PALYNOLOGICAL AND SEQUENCE STRATIGRAPHY CHARACTERIZATION OF THE EARLY-LATE CAMPANIAN NKPORO SHALE, OREKPEKPE-IMIEGBA AREA, ANAMBRA BASIN, NIGERIA

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ABSTRACT

Outcrop samples were collected at a road cut along Orekpekpe-Imiegba road in the western part of the Anambra Basin. These contain mainly of dark to black fissile shale, sandstone and claystone. The samples were processed using standard palynological procedure. The result shows that the entire sequence belong to *Milfordia* spp. acme zone dated Campanian based on the maximum development of *Milfordia jardinei, Milfordia* sp., in strong association with *Odontochitina costata*. The age of the Nkporo Shale was refined into epochs based on distinctive palynomorph assemblages and sedimentation processes. The lower section of the Shale dated Early Campanian is characterized by high quantitative occurrence of *Milfordia* spp., rare occurrence of *Longapertites* sp., *Cupanieidites reticularis, Constructipollenites ineffectus,* and *Longapertites* sp. 3 deposited in a deltaic to marginal marine setting. The middle section is dated Middle Campanian, marked by moderate abundance of *Milfordia* spp., continuous occurrence of earlier forms including *Periretisyncolpites* sp., *Syncolporites subtilis, Distaverrusporites* sp,, and different forms of dinoflagellate cysts. Sedimentation process was by aggradation in marginal marine environment. The upper section is dated Late Campanian based on the maximum development of *Milfordia* spp. in strong association with moderate occurrence of *Odontochitina costata*. Other important forms present are *Periretisyncolpites giganteus, Monocolpites marginatus, Foveotriletes margaritae* and high occurrence of dinoflagellate cysts and microforaminiferal wall lining. This interval is further characterized by forestepping depositional mechanism, sediment starvation, and condensed section, within which is the location of maximum flooding surface (mfs). The paleoenvironment of deposition was based on the synthesis of the quantitative occurrence of land derived forms such as pollen and spores, fluviomarine forms (algae and fungal spores), marine living forms (organic walled microplankton, and microforaminiferal wall lining), gonyaulacaceans (*Senegalinium* sp., *Trichodinium* sp., *Andalusiella* spp.) and few peridinacean (*Cyclonephelium distinctum)* in combination with *Botryococcus braunii* which suggest of marginal marine setting for most of the studied lithofacies section of the Nkporo Shale.

Keywords: Lithofacies, Campanian, Acme zone, Forestepping, Maximum Flooding Surface.

INTRODUCTION

Anambra Basin, the first area where intensive oil exploration was carried out in Nigeria, has about 12,000 metre of sedimentary rocks which accumulated in its thickest part since the

Cretaceous time (Agagu andAdighije 1983; Akinyemi *et al*. 2013).The dominant lithologies comprise sandstones, shales, limstones and coal seams. The unrewarding initial oil exploratory effort in the basin led to its neglect by most researchers in favour of the nearby Niger Delta Basin which is prolific in terms of oil and gas. With less than 50 wells so far drilled (two discoveries; Anambra River-1, Ihadagu-1) and very scanty 2-D seismic information, Anambra Basin is under explored. Again, a simple statistical analysis of the literature review shows that more than ninety percent of the studies so far in the basin are in the southeast section of the basin (Unomah and Ekweozor 1993; Akaegbobi and Schmitt 1998; Adebayo and Ojo 2004; Ojo *et al.*, 2009; Chiaghanam *et al*. 2012).

Since the search for crude oil in commercial quantity in the basin still remained a source of concern for oil companies and research groups, a better understanding of the stratigraphy of the outcrops will benefit the oil companies that had secured concession blocks in the basin; and those that may wish to use this information for deep-water exploration in the Niger Delta Basin. This is because some of these outcrops are said to be equivalent to the lithostratigraphic units in the subsurface of the Niger Delta (Short and Stauble 1967). Given the availability of improved exploration techniques and tools, and increasing global energy demand there is the need for increased research activities in the basin, most importantly in the western part.

The research study in the basin, particularly on Nkporo Shale, has continued to generate interest in the minds of geologists probably because of its importance in the capability to generate hydrocarbon because of its richness in kerogen. Some of the research works that had been carried out on the Nkporo Shale include: Maastrichtian dinoflagellate cyst assemblage from the Nkporo Shale on the Benin Flank of the Niger delta (Oloto 1987); palynostratigraphy of the Nkporo Shale exposure dated Campanaian to Maastrichtian on the Calabar Flank, South Eastern, Nigeria (Edet and Nyong 1994); sequence stratigraphy of the Anambra Basin with emphasis on the Campanian-Maastrichtian Nkporo Formation at Leru (Nwajide and Reijer 1996). These are followed by the palynological and paleoenvironmental investigation of the Campanian-Lowermost Maastrichtian Asata/Nkporo Shale in the Anambra Basin (Ola-Buraimo and Akaegbobi 2013a). From all the earlier research works none of them combined the use of palynology and sequence stratigraphy for the determination of the geologic age, paleoenvironment and sequence stratigraphic classification of the Nkporo Shale. These factors become the cardinal focus of this study on the Nkporo Shale deposit at Orekpekpe-Imiegba area (western part of Anambra Basin) (Figs. 1 and 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 is roughly triangular in shape and covers an area of about 40,000 square kilometers with sediment thickness increasing southwards to a maximum thickness of 12,000m in the central part of Niger Delta (Fig. 1). The basin lies between latitudes 5.0^0N and 8.0^0N and longitudes 6.3^0E and 8.0^0E. Anambra Basin which is one of the intracratonic basins in Nigeria is considered by some authors as the Lower Benue Trough, a NE-SW trending, folded, aborted rift basin that runs obliquely across Nigeria (Fig).Hence its origin was linked to the tectonic processes that accompanied the separation of the African and South

American plates in the Early Cretaceous (Murat 1972; Burke 1996). The rift model had been supported by evidence garnered by structural, geomorphic, stratigraphic and paleontologic studies (Burke *et al.* 1972; Benkhelil 1989;Guiraud and Bellion 1995).

