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LATE MAASTRICHTIAN- EARLY EOCENE DINOFLAGELLATE CYST BIOSTRATIGRAPHY AND PALEOENVIRONMENTAL STUDY OF SEDIMENTS IN AKUKWA-1 WELL IN THE ANAMBRA BASIN

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ABSTRACT

Dinoflagellate cyst biostratigraphy and palaeoenvironment of deposition of sediments penetrated by Akukwa-1 Well was carried out with a total of 253*ditch* cuttings using the conventional maceration technique for recovering of acid insoluble organic-walled microfossils from sediments. Sedimentological description delineated five (5) lithological units within the well, which included those of Nkporo Shale, Mamu Formation, Ajali Sandstone, Nsukka Formation and Imo Shale. A total of 14 genera and 35 species of dinoflagellate cyst were identified. The recovered dinocysts were used to establish palaeoenvironment which ranged from marginal to shallow marine, the forms were also used to propose four (4) informal dinoflagellate cyst zonations labelled (A-D) based on the first and last occurrences of two or more species. They included Zone A (*Apectodinium paniculatum* zone), occurring at 7990ft(Maastrichtian), zone B(*Paleocystodinium australinium* zone) occurring between 7990ft -4000ft (Upper Maastrichtian), zone C(*Apectodinium homomorphum* zone) occurring between 4000ft -2550ft (Upper Maastrichtian), and zone D(*Homotryblum palladium* zone) occurring between 5550ft-1520ft(Paleocene- Early Eocene). The erected dinocyst zones were correlated with the existing biozones in tropical areas of Africa and northern South America.

Keywords: Dinoflagellate cyst, Palaeoenvironment, Lthological units, Dinocyst Zonations,

INTRODUCTION

In the early search for Hydrocarbon, Akukwa-1 well is one of the wells drilled in the Anambra Basin. It is Cretaceous to Tertiary and located at the Southern extremity of the NE-SW trending Benue Trough. It is bounded by the petroliferous Niger Delta to the south, the Benin hinge line to the southwest, the Precambrian basement complex rocks to the west and the Abakaliki Basin to the east. The basin is about 300km long and between 40km and 160km wide. Sediment thickness in Anambra basin ranges from 7000m to about 12000m (Ekweozor, 1982; Agagu and Ekweozor, 1982).

Anambra Basin has elicited much interest recently, due to the fact that both sedimentological and organic geochemical data suggest that the basin is capable of generating hydrocarbon, moreso, when it contains pre-requisites for trapping and accumulation of oil and gas

The various aspects of the basin have been looked at by several Geoscientists ranging from the stratigraphy and sedimentation, the geo-history, the organic geochemistry, structures and paleontology; these include works of Reyment,(1965); Petters and Ekweozor, (1982); Nwajide, (1990); Nwajide and Reijers,(1997);Ogala *et.al.,(*2009),Ola-Buraimo and Akaegbobi,(2013).These studies have always shown that there is paucity of biostratigraphic data hampering the delineation of key stratigraphic surfaces within the basin, particularly on marine palynomorphs which the present study intends to close up on.

The present study is intended to utilize Dinoflagellates to characterize the sediments penetrated by the well. Dinoflagellates are group of organisms that primarily occur in marine sediments and had an extensive fossil record. They are widely distributed in Mesozoic and Cenozoic sediments. The integration of palynomorphs abundance and diversity with dinoflagellate G/P ratio and non- pollen palynomorphs (NPP) will be utilized in interpreting the relative position of sea levels, associated climatic conditions and various palaeoenvironment of deposition of the sediments.

Aim and Objective of the Study

The aim of the present work is to identify and document the palynomorphs based on their abundance, composition and diversity and to characterize the sediments penetrated and determine their age. The specific objective would involve using the relative abundance of marine derived dinoflagellates to predict the depositional environment and palaeo-climatic condition

Location of Study Area

The location of Akukwa – 1 well (fig. 1), falls within the Anambra Basin. It is geographically located between longitudes 7^0 and 8^0E and Latitudes5^0 and 7^0N indicated with red dot.

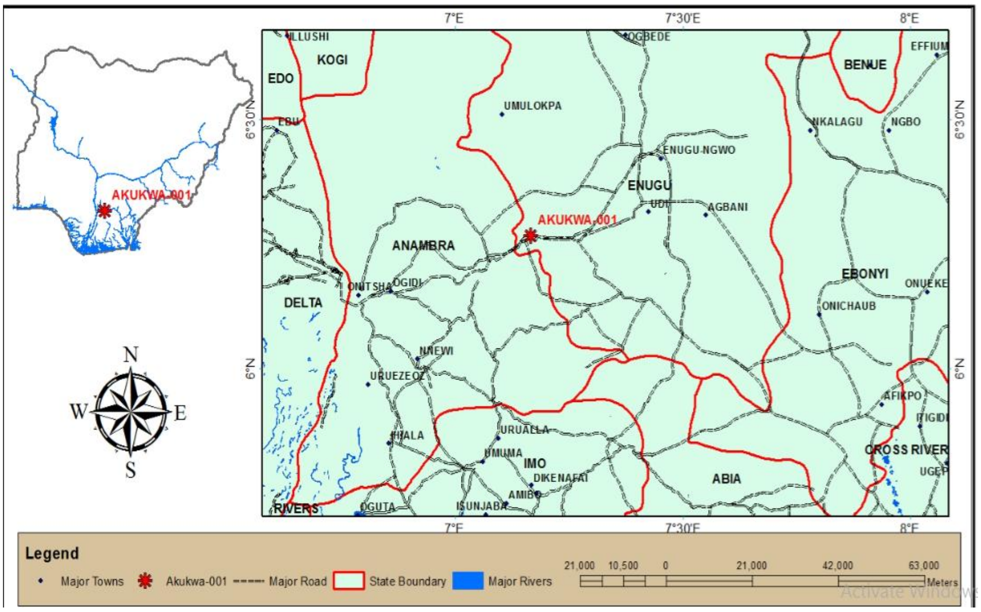

Figure. 1: Map of the study well (Akukwa – 1 well) showing well position (Red dot) within the Anambra Basin.

REGIONAL GEOLOGY AND STRATIGRAPHY

The geology of the Anambra Basin which the Well penetrated has been well studied and documented. The tectonic evolution of the Anambra and Niger Delta basins began probably in the Early Cretaceous time with the separation of Africa plate from the South American plate due to the opening of the Atlantic Ocean (Burke *et.al.*, 1972; Murat, 1972 and Nwachukwu, 1972).

