occurrence of *Milfordia* spp. The interval is sparse in miospores is characterized by the continuous occurrence of *Monocolpopollenites sphaeroidites* and occurrences of *Syncolporites* sp.*, Monosulcites* sp., *Ephedripites multicostatus, Milfordia* sp., *Milfordia jardinei, Laevigatosporites* sp.*,* and *Cyathidites* sp. The assemblage of palynomophs in this interval is comparable with other established zones. It is partly similar to earlier works of Ola-Buraimo, (2012) and Ola-Buraimo and Akaegbobi, (2013b). The interval is also dated Early Maastrichtian based on negative criteria: it lacks diagnostic Middle and Late Maastrichtian forms such as maximum development of Longapertites marginatus (Ogala *et al,* 2010), and appearance of Spinizonocolpites baculatus (Lawal and Moullade, 1986) respectively. It is also based on the stratigraphic position which suggests Early Maastrichtian age and well compared to the palynomorph assemblages reported on Tuma-1 well, Bornu Basin, northeastern Nigeria (Ola-Buraimo, 2012). Therefore, the interval is equivalent in terms of facies and age to Afikpo Sandstone established in Afikpo Basin (Nwajide, 1990; see Tables 1 and 2).

VI. Paleoenvironment of Deposition

The paleoenvironment of deposition of the sediments in the entire analyzed interval is characterized by continental to marginal marine The paleoenvironmental deduction made for this research work is based on the combined data of Non-Pollen Palynomorphs such as algae, fungi, microforaminiferal wall linings, gonyaulacacean/peridinacean ratio (G/P) after Harland (1983); and terrestrially derived pollens and spores.. The use of relative abundance of terrestrially derived pollen and marine derived dinoflagellate cysts have also been documented in the works of Lawal, (1982); Schrank, (1984); Edet and Nyong, (1992); Ojo and Akande, (2000); Ogala *et al,* (2009); Ola-Buraimo and Adeleye, (2010) and Ola-Buraimo and Akaegbobi (2013b).

The dinoflagellates that characterized this depositional system are peridinoid forms such as *Andalusiella polymorpha*, and *Andalusiella sp.* They are described to be dinocysts having relatively long processes. They are the only type of dinoflagellates that are present in the samples analyzed and they suggest deposition of the shale facie in the marginal marine environment.

The peridinoids which are the only form in abundance is attributed to relative low or reduced salinity as a result of admixture of fresh water (*Botryococcus braunii*) from the fluvial mixing with the saline water (dinoflagellate) of the marine environment present in the marginal marine setting. This similar view had been expressed by Upshaw (1964), Oloto (1987) and Ogala *et al (2009)*, Ola-Buraimo and Akaegbobi, (2013b).