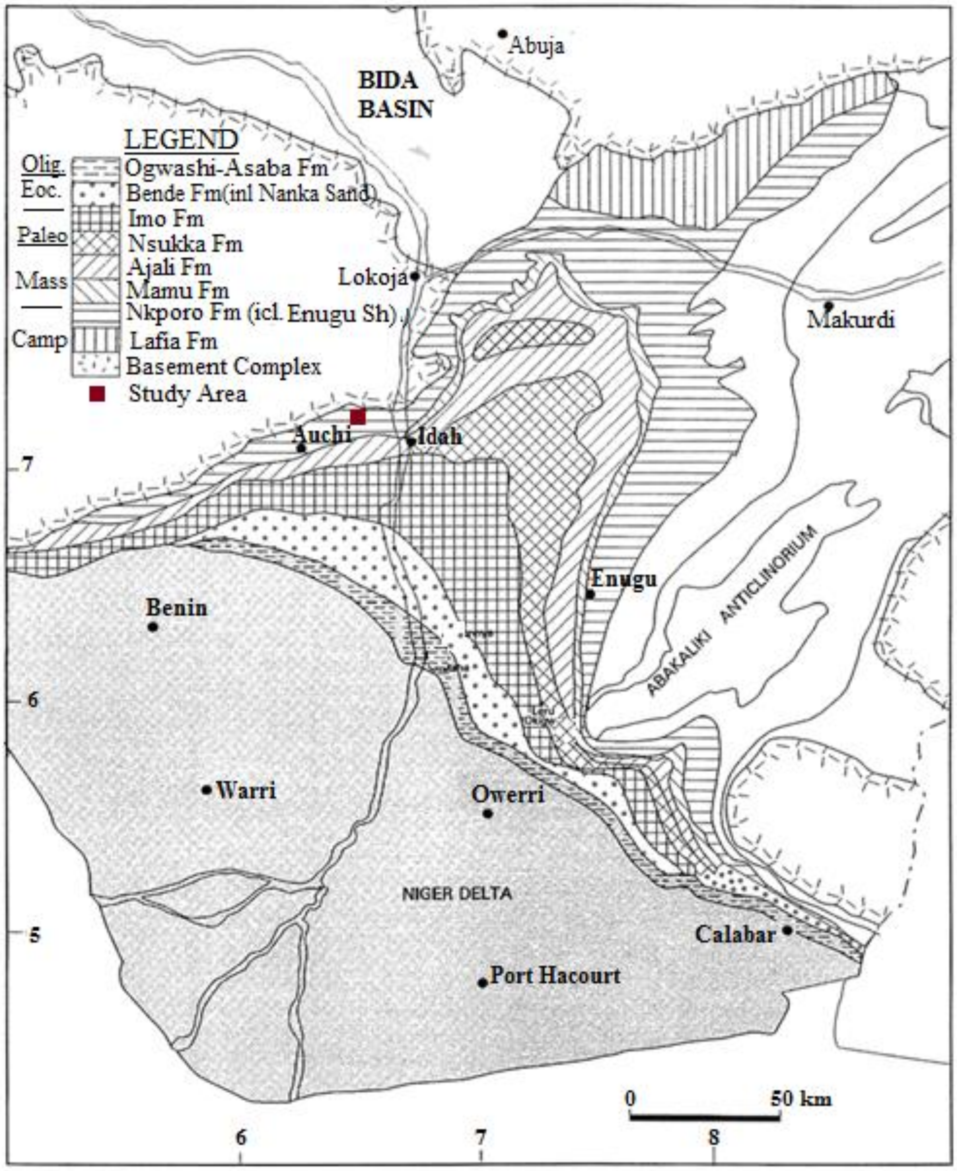

Fig. 1. Geological Map of Anambra Basin Showing the Area of Study (Modified after Nwajide and Reijers 1996).