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The geologic history of the Southern Nigeria has been attributed to three tectonic phases resulting to three successive basins- Anambra Basin, Afikpo Basin and Niger Delta (Murat,1972), though Murat (1972) did not recognize Afikpo Syncline as a basin.

Murat (1972) described the first phase to be characterized by movement along the major NE-SW trending faults resulting in the formation of the rift –like Abakaliki-Benue Trough. The second phase (Santonian) was characterized by compressional movement along the established NE-SW trend and resulted in the uplift of the Abakaliki fold belt contemporaneously with the Anambra Platform which subsided, displacing the axis of the basin to a position southward of the Benue folded belt and northwards of the Abakaliki uplift (Fig. 2). An older structural unit, the relatively shallow Dahomey Embayment existed to the west of the Benin Hinge line and was dated Neocomian (Omatsola and Adegoke, 1981; Jan du Chene, 2000).

Towards the end of Eocene, the third tectonic event occurred in which the eastern part of Niger Delta down-dip of the Abakaliki plunged out of the Calabar Flank and show repeated periods of erosion or non-deposition during the middle and upper Eocene. However, a large deltaic complex was developed in the down-dip of Anambra Basin. Thus, movement of blocks bounded by NE-SW and NE-SE trending fault preceded the subsidence of the Oligocene younger Niger Delta along NE-SE fault trend.

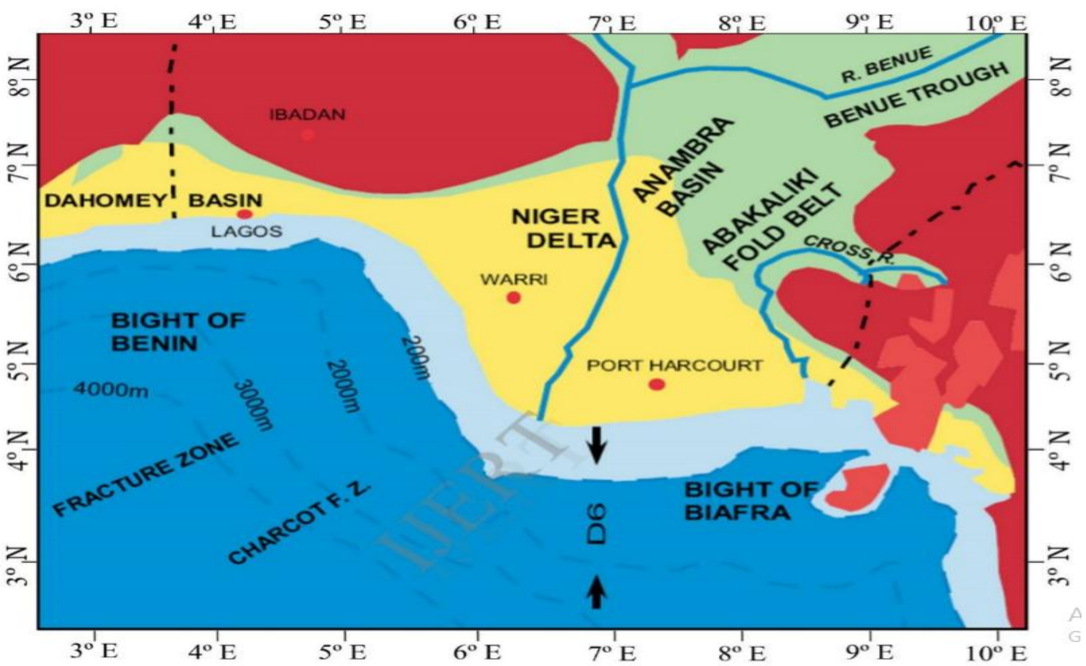

Figure. 2: Map of the Southern Nigeria showing uplift of the Abakaliki fold belt contemporaneously with the Anambra Platform which subsided, displacing the axis of the basin to a position southwards of the Benue folded belt and northwards of the Abakaliki uplift.(after Ola-Buraimo and Akaegbobi, 2013)

Stratigraphy

The Anambra Basin falls within the Southern Nigeria Sedimentary Basin, which was controlled by three megatectonic phases. These activities resulted in the displacement of the axis of the main basin, giving rise to three new basins, The Abakaliki – Benue Trough, The Anambra Basin and the Niger Delta Basin (Table 1).

The Abakaliki - Benue Trough

This marks the first phase (fig. 2) during Albian time, characterized by movements along NE - SW trending faults resulting in the formation of the rift like Abakaliki – Benue Trough. To the south west, the limit of the basin was the Benin – Benue (fault zone) between this hinge line and the Abakaliki Trough, shelf deposits were laid down on the Anambra platform

The Anambra Basin

This marks the second phase (Upper Santonian – Lower Campanian?) and was characterized by compressional movements along the established north east, southwest trend and resulted in the folding and uplifting of the Abakaliki - Benue folded belt contemporaneously with the Abakaliki uplift, subsidence of the Anambra platform, and displacement of the axis of the basin to a position southwest of the Benue folded Belt and northwest of the Abakaliki uplift. To the west of the Benin Hinge line, a new structural unit, the relatively shallow Dahomey Embayment appeared, probably as a result of an active NNE – SSW fault system (Murat, 1967).

The Niger Delta Basin

A third phase occurred towards the end of the Eocene, large areas in the eastern part of the Niger Delta downdip of the Abakaliki plunge and of the Calabar Flank show repeated periods of erosion and/or non-deposition during the middle and upper Eocene, where a large delta complex was deposited in the downdip Anambra Basin. These positive movements of the blocks bounded by the north-east, south-west and northwest, southeast trending faults, preceded the subsidence of the Oligocene and younger Niger Delta Basin along the north west, southeast fault trend (Oloto, 2009).

Table 1: Showing regional stratigraphic sequence of South Eastern part of Nigeria. (modified from Reyment (1965), Murat (1972).

AGE	FORMATION	SEDIMENTARY BASIN
Pliocene	Benin Formation	Niger Delta Basin
Pleistocene	Ogwashi-Asaba Formation	
Eocene	Ameki Formation	
Paleocene	Imo shale	
Maastrichtian	Nsukka Formation Ajali Sandstone Mamu Formation	Anambra Basin
Campanian	Nkporo/Enugu Shale (including Afikpo Sandstone & Owelli Sandstone)	
Santonian Coniacian	Awgu Shale	Abakaliki-Benue Trough
Turonian Cenomanian Albian	Eze-Aku Formation Odupkani Formation Asu River Group	

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METHOD OF STUDY

The study was carried out at three different stages starting with laboratory sample description, palynological sample preparation and mounting of palynological slides.