VII. Conclusion

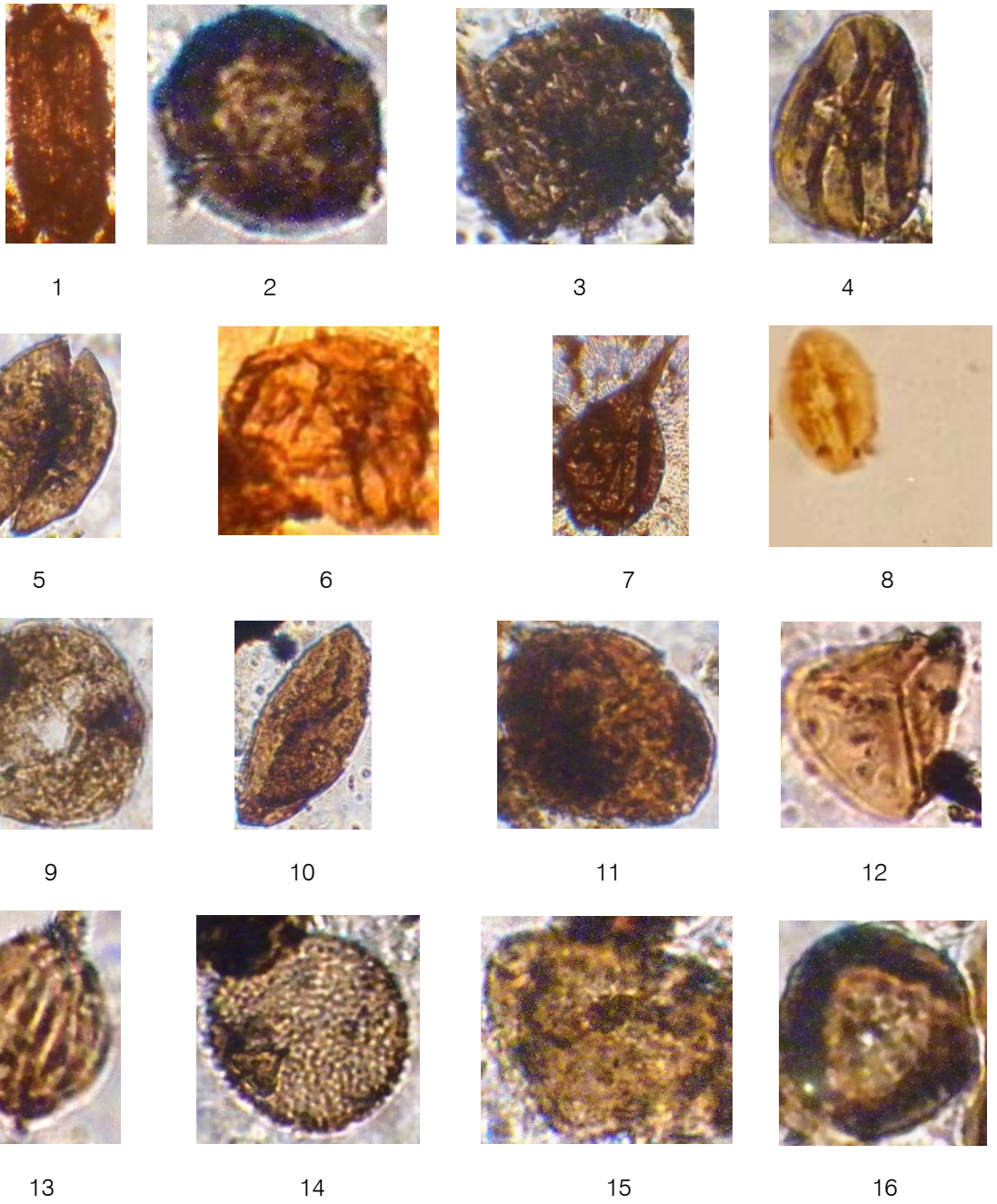
lithostatigraphy analysis revealed nine lithofacies units such as granulestone, coarse sandstone, pebbly sandstone, conglomeratic sandstone and medium grain sandstone characterized by medium to pebble sized grains, poorly sorted, erosional surfaces and fining upward signature, deposited in continental

environment under high energy current. Other facies include claystone and mudstone also deposited in continental environment. The heterolith facies such as sandy shale and shale sand were deposited in prograding deltaic system, while the dark grey shale was deposited in the marginal marine setting. The sandstone sequence is the Afikpo Sandstone unconformably overlying the Nkporo marginal marine shale.

Palynozones established indicated that the entire stratigraphic sequence belongs to Nkporo Shale/Afikpo Sandstone synonymous with Afikpo Basin but here established in Anambra Basin. This palynological revelation shows that there is lateral facies intertongueing of the Afikpo Sandstone in the Afikpo Basin into the Ubiaja- 1 well located in Delta State, Anambra Basin in Nigeria. The result reveals a new sandstone member in the Nkporo Formation or in another way makes Nkporo Formation to become Nkporo Group comprising of Nkporo Shale and Afikpo Sandstone. This further corroborates the complexity of Anambra Basin Stratigraphy and the need to further carry out investigations into the stratigraphy through the use of palynological tool and other useful tools.

Magnification ×800

PLATE I






17 18 19 20

Plate 1

1	*Ephedripites multicostatus*
2,3	*Milfordia* sp.
4	*Tricolpites* sp.
5	*Monocolpites* sp.
6	*Zlivisporites blanensis*
7	*Andalusiella* sp.
8	*Tricolporopollenites* sp.
9	*Milfordia jardinie*
10	*Monosulcites* sp.
11	*Monocolpopollenites sphaeroidites*
12	*Cythidites* sp.
13	*Ephedripites* sp.
14	*Proxapertites cursus*
15	*Syncolporites* sp.
16	*Milfordia* sp.
17	*Laevigatosporites* sp.
18	*Inaperturopolleinites* sp,
19	*Syncolporites marginatus*
20	*Verrucatospories* sp.

Acknowledgement

The author is grateful to Palystrat Limited for provision of materials used for analysis and print materials consulted for interpretation.

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