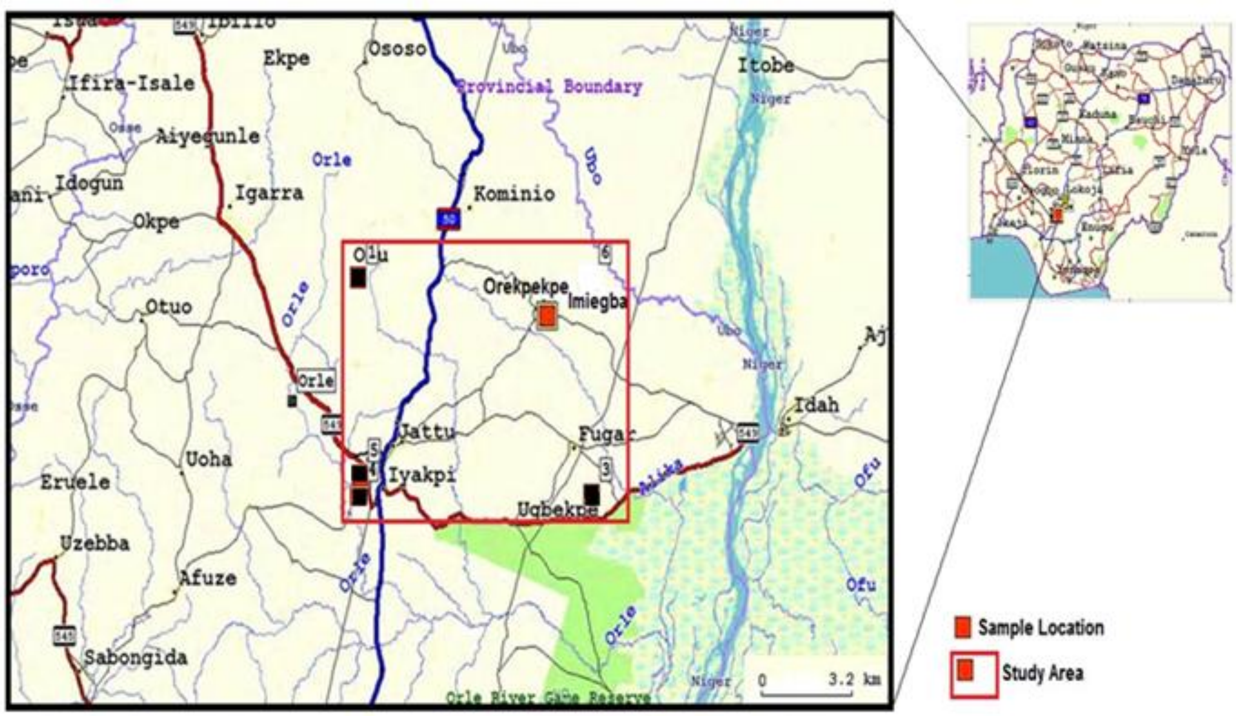

Fig. 2 Location map of the study area

The evolution of the basin represents the third cycle in the evolution of the trough and its associated basins when the Abakaliki Trough was uplifted to form the Abakaliki Anticlinorium whilst the Anambra platform was downwarped to form the Anambra Basin (Murat 1972; Weber and Daukoru, 1975) resulting in the westward displacement of the trough's depositional axis.Its sedimentation trend is patterned by the shifting of depocentres.

A great deal of work had been done to elucidate the age, paleoenvironment, paleogeography, sedimentary tectonics, origin of the deposits, the litho- and biostratigrapy and hydrocarbon (or fossil fuel) potentials of the basin (Reyment 1965; Murat 1972; Salami 1983; Agagu *et al*. 1985; Allix 1987; Akande *et al*. 1992; Nwajide and Reijers 1996; Akande 2007). The sequence of depositional events suggests a progressive deepening of the basin from lower coastal plain and shoreline deltas to shoreline and shallow marine deposits (Arua 1986; Anyanwu and Arua 1990; Fayose and Ola 1990). The resulting succession comprises 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 (Petters 1978; Agagu et al. 1985; Reijers 1996). The rich coal deposits of Middle – Early Maastrichtian ages suggest brackish marshes during their deposition (Ogala *et al* 2009).

It should be noted that earlier conception that Anambra Basin contain exclusively of post Santonian sediments has been invalidated (Ola-Buraimo and Akaegbobi 2013b). Recent revelation has shown that pre-Santonian sediments that are as old as Albian in age are present in the basin. As a result of this, pre-Santonian formational sequence have been dated using palynological tool. The Asu-River Group is the oldest facies (in the basin) dated Albian to Lower Cenomanian. This is overlain by Eze-Aku Formation dated Upper Cenomanian to Turonian age; further overlain by the pre-Santonian sediment deposit referred to as Awgu Formation dated

Coniacian in age (Ola-Buraimo 2013). The evidences of these pre-Santonian sediments are well documented in Nzam-1 and Umuna-1 wells located in Anambra Basin, Nigeria.

Table 1: Correlation Chart for Early Cretaceous 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	Npkoro Oweli formation/Enugu shale	Npkoro shale/Afikpo sandstone
87.5	Santonian		Non-deposition/erosion
	Coniacian	Agbani sandstone/ Awgu shale	
88.5	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	

METHODOLOGY

Samples were collected from a road cut outcrop from the base upward, numbering 1-13 in that order. The samples are mainly dark gray to black fissile shale, sandstone and claystone. About 20gm of each sample was soaked in hydrofluoric acid (HF) to remove silicates, and dilute hydrochloric acid (HCl) to remove the carbonates. This is followed by sieving process with 5μm mesh. 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 mountant. The preparation method was in accordance with standard methods (Traverse 1988; Faegri and Iversen, 1989; Wood *et al.*, 1996). Frequency count of pollen, spores, dinoflagellates, fungal spores, microforaminiferal wall linings and other stratigraphically significant forms present were determined for each sample, and interpreted by comparison with established works. However, diagnostic species photomicrographs were taken with Nikon Koolpix P6000 digital camera (see plates). Sample 6, an ironstone, was not processed for palynomorphs.