Sample Description

At the laboratory, a detailed lithological description of the various samples was carried out, each sample was tested with dilute hydrochloric acid. The degree of reaction of the samples with the acid was noted and expressed as calcareous, when there is effervescence and non-calcareous when there is no reaction with the acid. The various lithostratigraphic units penetrated by the well are as described below (fig. 3).

Palynological Sample Preparation

The palynomorph and associated materials were extracted by one of two preparation techniques according to the lithologic type (coals or clastic). All samples were washed and dried in order to avoid contamination.

Two to three grams of the samples were broken to a grain size of 4 mm, and transferred to a plastic beaker cup. The beakers were then labelled according to the depth of the samples. All the samples were then treated with commercial grade hydrofluoric acid. The essence of these was to separate the fossils from the rock debris. Most of the calcareous samples showed effervescence.

The length of time needed for the samples to digest varies depending on the quantity of silt and sand. But once the initial heat of reaction had been dissipated, hydrofluoric acid concentration was increased.

The samples were displaced in a water bath and stirred, with plastic rods twice a day for the period of maceration. The effect of the acid was neutralized by decanting and settling method.

The residual rock particle and megafossils were separated from the finer disaggregated material by passing them through a mesh of 106 µm and 200 µm. The filtrate was thoroughly washed with water using the 10 µm mesh nylon sieve. The subsequent residue was swirled on a 24 cm diameter watch glass. The lager residue was discarded while the final top material was boiled for a few seconds in water to which a few drops of concentrated hydrochloric acid was added. The residual was again washed in the 10 µm mesh nylon sieve and stained with safranin- O in a mild alkaline medium stored in small glass centrifuge tubes and labeled.

Slide Preparation

The stained specimen above is further diluted and washed out with water and the finished residual transferred into a tube with two drops of diluted solution of Norland glue added. A few of the residual was pipetted out on a clean dry cover slip, allowed to dry on a hot plate. Canada balsam is smeared on a slide on a hot plate at 100^0C. When warmed enough, the dried cover slip was stuck to the slide, pressed labelled correctly and properly stored after cooling. A total of One Hundred and Fifty palynological slides were produced.

RESULTS

The results of the study are as presented under Lithostratigraphy and Biostratigraphy;

Lithostratigraphy

The various lithostratigraphic units penetrated by Akukwa-1 well in the Anambra Basin are presented in fig. 3 and discussed as follows.

Nkporo Shale

This formation occurred from 7,990 ft – 5400 ft. It consists of extensive grey coloured fissile shales, slightly calcareous at the base and top but non calcareous at the middle, with central thin layer of sand and sandy mudstone. It has its lateral equivalents as the Enugu Shales and the Owelli Sandstone, which occurred towards the central parts of the Anambra Basin. The formation is fossiliferous.

Mamu Formation

This occurred between depth intervals 5900 ft – 3800 ft. The formation is composed of carbonaceous shale, fine sand and heteroliths of both lithologies. Although it is known to consist of coal seam but they were not in the sample. The formation is transitional between the clearly marine Campanian Enugu Shale and the marginal marine (largely tidal) Ajali sandstone.

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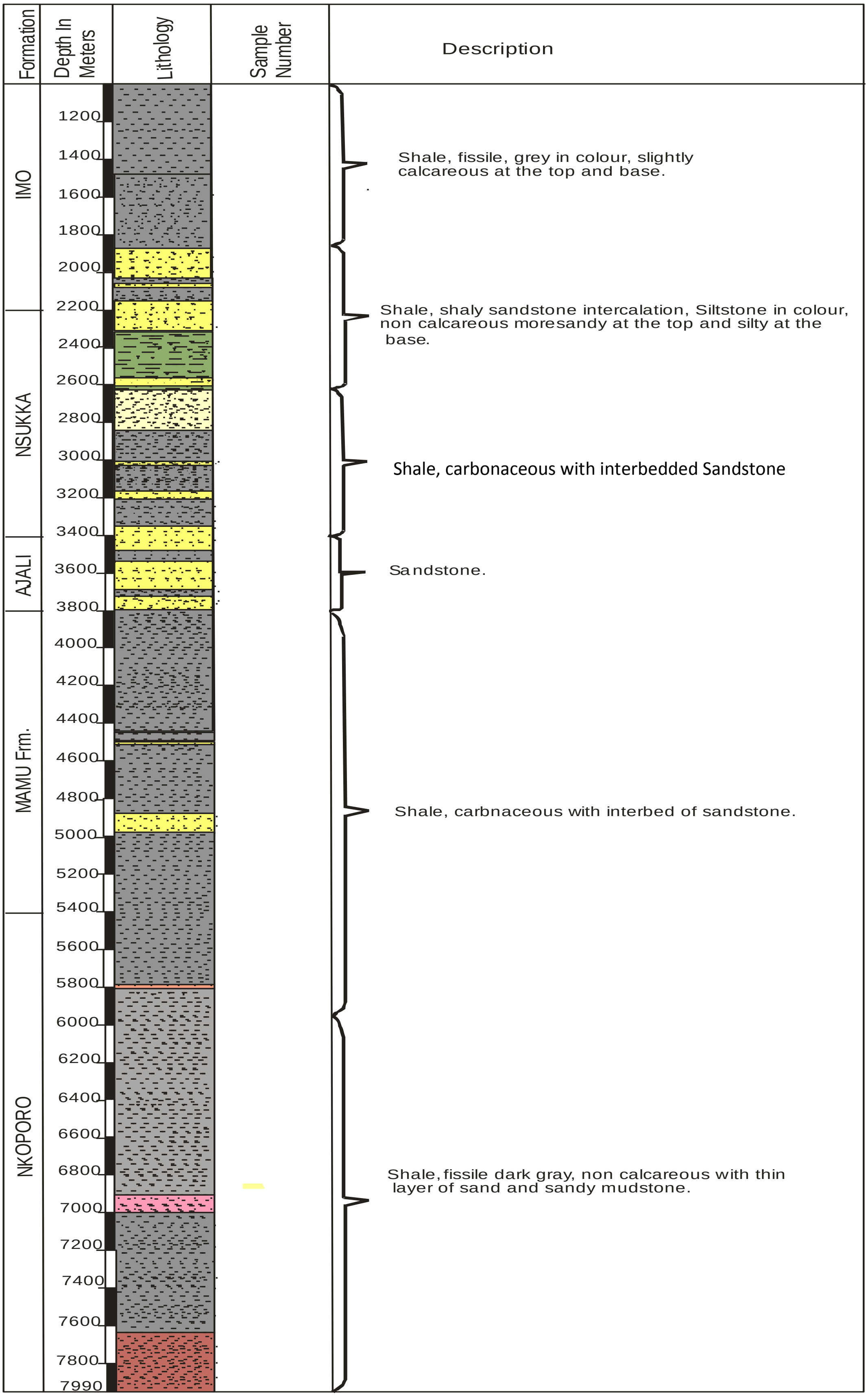

Figure, 3: Lithologic Description of various lithostratigraphic units penetrated by the Akukwa-1Well. (after Soronnadi-Ononiwu *et. al*., 2014)

Ajali Sandstone

It occurred between 3800 ft – 3400 ft. It consists of sandstone and indurated shale intercalations, known for its friability, shaly at the base and sandy at the top. They are coarse grained, commonly very granular and very coarse to fine grained. In general, they are poorly sorted. The composition and grain size indicate deposition in a continental environment.

Nsukka Formation

The formation occurred between 3400 ft -2200 ft intervals, it consists of shale, shaly sandstone and sandstone intercalations, becoming sandier at the base and top. The shale is brownish black, at some depths, sandy to silty and contains thin streaks and finely dispersed coal fragments with some plant debris. The shale is rich in micro fauna.

Imo Formation

This was encountered between 2200 ft-Top interval. The formation consists of blue grey carbonaceous, fissile, clayey shale. The formation is rich in carbonaceous organic debris and at some depths, the shale becomes silty or sandy with occasional admixture of yellowish - brown clayey ironstone. The formation becomes sandier towards the base. The entire formation is fossiliferous and contains few mica flakes.

Biostratigraphy

The identified forms enabled the erection of a biostratigraphic distribution chart (Fig. 4). The recovered dinoflagellates are further subdivided into two groups.The dinoflagellates are divided into classes that have affinity to the order Gonyaulacales or to the order Peridiniales. These two orders have been utilized in Palaeoenvironmental determination using the G/P ratio. Peridinialeans (P) are predominantly proximate cysts, usually adapted to near-shore marine, brackish water and stress environments whereas the Gonyaulacaceans (G), being predominantly chorate cysts, are adapted to normal salinity open marine conditions. (Harland, 1973).

The Order Gonyaulacales is usually characterized by a six-sided (one that contacts six superjacent paraplates) antapical paraplate (plate Y of Taylor (1980) on the hypocyst, and on the epicyst by lack of contact between the second and fourth apical paraplates.

The Order peridiniales, many species have a distinctly peridinoid outline with one apical, two antapical, and sometimes two lateral horns and they usually have a moderate amount of primary dorsa-ventral compression.

Order Gonyaulacales differ from Order peridiniales according to Taylor (1980) in the following ways:

1. Distinct asymmetry in overall paraplate distribution.
2. Asymmetrical and generally small anterior intercalaries.
3. Six rather than seven- precingulars.
4. Six rather than five post cingulars.
5. Large posterior intercalary.
6. One rather than two antapical paraplates.

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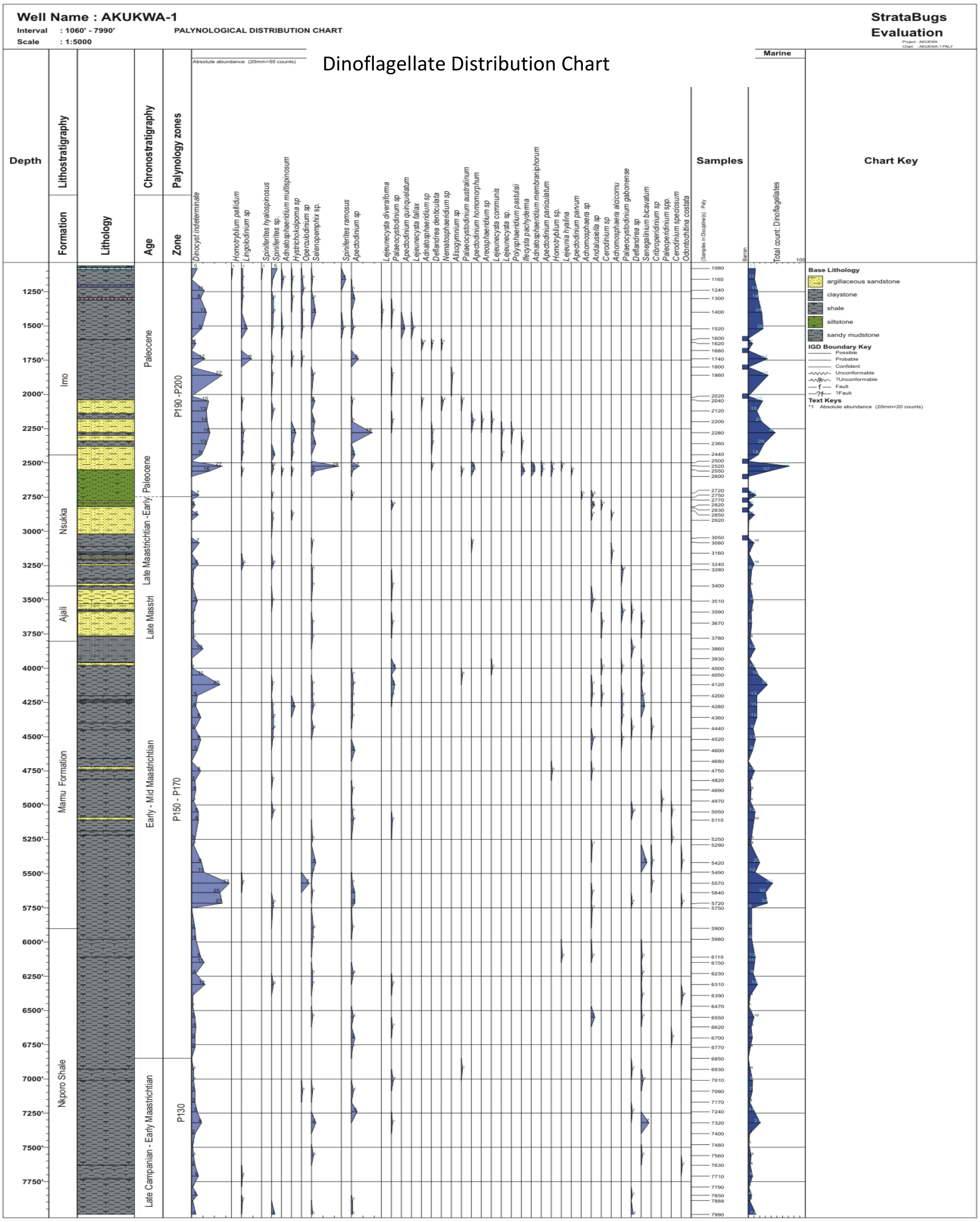

Figure 4: Distribution Chart of recovered Dinoflagellates in Akukwa – 1 well

Order Peridiniales:

These include the following identified forms:

Lejeunecysta fallax
Lejeunecysta communis
Lejeunecysta hyaline
Selempemphix sp
Apectodinium quinquelatum
Deflandrea denticulata
Apectodinium homomorphum
Areosphaeridium sp
Apectodinium acuminatum

Apectodinium paniculatum
Apectodinium parvum
Paleocystodinium australinum
Paleocystodinium golzowense,
Senegalinium bicavatum
Andalusiella sp

Cerodinium sp

Ifecystapachyderma

Gonyaulacales:

These include the following identified forms:

Homotryblium palladium
Spiniferites hyalospinosus
Spiniferitesramosus
Adnatosphaeridium multispinisum
Adnatosphaeridiummembramiphorum
Achomosphaeridium sp.
Cribroperidinium sp
Nematosphaeropsis sp.
Alisogymium sp.
Hystrichokolpoma sp.