RESULT AND DISCUSSION

The results of twelve samples were compared with previously studied sediments in different parts of Nigeria, Senegal and Cote d'voire in West Africa. The generated data obtained from microscopic study of the palynological slides were compared with the works of Jardine and Magloire (1965) on Senegal and Cote d Voire; Germeraad et al (1968) on the tropical areas; Evamy et al (1978); Lawal (1982); Lawal and Moullade (1986) on Benue Trough, Nigeria; Edet and Nyong (1994) on the Nkporo Exposure on the Calabar Flank, SE Nigeria; Adebayo and Ojo (2004) on Cretaceous deposits, Anambra Basin; Ola-Buraimo (2012) on Bornu Basin, NE Nigeria and Ola-Buraimo and Akaegbobi (2013a) on the Asata/Nkporo Shale in Anambra Basin, SE Nigeria. The details of the palynostratigraphy of the twelve samples studied are given below.
The base of the stratigraphic interval studied is marked by high abundance and high diversity of palynomorphs which are well preserved (Table 2, plates). Diagnostic forms that characterized this sample 1 are the quantitative occurrence of *Milfordia jardinei*, *Milfordia sp* which suggest good development. The sample 1 compare favorably with the *Milfordia* spp. acme zone established by Ola-Buraimo (2012), dated Campanian age. It also compares in part with the stratigraphic interval delineated in the Asata /Nkporo Shale present in Nzam- 1 well, located in anambra Basin, Nigeria; dated campanian age (Ola-Buraimo and Akaegbobi 2013a).
There are other important forms that are associated with the *Milfordia spp*. such as relative quantitative occurrence of *Leiotriletes sp*, *Distaverrusporites sp*, and *Monosulcites sp*. Forms with moderate occurrence include *Periretisyncolpites sp* and *Inaperturopollenites sp*. However, large numbers of important miospores that occur in rare quantity are *Longapertites sp*, *Syncolporites sp*, *Cupanieidites reticularis*, *Constructipollenites ineffectus*, *Cingulatisporites ornatus* and *Longapertites sp 3*. The overlying intervals 2 and 3 show paucity of palynomorphs recovery which might be due to increase in sedimentation; while the pollen and spores recovered include *Distaverrusporites sp.*, *Milfordia sp* (in moderate frequency) and *Botryococcus braunii* (Table 2).

Sample 4 contains moderate recovery of palynomorphs, characterized by continuous occurrence of *Milfordia jardinei*, *Milfordia sp.* (in moderate quantity), *Monosulcites sp* and *Inaperturopollenites sp*. New forms that evolved at this level include *Trichotomosulcites sp. 1* (Lawal and Moullade 1986), *Buttinia andreevi* (Boltenhagen 1967), *Echimonocolpites major* (Jan du Chene et al 1978) and *Proxapertites cursus* (Van Hoekin-Klinkenberg 1964). Though some of these forms are notable Maastrichtian forms but they are found to have evolved in older sediments. Therefore, their association with the quantitative occurrence of *Milfordia* spp. is suggestive of a Campanian age. Here, samples 1, 2, 3 and 4 are referred to as the lower part of the studied section.

Table 2: Distribution chart, age, Sequence Stratigraphy and Paleoenvironment of Deposition of Nkporo Shale Located at Orekpekpe-Imiegba Area, Anambra Basin, Nigeria.

SAMPLE NO	LITHOLOGY	FORMATION	POLLEN AND SPORE																													DINOFLAGELLATES														OTHERS					AGE	SEQUENCE STRATIGRAPHY	PALEOENVIRONMENT OF DEPOSITION
			INAPERTUROPOLLENITES SP	LEIOTRILETES SP	MILFORDIA JARDINIE	PERIRETISYNCOLPITES GIGANTEUS	MILFORDIA SP	MONOSULCITES SP	LONGAPERTITES MARGINATUS	CINGULATISPORITES ORNATUS	MONOCOLPITES MARGINATUS	PERIRETISYNCOLPITES SP	FOVEOTRILETES MARGARITAE	SYNCOLPORITES SUBTILIS	VERRUCOSISPORITES SP	EPHEDRIPITES SP	SYNCOLPORITES SP	TRICOLPOROPOLLENITES SP	DISTAVERRUSPORITES SP	EPHEDRIPITES MULTICOSTATUS	TRICOLPITES SP	CONSTRUCTIPOLLENITES INEFFECTUS	LONGAPERTITES SP	TETRADITES SP	TRICHOTOMOSULCITES SP 1	BUTTINIA ANDREEVI	ECHIMONOCOLPITES MAJOR	PROXAPERTITES CURSUS	CUPANIEIDITES RETICULARIS	LONGAPERTITES SP 3	TRICHODINIUM SP	BATIACASPHAERA SP	PHELODINIUM BOLONIENAE	ODONTOCHITINA COSTATA	DINOFLAGELLATE CYSTS	ANDALUSIELLA POLYMORPHA	SENEGALINIUM SP	PALAEOHYSTRICHOPHORA INFUSORIOIDES	TRICHODINIUM DELICATUM	ANDAALUSIELLA SP	ANDALUSIELLA SP 2	CANINGIA SP	COMETODINIUM SP	CYCLONEPHELIUM DISTINCTUM	SENEGALINIUM SP 4	MICROFORAMINIFERAL WALL LINING	BOTRYOCOCCUS BRAUNII	FUNGAL SPORE	PALYNOMORPH ABUNDANCE	PALYNOMORPH DIVERSITY			
13		NKPORO	1	11	5	1	21	8	2	1	3	1	1																		1	1	3	1	2	2										5	14		85	20	Late Campanian	HST	Middle Shoreface
12			1	2	1		12	4			4	1		1	1																1	2		5		1	1	1								6	2		46	17			
11			1	3	19		1	2					1			1	1														3	1	3	7	3	20	1		2	1	2	1	1			27	1		116	22			
10				1			3	2										2														1		5						2						1	55		72	10			
9			3	2			1	1				1			1				1	1																								1		1	38		50	11			
8			1	5			3	4										1			1	1											1		2	1	1									1	23		45	14	Middle Campanian	TST	Marg. Mari
7			1	12	1		2	2			3	1		1					2		1	1										2	1		3											3	25		63	17			
6																																																					
5			4	5	1		3	11		1	1				1						1		2	1								1	1		2		1							1			10	6	54	20			Deltaic -Marg. Mari
4			1		1		3	1													1				1	1	1	1							2									1			7	1	22	14	Early Campanian	LST	
3																																															3		3	1			
2							4												1																														6	3			
1			3	15	6		7	7		1	5	4		1			1		5			1	1						1	1	1	7			1		1								1	1	4	3	82	25		TST	

Overlying sample 4 stratigraphically is sample 5 which shows similar palynomorph assemblage to sample 4 below, though re-occurrence of forms such as *Monocolpites marginatus, Cingulatisporites ornatus* and *Inaperturopollenites sp* are present, while only two different forms show new appearance which are *Verrucosisporites sp,* and *Tetradites sp*. However, organic walled microplankton show significant occurrence and they include *Phelodinium bolonienae, Cyclonephelium distinctum, Batiacasphaera sp,* and *Senegalinium,* sp..The sample is suggested to belong to Milfordia spp acme zone dated Camapanian age (Table 2).