DISCUSSION

Dinoflagellate Cyst Zonations for Akukwa – 1 Well

The identified dinoflagellates from Akukwa – 1 well were zoned and compared with Oloto (1994) zonation scheme. The zonation produced zone A to D as presented in Table 2. The zones were defined by the first occurrence of two or more species. The following dinoflagellate zones are described below:

Zone A: ***Apectodinium paniculatum***
Age: **Maastrichtian**
Depth: **7990 ft**

Species having their first appearances are difficult to differentiate because this zone represents the base of the well. The zone is marked by the first downhole occurrence of *Deflandrea* sp, and *Apectodinium paniculatum*.

Zone B: ***Paleocystodinium austrialinium***
Age: **Upper Maastrichtian**
Depth: **7990 ft – 4000 ft**

The base of this zone is the same as the top of Zone A marked by the last downhole occurrence of the following: *Paleocystodinium* sp ,*Paleocystodinium austrialinium, Cerodinium speciosum, Lejeunecysta hyaline*, *Homotryblium* sp., *Paleocystodinium golzowense*.

Zone C: ***Apectodinium homomorphum***
Age: **Upper Maastrichtian – Late Paleocene**
Depth: **4000 ft – 2550 ft**

The base of this zone is the same as the top of Zone B characterized by the last downhole occurrence of the following: *Paleocystodinium gabonese, Lejeunecysta communis, Achomosphaera alicormu, Apectodinium homomorphum, and Achomosphaera sp.*

Zone D: ***Homotryblium palladium***
Age: **Paleocene – Early Eocene**
Depth: **2550 ft – 1520 ft**

The base of this zone marks the top of Zone C, characterized by the last downhole occurrence of the following: *Apectodinium parva, Adnaetosphaeridium multispinosum, Ifecysta pachyderma, Adnaetosphaeridium membramophorum, Deflandrea denticulatum, Polysphaeridium pastulsii, Areosphaeridium* sp, *Alisogymnium* sp, *Adnaetosphaeridium* sp, *Lejeunecysta fallax, Apectodinium quinquelatum, Spiniferites ramosus, Lejeunecysta diversiformis* and *Homotryblium palladium.*

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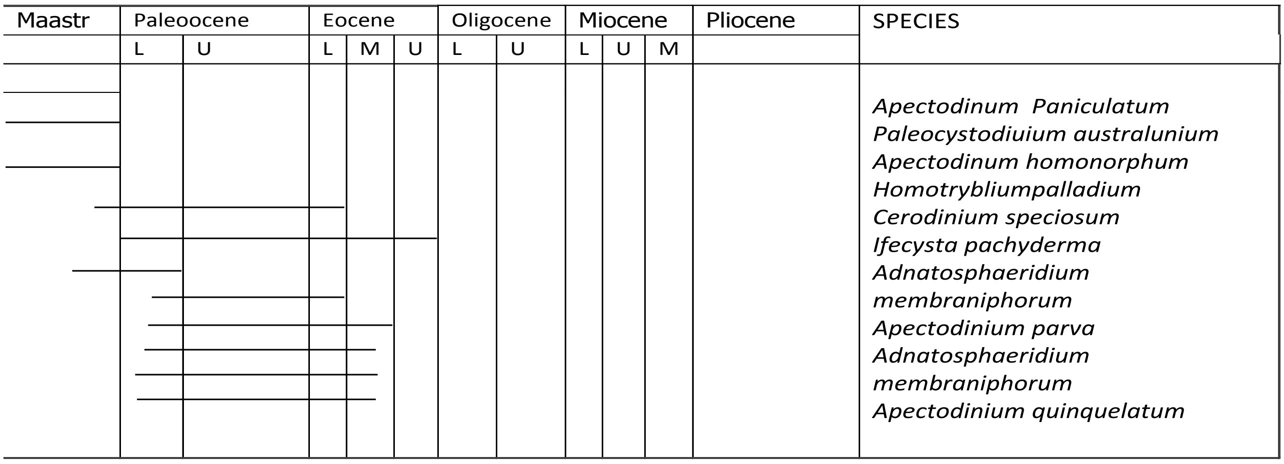

Fig. 5: Stratigraphic distribution of the age diagnostic Dinoflagellate cyst

Table 2: Biozonation of identified Dinoflagellates from Akukwa-1 well compared with Oloto (1994) zonation scheme.

LITHOSTRATI-GRAPHY	AGE: EPOCH	AGE: STAGE	DEPTH (ft)	ZONE CODES	PRESENT STUDY	Comparism with published biozonation schemes: Oloto (1994)	
IMO SHALE	Early Paleocene to Early Eocene		1520 2200	D	Homotryblium palladium	J - M	Apectodinium hyperacanthum zone Costa and Downie (1976)
NSUKKA FORMATION	Late Maastrichtian to Early Paleocene	DANIAN	2550 3400	C	Apectodinium homomorphum	G - I	Danea mutabilis: Hafniasphaera cryptovesiculata Hansen,1977; Senoniasphaera inomata (Hansen,1977)
AJALI SANDSTONE	Late Maastrichtian		3800 4000			A - F	Palynodinium grallator zone (Hansen,1977)
MAMU FORMATION	Late Maastrichtian		5900	B	Paleocystodinium austrialinium		Zone IV (Jain and Millepied) 1975
NKPORO SHALE	Late Campanian - Late Maastrichtian		7990	A	Apectodinium paniculatum		

Age Characterization Based on Identified Dinoflagellate Cysts

The zonal divisions discussed here are mainly based on the distribution of dinoflagellate species identified in Akukwa – 1 well studied interval. The zones are discussed with the stratigraphic distribution of the age diagnostic dinoflagellate cysts.(fig.5)

The use of first occurrences in dinoflagellate stratigraphy has been shown to yield a high level of biostratigraphic resolution in the Paleogene of North western Europe (Costa and Downie, 1976). Ages of the delineated zones were determined by comparing with assemblages from European surface sections and other areas. The zones were compared with those of Oloto (1994), Williams and Bujak (1977) which were based on dinocysts studied by Willams and Brideaux (1975) on the Grand Banks shallow coreholes, Canada; Hansen (1977) on the Upper Maastrichtian and Danian of Denmark; and Bujak *et al*., (1980) on the Eocene of Southern England.