Samples 7, 8, and 9 show moderate occurrences of *Milfordia jardinei* and *Milfordia sp* compared with overlying samples 10, 11, and 12. Most of the pollen and spores which have their offshoot in the underlying facies are found in samples 7, 8, and 9. The only pollen that appeared newly is *Ephedripites multicostatus*. Other stratigraphically important forms present in them include *Leiotriletes* sp., *Monocolpites marginatus, Distaverrusporites sp, Constructipollenites ineffectus, Periretisyncolpites* sp., *Syncolporites subtilis, Tricolpites* sp., *Verrucosisporites* sp., and different forms of dinoflagellate cysts in association with microforaminiferal wall lining (Table 2).

The upper part of the outcrop profile constitutes samples 10, 11, 12 and 13. The interval is characterized by two main features viz-a-viz maximum development of *Milfordia spp.* and continuous occurrence of *Odontochitina costata*. The *Odontochitina costata* has been observed in other research works to be strongly depictive of Campanian age (Ola-Buraimo, 2012; Ola-Buraimo and Akaegbobi, 2013a).

In terms of relative comparison of quantitative occurrence of both *Milfordia jardinei* and *Milfordia* sp. in the analyzed section, there is the highest occurrence of *Milfordia* spp. in the uppermost part. They are strongly associated with *Odontochitina costata, Periretisyncolpites* sp., *Periretisyncolpites giganteus, Longapertites* sp., *Cingulatisporites ornatus, Syncolporites subtilis, Verrucosisporites sp. Ephedripites* sp., *Monocolpites marginatus and Fovoetriletes margaritae*. These characteristic features are peculiar and suggest Late Campanian age (Table 2). The interval is further marked by quantitative occurrence of dinoflagellate cysts such as *Trichodinium* sp., *Batiacasphaera sp, Phelodinium bolonienae, Andalusiella polymorpha, Senegalinium* sp., *Palaeohystrichophora infusorioides, Trichodinium delicatum, Caningia sp, Cometodinium* ssp. and microforaminiferal wall linings. Therefore, maximum flooding surface (MFS) is placed at sample 11 defined by dark gray to black shale, very abundant miospore recovery located within an upper condensed section. The Late Campanian is also characterized by maximum development of *Milfordia jardinei*. The trend of *Milfordia* development observed here is similar to the observation made in the work of Ola-Buraimo and Akaegbobi (2013a), and demonstrated the evolutionary trend of *Milfordia* spp. The Maastrichtian age allocated for the top of Nkporo shale in the work of Ola-Buraimo and Akaegbobi (2013a) and suggested for uppermost part for Nkporo Shale at Leru (Nwajide and Reijers, 1996 in Reijer, 1996) is not present in the analyzed section of the studied outcrop of Nkporo Shale at Orekpekpe-Imiegba area.

Table 3: Palynozone, Characteristics, Age, Epoch and Sequence Stratigraphy of Nkporo Shale

Sample No	Formation	Palynozone	Characteristics	Age	Epoch	Sequence Strat.
13	NKPORO SHALE	MILFORDIA SPP. ACME ZONE	Based on maximum development of Milfordia spp. ,strong association with moderate frequency of Odontochitina costata. Other forms include Monocolpites marginatus, periretisyncolpites giganteus, Foveotriletes margaritae. Sedimentation is by forestepping associated with MFS	CAMPANIAN	LATE	HST
12						
11						
10						
9			Moderate abundance of Milfordia spp, associated with Periretisyncolpites sp, Syncolporites subtilis, Distaverrusporites sp. Sedimentation is by aggaradation with a transgressive surface represented by ironstone in sample 6		MIDDLE	TST
8						
7						
6						
5						
4			Based on relative quantitative occurrence of Milfordia spp., rare occurrences of Longapertites sp, Cupanieidites reticularis, Constructipollenites oneffectus, Longapertites sp 3. High palynomorph recovery at the baseSedimentation is by by progradation and shallowing upward.		EARLY	LST
3						
2						
1						TST

The middle part of the lithofacies sequence belongs to sample 5, 7, 8 and 9. They are described to have relatively low frequency of *Milfordia jardinei* (rare occurrence) and *Milfordia* sp (rare to moderate frequency), but are associated with forms such as *Trichotomosulcites sp 1, Buttinia andreevi, Echimonocolpites* sp., *Proxapertites* sp., *Cingulatisporites ornatus, Monocolpites sp, Constructipollenites ineffectus, Periretisyncolpites sp, Syncolporites subtilis, Distaverrusporites* sp., and *Tricolpites sp* in rare quantity; while *Leiotriletes sp* occur in relatively moderate frequency. This segment of the sequence is highly suggested to belong to the Middle-Campanian age.

The lower part is the oldest part of the lithofacies sequence and is marked by basal high quantitative occurrence of *Milfordia* spp. associated with *Longapertites sp 3* (Lawal and Moullade, 1986), relative moderate occurrence of *Leiotriletes sp, Periretisyncopites sp, Monocolpites marginatus, Distaverrusporite sp, Monosulcites sp* and *Inaperturopollenites sp*. Forms with rare occurrence are *Syncolporites subtilis, Syncolpites sp, Cupanieidites reticularis, Constructipollenites ineffectus, Cingulatisporites ornatus and Longapertites sp 3.* The base is strongly associated with *Batiacasphaera* sp., *Trichodinium* sp., *Senegalinium sp 4* and microforaminiferal wall lining. They are all in low frequency compared with upper section of the sequence which occurs in high frequency. The basal part may suggest the onset of increase in sea level that led to the initial deposition of Nkporo Shale. This description fits into the observation of Nwajide and Reijers, 1996 (in Reijer, 1996) for the base of Nkporo Shale at Leru where a shell lag was noted and described to demonstrate the initial transgressive sea movement after the Santonian tectonic event thereby indicating first transgressive systems tract (TST) in the section (Table 3).