The stratigraphic ranges for Akukwa – 1 well yielded twenty-three biozones for pollen/spores and four dinoflagellate cyst zones.

Assemblage Zones A - B in Akukwa – 1 well (this study), based on its stratigraphic position and series of last downhole occurrence, corresponds to Late Campanian – Late Maastrichtian of Oloto (1994) A – F and Germeraad *et al.*, (1968).

The age assigned age corroborates with Oloto (1994) dinoflagellate zone A – F and zone IV of Jain and Millepied (1975) with key dinoflagellate cyst such as *Apectodinium paniculatum* and *Paleocystodinium australinium* also present in the present study.

Dinoflagellate zone C (*Apectodinium homomorphum* zone) in the present study was compared to G – I zone of Oloto (1994), Late Maastrichtian to Early Paleocene was assigned to Zone C in Akukwa – 1 well.

Assemblage zone D in the present study which corresponds to Oloto (1994) J – M biozones and Costa and Downie's (1976) *Apectodinium hyperacauthum* zone was used to assign an early Paleocene to Early Eocene age to Imo Shale.

The graphic log above was used in delineating five lithostratigraphic units, the Nkporo Shale, Mamu Formation, Ajali Formation, Nsukka Formation and Imo Shale and the Dinoflagellate zonations helped in assigning ages.

Palaeoenvironmental Determination

Palynological data is a useful tool in palaeoenvironmental analysis (Van Bergen *et al.,* 1990; Petters and Edet, 1996; Ojo and Akande, 2004; Oloto, 1990, 1992, 1994; Umeji 2002, 2005, 2006). Environmental changes are usually reflected in the palynologic assemblages (Oloto, 1989, Ojo and Akande, 2004) that is why the composition and relative proportions of different groups of palynomorphs were utilized in the study.

The depositional environment of the well was evaluated following detailed analysis and characterization of the biogenic and physical features of the sedimentary lithofacies coupled with the palynological characteristics. The major groups utilized in this study are pollen/spores dinoflagellates, other associated non pollen palynomorphs which includes foraminiferal test linings, fungal spores, pediastrum etc.

Tables 3 shows the percentage distribution of each form per depth. From the table, it is obvious that terrestrially derived palynomorphs dominated the assemblage. Shrank

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(1984) suggested that palynomorph assemblage with higher content of large land derived miospores indicates terrestrial influence and vice versa.

Helenes et al. (1998) applied palynological marine index (PMI) values to interpret the depositional environments. PMI which is the ratio of abundance of marine to terrestrially derived palynomorphs was calculated (Table 4) and plotted into palynological marine index (fig. 6) using the Akukwa –1 Well species. Based on the plot, sediments in the lower part of the section indicate a marine influence.

The following inferences could be made from the plot:

1. The interval 7900 ft – 5900 ft corresponding to the Nkporo Shale, is dominated by terrestrial forms except at 7850 ft and 7320 ft where marine forms dominated the terrestrial. From the base at 7990 ft, the total percentage of terrestrial forms stands at 86.1% as against the marine forms 14.1%. At 7888 ft, the percentage of the marine forms equate with those of terrestrial forms (marine forms 50%, terrestrial forms 50%). At 7850 ft, the marine Index forms dominate the assemblage with 64.3%, while the terrestrial Index forms stands at 35.7%. Beginning at 7850ft to 7560 ft the values of the terrestrial markers fluctuate between 66.6% to 68.9%. Between 7560 ft depth to 5900 ft, the values of the terrestrial markers (Pollen & Spores) which fluctuates between 92.4% to 86.4%, while marine forms recorded low values ranging from 6.7% to 33.4% at a depth of 5980 ft showing a slight growth and declines to 26.1% at 5900 ft.
2. The interval between 5900 ft – 3860 ft, corresponds to the Mamu Formation. It recorded a high percentage of terrestrial markers, increasing from 73.9% at 7550 ft to 86.8% at 3860 ft; whereas there is a sharp decrease of Marine Index forms from 40% at 5640 ft to 13.2% at 3860 ft.
3. The interval between 3860 ft – 3400 ft, corresponding to the Ajali Sandstone, maintained a high percentage value of terrestrial derived forms. Ranging from 91.1% at 3780 ft to 96.97% at 3400 ft. The marine index forms vary from 8.9% at 3780ft, decreased to 8% at 36.70ft, a further decrease to 7.8% at 3590ft and an increase to 12.7% at 3510 ft and a sharp decrease to 3.03% at 3400 ft.
4. The interval between 3400 ft and 2200 ft corresponds to the Nsukka Formation, recorded still high values of terrestrial palynomorphs ranging between 89.9% at depth 3280 ft and 82.0% at depth 2200 ft. The fluctuations were slight, especially at 3160 ft, it recorded the highest peak of 98.8% and decreased to 88.0% before declining to 67.5% at 2850 ft, increased from this point to 94.6% at 2750ft and declined to 69.8% up to 2520 ft and a further increase to 82.0% at 2200 ft. The marine forms showed a slight increase to 10.2% at 3280 ft – 3240 ft, a sharp decrease at 3160 ft to 2.0%. A gradual increase from 2920 ft, 17.5% to 36% 2520 ft; and a further decrease to 16.7% of marine forms at 2200 ft.
5. The interval between 2200 ft – 1080 ft corresponds to the Imo Formation. It recorded high percentage values of terrestrial markers beginning with 84.5% at 2120 ft to 92.0% at 1160 ft. In between the two end values, the values fluctuated between 74.2%, 61.1%, 76.4% and 80.7%, 62.6% and 75.5% at 1080 ft (the Top).
6. The marine forms show a gradual increase between 16.1% at 2120ft to 24.5% at the top (1080). The highest peak of marine

forms occurred at 1860ft with 38.9% and 37.2% at 1240ft.

The percentage of the terrestrial palynomorphs from the base to the top of the well is greater than those of the Marine Index forms. Using an integrated approach and a hybrid technique of combined land derived forms, marine derived forms (dinocyst), G/P ratio and non-pollen palynomorphs (NPP), paleoenvironment of deposition was deduced, showing that the entire sequence analyzed was mainly deposited within the alternating marginal marine and open marine systems.

Table 3: Showing the percentage distribution of palynomorphs

Depth(ft)	Total	% Dinoflagellate	% Terrestrial index forms (Spores & Pollen)
1080	49	24.5	75.5
1160	112	8	92
1240	43	34.9	65.1
1300	93	18.3	81.7
1400	117	18.8	81.2
1520	137	22.6	77.4
1620	37	21.6	78.4
1740	221	21.7	78.3
1860	90	35.6	64.4
2040	97	23.7	76.3
2120	93	16.1	83.9
2200	144	16	84
2280	238	18.5	81.5
2360	120	14.7	85.3
2440	110	15.5	84.5
2520	200	35.5	64.5
2550	125	28.8	71.2
2750	147	4.1	95.9
2820	46	13	87
2850	43	23.3	76.7
2920	63	15.9	84.1
3160	36	2.8	97.2
3240	57	17.5	82.5
3280	59	8.5	91.5
3400	132	2.3	97.7
3510	71	11.3	88.7
3590	64	7.8	92.2
3670	75	8	92
3780	45	6.7	93.3
3860	91	13.2	86.8
3930	84	-	100
4000	73	11	89
4050	111	12.6	87.4
4120	104	31.7	68.3
4200	100	13	87
4280	153	98	2
4360	132	9.1	90.09
4440	115	7.8	92.2

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4520	85	14.1	85.9
4600	103	7.8	92.2
4680	105	9.5	90.05
4750	53	18.9	81.1
4820	50	8	92
4890	63	6.3	93.7
4970	60	5	95
5050	88	6.8	93.2
5110	74	12.2	87.8
5250	80	7.5	92.5
5290	35	8.6	91.4
5420	74	27	73
5490	55	21.8	78.2
5640	75	40	60
5750	23	8.7	91.3
5900	45	13.3	86.7
5980	18	27.8	72.3
6110	74	14.9	85.1
6150	47	23.4	76.6
6230	58	13.8	86.2
6310	67	23.9	76.1
6390	28	14.3	85.7
6470	28	3.6	96.4
6550	63	15.9	84.1
6620	31	16.1	83.9
6700	48	14.6	85.4
6770	62	6.5	93.5
6850	11	-	100
6930	20	20	80
7010	49	12.2	87.8
7090	43	16.3	83.7
7170	43	7	93
7240	44	25	75
7320	41	51.2	48.8
7400	48	6.3	93.7
7480	15	6.7	93.3
7560	29	31	69
7630	11	36.4	63.6
7710	20	35	65
7790	3	33.3	66.7
7850	14	64.3	35.7
7888	6	50	50
7990	78	12.8	87.2

-

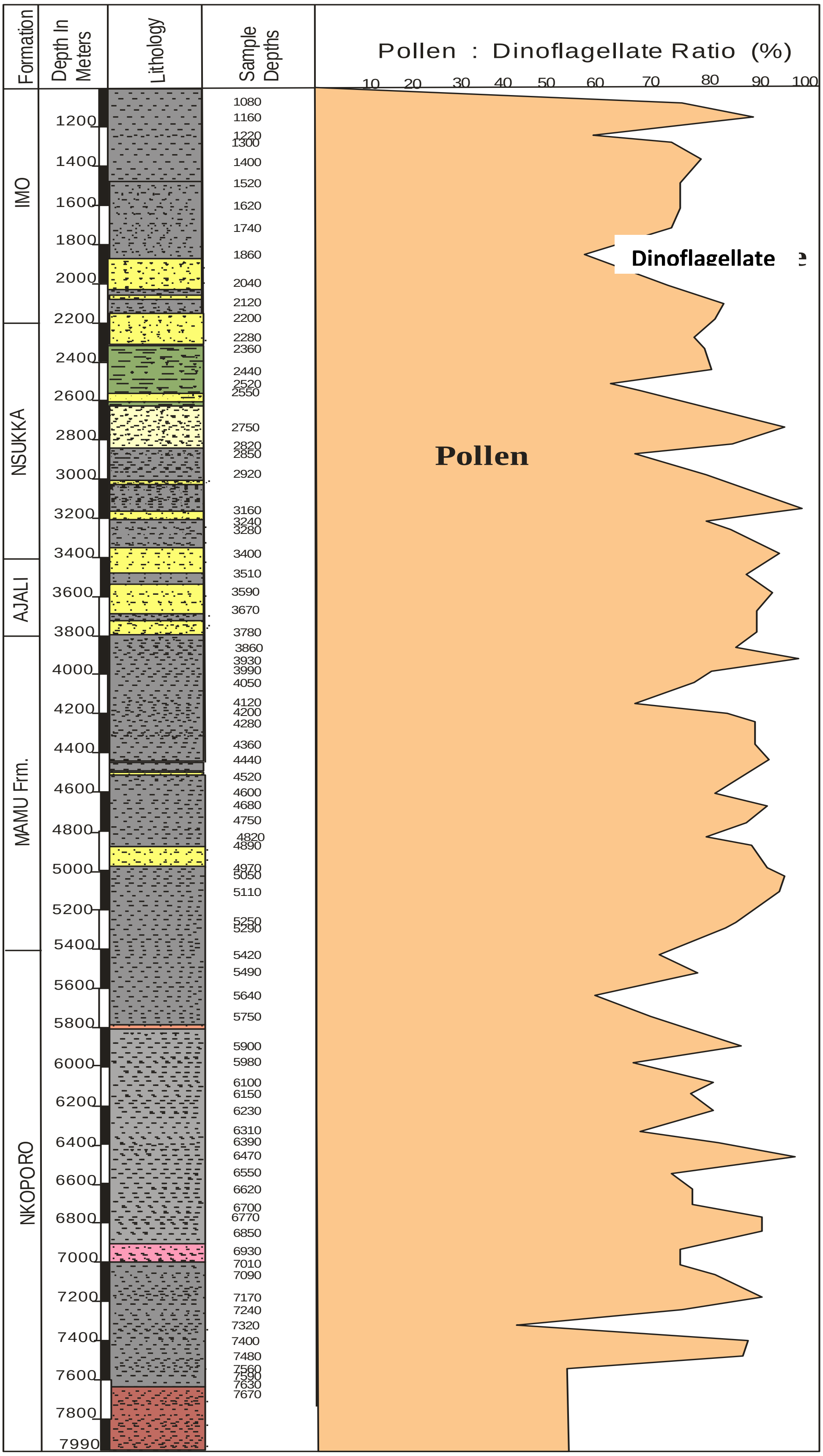

Figure 6: Continental Marine Index Plot of Akukwa-1 Well.