However, the upper part of the lower section show paucity of palynomorphs recovery which might be a response to fluctuation in sea level where coarser sediments were brought into the basin due to regression or freshwater incursion. Therefore, the lower section of the analyzed outcrop is here suggested to belong to Lower Campanian age. In this study, it is established that the analyzed Nkporo Shale is sub-divided into epoch: Early-Middle and Late Campanian for the first time and this shall help in the sub-surface regional correlation of the facies.

Paleoenvironment of Deposition

Paleoenvironment of deposition of the exposed and established Nkporo Shale deposit at Orekpekpe-Imiegba area is based on the synthesis of the quantitative occurrence of land derived forms such as pollen and spores, fluviomarine forms such as algae and fungal and marine living forms such as organic walled microplankton and microforaminiferal wall linings present. The use of preponderance of these forms over the others have been used widely by various authors as noted in the work of Edet and Nyong, (1994); Ola-Buraimo and Adeleye, (2010). However, the dinoflagellates have been further categorized into gonyaulacacean which are suggestive of shallow marine (marginal marine) and peridinacean forms which are interpreted to suggest deeper marine water. This method has been used and found useful for paleoenvironmental deduction (Schrank, 1984, 1987; Ogala et al, 2009; Ola-Buraimo and Adeleye, 2010, Ola-Buraimo, 2012; Ola-Buraimo and Akaegbobi, 2013a, 2013b; Ola-Buraimo et al, 2012; Ola-Buraimo 2013a, b; Adeigbe et al, 2013a, b; 2014).

Therefore, the lower section which contains sample 1, 2, 3 and 4 can be described in terms of paleobathymetry to indicate shallowing upward sequence. Dinoflagellates cysts contained in the lowermost depth are mainly of gonyaulacacean forms such as *Senegalinium spp*, *Trichodinium sp*, and rare occurrence of peridinaceans forms (e.g. *Cyclonephelium distinctum*). The interval is further characterized by the incursion of fluviomarine forms such as fungal spores and *Botryococcus braunii*. Therefore, the lower section varies from marginal marine at the base to deltaic setting at the upper part due to the paucity of palynomorphs, fall in sea level or backstepping of the shoreline, increase in sedimentation, and deposition of coarser particles thereby generating deltaic setting (Table 3).

Table 4 Summary: Quantitaive Abundance and Diversity of Palynomophs, Epoch, Pleoenvironment and Sequnce Stratigraphy of Nkporo Shale at Orekpekpe-Imiegba Area

Sample No	Formation	Total Pollen	Total Dinoflagellate	Foram Lining	Total Algae	Total Fungal	Total Abundance	Total Diversity	Age	Epoch	Paleoenvironment	Sequence Strat.
13	NKPOROSHALE	56	10	5	14	0	85	20	CAMPANIAN	LATE	MARINE	HST
12		27	11	6	2	0	46	17				
11		41	47	27	1	0	116	22				
10		5	8	1	55	0	72	10				
9		10	1	1	38	0	50	11		MIDDLE	MARGINAL MARINE	TST
8		16	5	1	23	0	45	14				
7		29	6	3	25	0	63	17				
6												
5		32	6	0	10	6	54	20				
4		12	3	0	6	1	22	14		EARLY	DELTAIC TO MARGINAL MARINE	LST
3		0	0	0	3	0	3	1				
2		6	0	0	0	0	6	3				
1		64	4	0	11	3	83	25				TST

The middle section of the sequence studied is composed of samples 5, 7, 8 and 9.The palynomorph abundance and diversity recovered in this section suggest sediment accretion within a marginal marine environment. The interval is characterized by admixture of land derived miospores, marine water forms and fluviomarine species. Like the underlying older section, dinocysts contained are mainly of gonyaulacacean forms such as *Phelodinium bolonienae*, *Andalusiella polymorpha*, and *Senegalinium* sp. Other marine forms present are microforaminiferal lining, while fluviomarine forms are relatively high abundance of *Botryococcus braunii*. Thus, the shale sequence is suggested to have been deposited in a marginal marine environment (Table 4).

The upper section of the studied lithofacies sequence (sample 11) shows relatively high abundance and high diversity of palynomorphs which characterized a condensed section within which a maximum flooding surface (MFS) is located (Table 4). As a result, basinal sedimentation pattern shows an increased forestepping, that is overstepping of the shoreline landward, paleobathymetry deepening of the upper section, and sediment starvation characterized by dark colored fossiliferous, fissile shale. The interval is characterized by the co-occurrence of *Andalusiella sp, Batiacasphaera sp, Odontochitina costata, Trichodinium delicatum, Andalusiella polymorpha*, increased frequency of microforaminiferal lining, *Trichodinium* sp., *Caningia* sp., *Cometodinium* sp., *Phelodinium bolonienae, and Palaeohystrichophora infusorioides*.

Though, the paleoenvironment of deposition is suggested to be marginal marine but when compared with the underlying facies, there seems to be a relative deepening in the paleobathymetry and tending towards middle-lower shoreface as observed in this section.

CONCLUSION

Twelve samples collected from an outcrop sequence in an upward order are composed mainly of dark gray to black fissile shale facies with intercalated claystone and sandstone. Palynological analysis indicates that the samples contain a relatively high abundance and diversity of palynomorphs. The entire sequence is dated Campanian based on the maximum development of *Milfordia* spp; thus, the sequence belongs to Milfordia spp acme zone characterized by strong development of *Milfordia jardinei*, *Milfordia* sp. and *Odontochitina costata*. The studied section is dated Campanian and further refined into epochs based on distinctive palynomorph assemblages in particular and sedimentation pattern in relation to sea level changes.

The lower part of the studied Nkporo Shale is characterized by relative quantitative occurrence of *Milfordia spp*, associated with rare occurrence of *Longapertites sp*, *Cupanieidites reticularis, Constructipollenites ineffectus, Cingulatisporites ornatus and Verrucosisporites sp, Tetradites* sp., and *Longapertites sp 3.* It is further characterized by the shallowing upward, backstepping sedimentation pattern; deposited in deltaic to marginal marine setting. The interval 1-4 is suggested to belong to Early Campanian age.

The middle section (samples 5-9) is characterized by moderate abundance and continuous occurrence of *Milfordia jardinei* and *Milfordia* sp. compared with the underlying section dated Early-Campanian. The interval shows continuous occurrence of some of the forms that appeared earlier in the stratigraphic sequence. Other forms present *are Perireisyncolpites sp, Syncolporites subtilis*, *Distaverrusporites* sp., *Tricolpites* sp. and different forms of dinocysts and microforaminiferal wall lining. The sedimentation pattern is mainly by aggradation, deposited in marginal marine environment. The interval 5-9 is therefore suggested to belong to Middle-Campanian age.

The upper section 10-13 dated Campanian is based on high abundance and diversity of palynomorphs; marked by maximum development of *Milfordia* spp. in strong association with moderate frequency of *Odontochitina costata*. Other important forms present include those that had appeared earlier in the older stratigraphic sequence in addition to *Periretisyncolpites giganteus*, *Monocolpites marginatus*, *Foveotriletes margaritae,* and high occurrence of dinoflagellate cysts and microforaminiferal lining. It is further characterized by a deepening marginal marine setting, marked by a forestepping depositional mechanism associated with a condensed section, within which is the location of maximum flooding surface.

Magnification ×800 **PLATE 1**

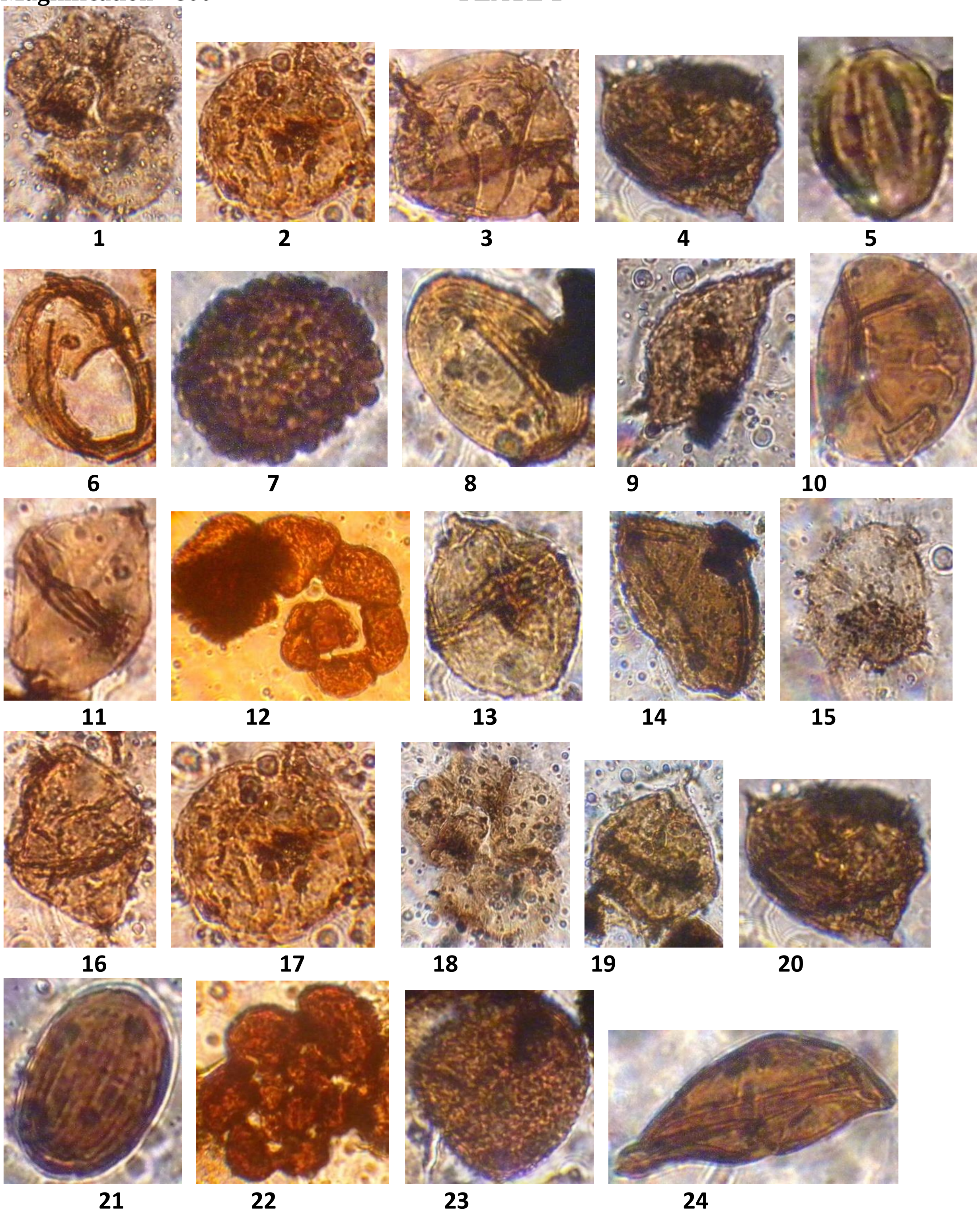

PLATE 1

1,12,18,22 Microforaminiferal wall lining
2 *Batiacasphaera* sp.
3 *Inaperturopollenites* sp.
4 *Senegalinium* sp.
5, 21 *Stephanocolpites* sp.
6 *Milfordia* sp.
7 *Butinia andreevi*
8 *Monocolpites marginatus*
9 *Odontochitina costata*
10 *Longapertites* sp.
11,16 *Andalusiella polymorpha*
13 *Trichodinium delicatum*
14 *Longapertites sp. 3*
15 *Palaeohysrichphora infusorioides*
17 *Milfordia* sp.
19 *Senegalinium* sp.
20 *Senegalinium sp B*
23 *Foveotriletes margaritae*
24 *Monosulcites* sp.

Magnification ×800

PLATE 2

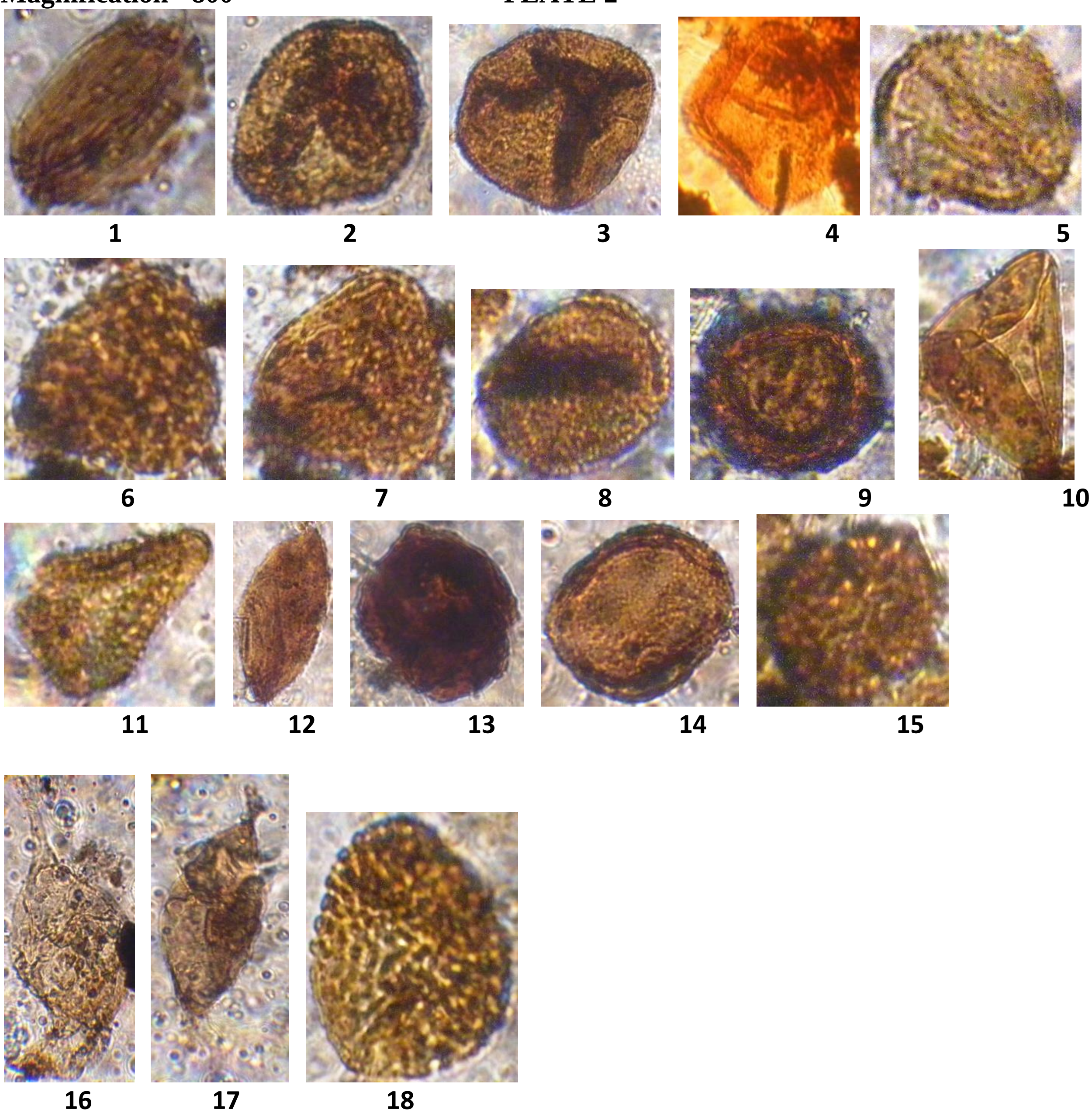

PLATE 2

1 *Ephedripites multicostata*
2 *Verrucosisporites* sp.
3 *Cyclonephelium distinctum*
4 *Phelodinium boloninae*
5 *Monocolpites marginatus*
6 *Distaverrusporites* sp.
7 *Verrucosisporites* sp.
8 *Constructipollenites ineffectus*
9 *Cingulatisporites ornatus*
10 *Syncolporites subtilis*
11 *Trichotomosulcites* sp.
12 *Retimonocolpites* sp.
13 *Milfordia* sp.
14 *Proxapertites cursus*
15 *Milfordia jardinei*
16,17 *Odontochitina costata*
18 *Periretisyncolpites* sp.

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