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Table 5: Showing the G/P ratio and Non pollen palynomorphs (NPP)

Depth (ft)	Gonyaulacales	Peridiniales	Fungal spores	Foram lining	G/P ratio	Paleoenvironment
1080	7	0	0	0	7	Open marine
1160	8	1	3	0	8	Open marine
1240	0	1	1	1	-1	Marginal marine
1300	3	5	6	1	0.6	Open marine
1400	2	6	1	2	0.33	
1520	4	7	2	0	0.57	
1620	3	1	1	0	3	
1740	2	6	4	4	0.33	
1860	2	3	2	5	0.67	
2040	3	5	1	1	0.6	
2120	2	0	0	0	2	
2200	0	9	2	1	-9	Marginal marine
2280	4	21	6	3	0.19	Open marine
2360	1	4	0	3	0.25	
2440	4	4	4	0	1	
2520	6	37	2	1	0.16	
2550	7	12	2	1	0.58	
2750	2	3	1	2	0.67	
2820	0	6	0	0	-6	Marginal marine
2850	3	1	3	1	3	Open marine
2920	1	0	0	0	1	
3080	0	2	1	1	-2	Marginal marine
3160	3	0	1	0	3	Open marine
3280	0	3	0	1	-3	Marginal marine
3400	0	2	4	1	-2	
3510	1	2	4	1	0.5	Open marine
3590	0	3	4	0	-3	Marginal marine
3670	0	4	2	0	-4	
3780	0	1	0	1	-1	
3860	0	2	2	0	-2	
3930	0	0	1	2	0	Open marine
4000	0	8	3	3	-8	Marginal marine
4050	0	3	4	4	-3	
4120	1	7	0	1	0.14	Open marine
4200	0	8	4	2	-8	Marginal marine
4280	4	7	2	0	0.57	Open marine
4360	2	2	0	3	1	
4440	3	3	1	0	1	
4520	1	3	3	1	0.33	
4600	0	3	1	0	-3	Marginal marine
4680	0	0	2	0	0	Open marine

4750	1	1	1	1	1	
4820	1	0	1	0	1	
4890	0	1	1	0	-1	Marginal marine
4970	0	1	0	1	-1	
5050	2	4	0	0	0.5	Open marine
5110	0	3	1	1	-3	Marginal marine
5250	0	1	2	0	-1	
5290	0	1	0	2	-1	
5420	1	8	1	0	0.125	Open marine
5490	0	1	0	0	-1	Marginal marine
5570	1	1	3	0	1	Open marine
5640	0	5	0	0	-5	Marginal marine
5720	2	4	1	0	0.5	Open marine
5750	1	1	1	4	1	
5900	0	3	0	0	-3	Marginal marine
5980	0	1	0	1	-1	
6110	0	3	2	1	-3	
6150	0	0	1	0	0	Open marine
6230	0	3	2	1	-3	Marginal marine
6310	2	2	5	0	1	Open marine
6390	0	1	1	0	-1	Marginal marine
6470	0	0	0	0	0	Open marine
6550	0	7	7	0	-7	Marginal marine
6620	0	1	2	0	-1	
6700	0	4	4	0	-4	
6770	0	1	2	0	-1	
6850	0	0	1	0	0	Open marine
6930	0	2	1	0	-2	Marginal marine
7010	0	4	4	2	-4	
7090	0	3	1	0	-3	
7170	0	0	1	0	0	Open marine
7240	0	6	0	0	-6	Marginal marine
7320	0	12	2	0	-12	
7400	0	0	3	0	0	Open marine
7480	0	0	1	0	0	
7560	0	3	3	0	-3	Marginal marine
7630	0	0	1	0	0	Open marine
7710	0	0	1	1	0	
7790	0	0	1	0	0	
7850	0	1	0	0	-1	Marginal marine
7888	0	1	0	0	-1	
7990	3	4	5	1	0.75	Open marine

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SUMMARY AND CONCLUSION:

Based on the Continental Marine Index Plot (fig.6), sediments in the lower part of the section indicate a marine influence and a rather paralic condition, leading to a more continental condition, hence the dominance of pollen and spore assemblage suggests a paralic condition in a shallow marine setting.

This is further supported by the presence of organic walled microplankton such as *Paleocystodium australinium,Homotriblium palladium,Lejeunecysta hyaline* and *Pediastrium*.

The Akukwa – 1 Well is lithologically characterized by a coarsening upward sequence from a sequence of interbedded Shale and Siltstone into Sandstone units. The basal part is predominantly shale, siltstone and minor sandstone units indicating prodeltaic to delta front environments where normal sea water is diluted by rain and run-off (Ojo, 1999; Ojo et al., 1999, Ojo and Akande, 2004). At the upper part of the section, the sandstone to siltstone units corresponds to delta plain, dominated by continental condition as indicated with lack of dominance of marine forms.

The Cretaceous microfloral provinces discussed by Herngreen and Chinova (1981) shows that West Africa belongs to the Late Cretaceous Palmae Province. This is confirmed by the recovered microflorals in the Palmae Province and those obtained from the study area. Palmae pollen such as*Spinizonocolpites*, *Proxaperites* and *Longapertites* suggests a prevailing tropical climate (Awad, 1994, Shrank, 1987). *Spinizonocolpites*, *Retidiporites* and *Echinmonocolpites*all belong to the semi Mangrove Palm (Nypa) (Muller, 1968; Germeraad *et al*, 1968). The assemblage suggests estuarine conditions similar to Mangrove swamps (Ojo *et al*, 1999). Jan du Chene (1980) suggested a mangrove environment in the Maastrichtian of Nigeria on the basis of the presence of *Spinizonocolpites baculatus.*

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EXPLANATION TO PLATES

Order Peridiniales:

1. *Apectodiniumpaniculatum*(30 µ)
2. *Lejeunecystacommunis*(30 µ)
3. *Apectodiniumquinquelatum* (25 µ)
4. *Apectodiniumhomomorphum*(25 µ)
5. *Cerodinium sp.* (25 µ)
6. *Apectodinium parvum* (25 µ)
7. *Selempemphix sp.* (30 µ)
8. *Selempemphix sp.* (30 µ)
9. *Selempemphix sp.* (30 µ)
10. *Lejeunecystafallax*(30 µ)

Order Gonyaulacales:

11. *Hystrichokolpoma sp.* (25 µ)
12. *Hystrichokolpoma sp.* (30 µ)
13. *Homotryblium palladium* (30 µ)
14. *Nematosphaeropsis sp.* (25 µ)
15. *Cribroperidinium sp.* (30 µ)
16. *Spiniferitesramosus*(15 µ)

PLATE: