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Palynostratigraphy and Paleoenvironment of Afikpo Well_3, Afikpo Syncline, Nigeria

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Abstract
The Afikpo Syncline constitutes the western segment of the southern part of the Benue Trough. The syncline orients in the northeast-southwest direction and unconformably overlies the pre-Santonian strata of the Benue Trough. This study investigates the sediments of Afikpo Well_3, drilled within the syncline, identifies its different palynozones, and interprets their paleoenvironments of deposition. Forty-two ditch-cutting samples recovered from the well at a 150 ft interval consist of mudstones, calcareous mudstones, carbonaceous shales, and calcareous shales. These samples were subjected to palynological analysis following the conventional acid maceration technique. A total of 637 palynomorph counts were recovered. These comprise 316 pollen grains, which make up 49.61%; 129 spores, which make up 20.25%; 9 fungi spores, which make up 1.41%; 17 microforaminifera wall linings, which make up 2.67%; and 166 dinoflagellate cysts, which make up 26.06%. Two palynozones were identified within the well. These include zone AF-01 (Monocolpites marginatus assemblage zone), which ranges from depths of 1500–1320 ft and is Campanian in age; and zone AF-2 (Dinogymnium sp. assemblage zone), which extends from depths of 50 ft–1320 ft and dates back to the Maastrichtian period. Based on the predominance of palmae pollen, together with the subordinate occurrence of dinoflagellate cysts, and the fair representations of spores (Cyathidite minor), the environment of deposition of the sediments ranges from a nearshore brackish water to a shallow marine environment. The shallow environment is further confirmed by the frequent occurrence of microforaminifera wall lining and the dominance of the peridinoid dinoflagellate cysts over the gonyaulacinoids.
Keywords: *Palynozones, Palynomorphs, Paleoenvironments, Afikpo Syncline*

INTRODUCTION
The Afikpo Syncline is a depression that runs in a northeast-southwest direction and is situated in southern Nigeria (Fig. 1). It is an extension of the Central Africa Rift System, which formed due to the stretching and subsidence of substantial portions of the Earth's crust during the early Cretaceous period when the Gondwana supercontinent broke apart (Fig. 2). Reyment (1965) describes the syncline and the Anambra Basin as contemporaneous basins situated unconformably on the Santonian strata of the Benue Trough. The northern flank of the Niger Delta bounds the syncline to the south, while the Abakaliki anticlinorium occupies a position to the west. Furthermore, the Mamfe embayment is adjacent to the syncline on its eastern side, and the middle Benue Trough borders its northern portion.

The syncline contains four (4) notable borehole wells drilled by the Royal Dutch Shell BP. These borehole wells include Afikpo Well_1 (AFK_01), Afikpo Well_2 (AFK_02), Afikpo Well_3 (AFK_03), and Afikpo Well_4 (AFK_04). The samples for this study emanate from Afikpo Well_3 (AFK_03), and were acquired from the Nigerian Geological Survey Agency (NGSA). Only the work of Umeji (2010) on palynostratigraphy, sequence stratigraphy, and paleoecology of the Campano-Maastrichtian sediments of the Afikpo Syncline from the Afikpo-4 well cuttings has been reported in the literature, out of the four borehole wells. The research revealed four lithologically controlled ecological zones. These include Zone 1 *Dinogymnium acuminatum* abundance peak-Pebbly sandstone; Zone 2 *Elytrocysta druggi* abundance peak-Interbedded Sandstone/shale; Zone 3 *Apteodinium-Xenascuss-Phelodinium gaditanum* abundance peak-Grey shale; and Zone 4 *Palaeohystrichophora infusorioides* abundance peak-Black shale. Also, the plots of terrigenous versus marine palynomorph species indicate shallowing from base to top. The deposition of shales and sandstones occurred under marine conditions, with the shales being in deeper water and the sandstones in shallower water.

Meanwhile, geological information about the other three wells within the syncline is unknown. These have constituted the basis for the present research, which is aimed at investigating the palynostratigraphy and depositional environment of the sediments of Afikpo well_3 (AFK_03). The research is worth investigating due to the poor record of geological data on the subsurface component of the Afikpo Syncline.

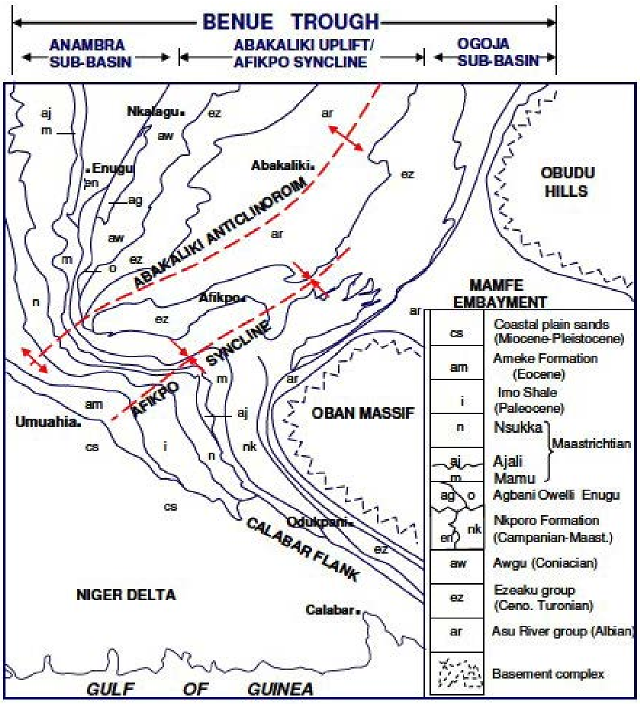

Fig. 1: Geological map of southern Benue Trough showing the NE-SW trending Afikpo Syncline

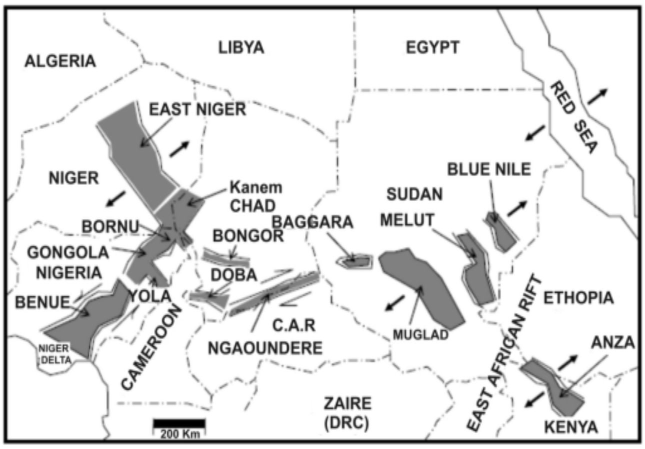

Fig. 2: The Central West African Rift systems showing trends rift basins (Schull, 1988)

GEOLOGICAL SETTING OF THE AFIKPO SYNCLINE

The Afikpo Syncline, along with the adjacent Abakaliki Anticlinorium and Anambra Basin, forms the southern portion of the Benue Trough (Fig. 1). Therefore, to comprehensively understand the geological characteristics of the syncline, it is pertinent to have a detailed understanding of the geological setting of the Benue Trough. The Benue Trough is a sedimentary basin that lies on the western coast of Africa, namely within the Gulf of Guinea re-entrant. It is elongated and exhibits a linear morphology. The trough is approximately 1000km long and about 100km wide, with a fault-bounded depression containing about 5000m thick of deformed Cretaceous-Tertiary sediments and volcanic deposits. Except for the terminal segment of the Yola Branch, which extends into Cameroon (Benkhelil, 1989), the trough is primarily located in Nigeria. Nwachukwu (1972) states that the trough on the African continent is unique because it extends over multiple continents and contains a significant deposit of Cretaceous supracrustal material that has folded under compression. Olade (1975) proposed a tectonic model that elucidates the upward movement and cessation of a mantle plume as the primary reason for the evolution of the trough. The author postulated that the initial stage of its formation involved the manifestation of a concentrated column of hot plumes beneath the Niger Delta. The uplift in the Benue region caused the formation of domes and rifts and ultimately culminated in the creation of a triple plate junction called the Rift-Rift-Rift (RRR) involving the Benue Trough, the Gulf of Guinea, and the South Atlantic during the Aptian to Early Albian periods (Burke and Whiteman 1973).

Currently, the vertical motion of the Earth's mantle has ceased or changed direction towards the west concerning the continent. The rotation of the African plate is the probable cause of this alteration. The thermal plume's movement or displacement generated a reduction in thermal energy, which in turn caused the layer under the Earth's crust to contract. This contraction finally resulted in the construction of a wide, uneven downward bend in the earth's surface (Ajakaiye and Burke, 1973). The rocks in the depression experienced significant but gentle compressive deformation before the Santonian epoch. Consequently, a series of folds aligned in a northeast-southwest direction occurred, resulting in the formation of the Abakaliki Anticlinorium. This caused the Anambra Platform to subside, creating the wide Anambra basin and the narrow Afikpo Synclinorium to the west and east of the Abakaliki Anticlinorium, respectively. During the Campanian and Paleocene periods, sediment deposition primarily occurred in the depressions.

Sedimentation commenced within the syncline with the deposition of the Campanian Nkporo Shale (Reyment and Morner, 1977). The formation is regarded as the consequence of the initial marine incursion within the basin. The formation consists of dark grey, easily split shale, brown silty and sandy shale, mudstone, and sandstone with a fine grain. Occasionally, it contains carbon and lacks foraminifera, but usually, it is rich in fossils. The formation commonly includes burrows made by Skolithos isp., Ophiomorpha isp., and Thalassinoides isp., and is believed to be a result of a shallow marine setting that gradually transformed into low-energy wetlands with channels.

Sediments of the Mamu Formation (Fig. 3) overlie the Nkporo Formation, which is characterized by transgressive features. The formation comprises mudstones, siltstones, shales, sandstones, and coal seams that are layered together in a deltaic environment. The coal beds and carbonaceous shales are predominantly located in the lower part of the formation and decrease in abundance towards the higher region. The Mamu Formation has a range of depositional environments, including paludal environments with channels and potentially peripheral marine environments, as proposed by Nwajide and Reijers (1996). The formation emerged during the later phase of the Campano-Maastrichtian transgression, which enabled the growth of the vast coal deposits. A vast and shallow marine environment persisted during the deposition of the Nkporo deposit. Kogbe (1989) restricts the presence of the formation to the Afikpo Syncline and the Anambra Basin in the southern region of Nigeria.

Overlying the Mamu Formation is the Ajali Sandstone. Reyment (1965) used the term "Ajali Sandstone" as a replacement for previous designations such as the "False-bedded Sandstone and the Sandstone Series" coined by Tattam (1944). During the late Maastrichtian period, there was a regressive phase that led to the deposition of mostly sand over a vast expanse. The lithology of this formation is defined by white, friable, coarse-grained sandstone with moderate to low sorting. The rock formation also exhibits cross-bedding, thin layers of pale claystone, and occasional bands of multicoloured shale that infrequently include carbonaceous material (Reyment, 1965; Agagu *et al*., 1985). The occurrence of bioturbation and cross-stratification suggests that the depositional environments are characterised by shallow marine conditions. However, most of the sedimentary structures suggest a repetitive sequence of tidal currents that alternate direction at regular intervals, with periods of still water in between.

The Nsukka Formation, commonly known as the "Upper Coal Measure," spans from the last Maastrichtian to the earliest Paleocene. The formation overlies the Ajali Formation and extends from the Calabar flank to Nsukka. The formation has a similar geological makeup to the Mamu Formation. The formation consists of layers of shales, siltstones, sands, and thin coal seams that cyclically move back and forth. Sandstones of varying grain sizes, from coarse to medium, compose the basal bed. These sandstones transition into well-layered blue clays, fine-grained sandstones, and carbonaceous shales. Occasionally, thin bands of limestone can be found within this formation (Reyment, 1965; Obi *et al*., 2001). The Nsukka Formation originated in a paralic environment (Whiteman, 1982), during the second transgression cycle that occurred after the Santonian period.

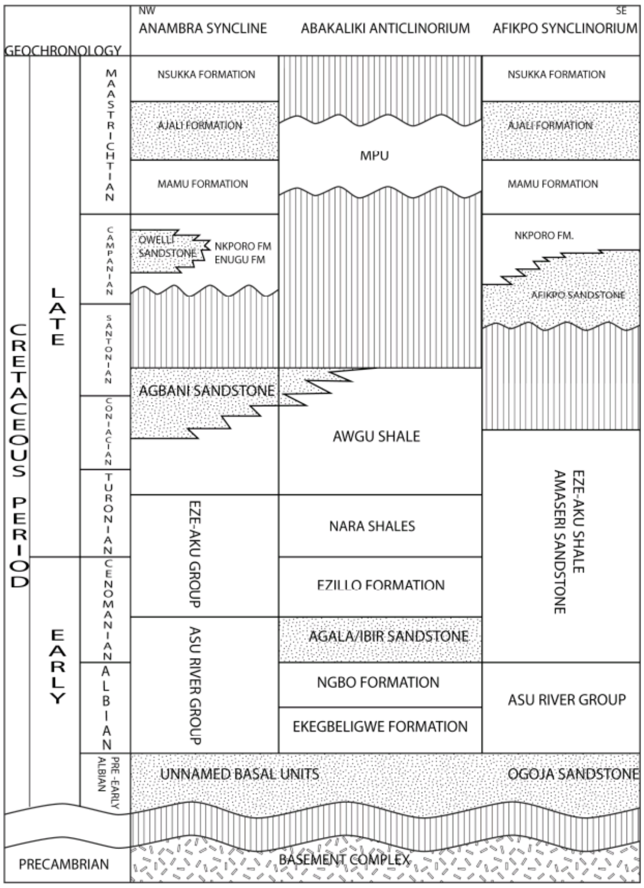

Fig. 3: Stratigraphic framework of the Cretaceous sediments of the Southern Benue Trough (Nwajide, 2005)

MATERIAL AND METHODOLOGY

Palynological Analysis Forty-two (42) samples were subjected to palynological analysis following standard acid maceration procedures, as illustrated by Traverse (2007). Initially, 20g of the samples were weighed and reduced to smaller chips using a mortar and pestle. This process is to enable quick dissolution and easy washing. Then, the samples were carefully put in a well-labeled beaker and digested using 5% diluted hydrochloric acid (HCl) to enable the breakdown of the carbonate contents. After 5 minutes of proper reaction, 40% of concentrated hydrofluoric acid (HF) was added to eliminate the silicate contents. Furthermore, the mixture was reacted with 60% hydrochloric acid (HCl) to achieve complete decarbonization. Furthermore, the addition of one to two drops of 70% concentrated nitric acid (HNO3) to the sample facilitated complete oxidation, breaking up the amorphous organic matter and enabling adequate visibility of the palynomorphs under a transmitted light microscope. After leaving the mixtures for about 1 hour, they were placed on a plate at a regulated temperature for 5 minutes. This allows proper digestion of all the chemical mixtures and the dissolution of samples. After removal from the hot plate, the samples are left to cool under normal atmospheric conditions before washing takes place using a 0.5-mm sieve-size mesh under controlled running distilled water. The retained residual contents were then treated with 2% concentrated potassium hydroxide (KOH) to neutralize the effect of the remaining acid on the residuals. The swirled residual content was centrifuged using zinc bromide ($ZnBr_2$), and the mineral matter and undigested sample contents were discarded. The obtained residues were further stained with safranin-O for a few minutes and stirred. Subsequently, the stained residual contents were obtained and carefully mounted on a well-labeled glass slide and covered with a cover slip using Norland optical adhesive while on the surface of a well-regulated hotplate for dryness. Meanwhile, the coverslip helps to prevent the elimination of the palynomorphs when there is a scratch on the surface of the slide. Lastly, the prepared slides were all viewed under an Olympus Cx41 microscope using an oil immersion technique, while photomicrographs of notable species were taken with the associated microscope camera. Identification of the species was made by comparing the forms with a wide range of published palynological charts. The palynomorphs were grouped into terrestrial pollen and spores, freshwater fungi, marine dinoflagellates, acritarchs, and foraminiferal wall lings.

RESULT

PALYNOLOGICAL RESULT AFK_03

Palynological analysis of forty-two (42) shale samples from AFK_03 revealed a low to moderate yield of palynomorphs. A total of 637 palynomorphs were recovered from the analysis (Fig. 4), consisting mainly of pollen grains (316 species, 49.61%), followed by dinoflagellate cysts (166 species, 26.06%), spores (129 species, 20.25%), and a small number of *foraminifera* wall lining and fungi spores (17 species, 2.67% and 9 species, 1.41% respectively). The angiosperm dominates the pollen grains, while the proportion of the gymnosperm is fairly moderate (Table 1). While certain samples exhibited low yields, none of the samples were completely barren. *Monocolpites marginatus* recorded the highest yield, with a population count of 109 species. Cyathidites minor follows with a population count of 87 species. Sample 3.560 exhibited the highest recovery of palynomorph with a population of 59 species, while the lowest recovery, with a count of 5 species, was observed at 1440. The palynoflora is mostly made up of terrestrial sporomorphs like *Cyathidites* minor, *Retimonocolpites* sp., *Echitriporites trianguliformis*, *Longapertites* sp., *Spinizonocolpites baculatus*, *Longapertites* sp., Cingulatisporites ornatus, and Proteacidites sigalii (Fig. 5). The palynomorph assemblage is also characterized by the occurrence of *Cleistosphaeridium* sp., *Senegalinium* sp., *Subtilisphaer*a sp., *Cerodinium* sp., *Dinogymnium* sp., *Cerodinium diebelii*, *Senegalinium* sp., *Odontochitina* sp. and *Cleistosphaeridium* sp., amongst others. *Microforaminifera* wall linings and acritarchs, such as *Leoisphaeridia* sp., were also identified. Amidst the *dinoflagellates*, the peridinoid forms constitute the highest occurrence (Table), while the *gonyaulacinoids* occur as *Spiniferites* and *Florentina* species.

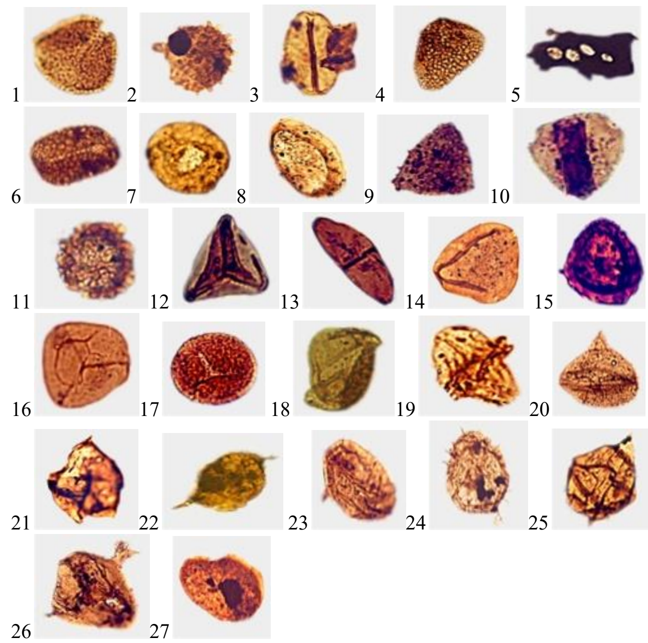

Fig. 4: Photomicrograph of some palynomorphs recovered from AFK_03. (1) *Foveotriletes margaritae* (2) *Spinizonocolpites baculatus* (3) *Monocolpites marginatus* (4) *Longapertites* sp. (5) *Charred gramineae cuticle* (6) *Retimonocolpites* sp. (7) *Milfordia jardinei* (8) *Milfordia* sp. (9) *Echitriporites trianguliformis* (10) *Proteacidites* sp. (11) *Distaverrusporites simplex* (12) *Cyathidites minor* (13) Fungal spore (14) *Cyathidites* sp. (15) *Cingulatisporites ornatus* (16) *Zlivisporis blanensis* (17) *Rugulatisporites caperatus* (18) *Leiosphaeridia* sp. (19) *Dinogymnium acuminatum* (20) *Senegalinium* sp. (21) *Cerodinium* sp. (22) *Palaeocystodinium australinium* (23) *Florentinia* sp. (24) *Cleistosphaeridium* sp. (25) *Cerodinium diebelii* (26) *Subtilisphaera* sp.(27) *Dinogymnium* sp.

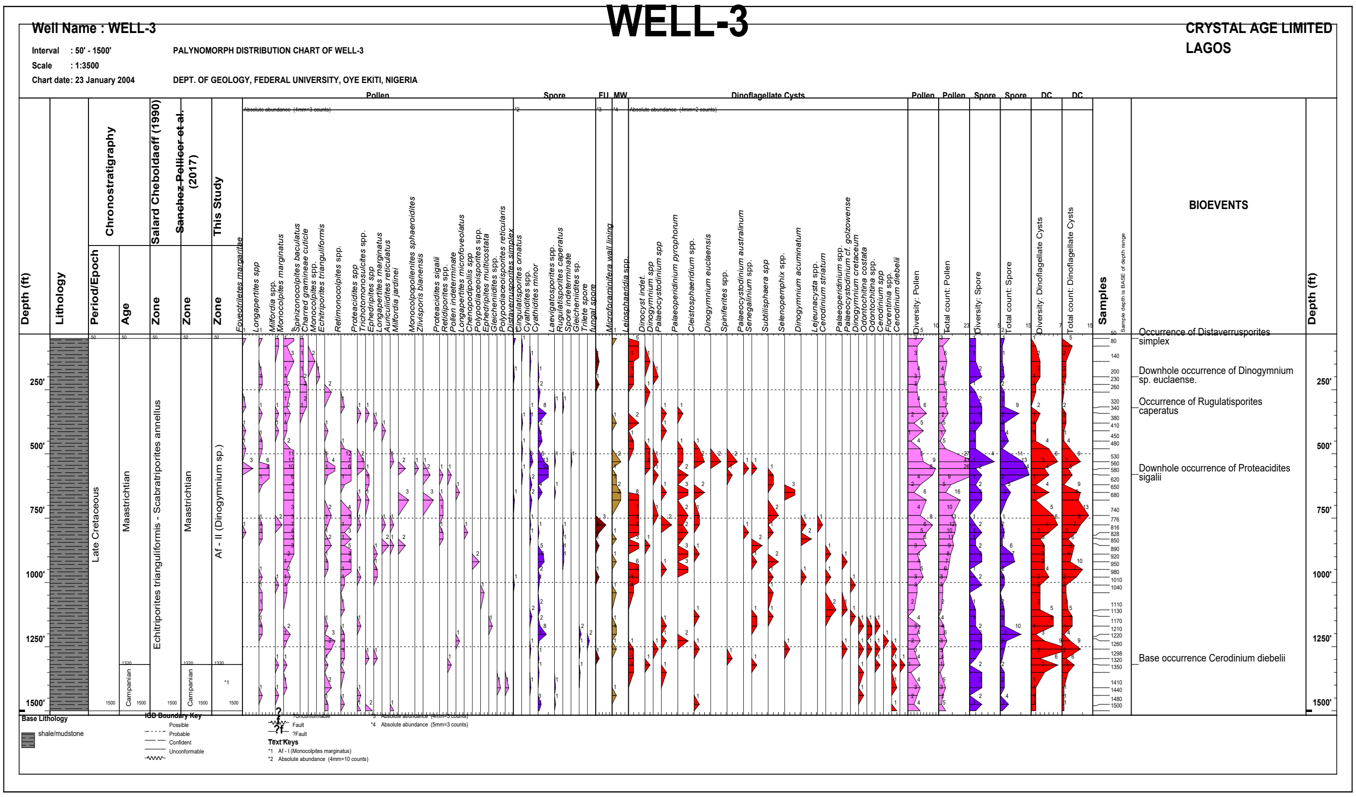

Fig. 5: Distribution chart of palynomorphs recovered from Afikpo Well_3 (AFK_03).

Table 1: Different species of the palynomorphs

Pollen		Spore	Dinoflagellate	
Angiosperm	**Gymnosperm**	**Pteridophyte**	**Peridinoids**	**Gonyaulacinoids**
Longapertites	Classopollis	Cyathidites	Dinogymnium	Spiniferites
Proteacidites	Ephedirites	Laevigatosporites	Lejeunecysta	Florentina
Retimonocolpites	Auracariacites	Rugulatisporites	Selenopemplix	
Monocolpollenites	Echitriporites	Cingulatisporites	Subtilisphaera	
Gleicheniidites	Trichotomonosulcites		Palaeocystodium	
Retimonocolpites			Senegalinium	
Milfordia			Cerodinium	
Monocolpites			Odontochitina	
Tricolporopollenites			Andalusiella	
Periretisyncolpites				
Retidiporites				
Spinizonocolpites				
Chenopodipollis				
Tubistephanocolpites				

DISCUSSION

LITHOLOGICAL DESCRIPTION OF AFK_03

The AFK_3 has a total thickness of 1500 ft, with carbonaceous shale at the base of the well (Fig. 4). The carbonaceous shale is dark grey, thinly laminated, and fissile. It has been overlain by cyclic sedimentation of calcareous and carbonaceous shales to a depth of 1040 ft. Overlying the carbonaceous shale at a depth of 1040 ft is calcareous shale. The shale is dark grey and fissile. The unit has evidence of white, broken shells, probably gastropod shells. The shale measures 420 ft in thickness and is observed at depths ranging from 1040 to 620 ft. Overlying the calcareous shale is dark grey calcareous mudstone. The unit is massive and about 60 ft thick. The bed is observed from depths ranging from 620–560 ft. Thereafter, the carbonaceous mudstone sits conformably over the calcareous mudstone and is recorded between 260 and 560 ft. Subsequently, calcareous mudstone overlies carbonaceous mudstone. The calcareous unit is slightly indurated and appears dark brown to grey. Meanwhile, carbonaceous mudstone that is light grey sits directly on the calcareous mudstone and is observed to cap the well section from 200 ft to the top of the well. The lithologic sequences within this well section fully position themselves into the sediments of the Nkporo Formation. This is in view of the sedimentologic attributes, which include being calcareous, dark grey, fissile, fossiliferous, and occasionally carbonaceous, that are recorded from the base of the well to the top.

PALYNOSTRATIGRAPHY

Universally, the use of dinoflagellate cysts in palynostratigraphic interpretation has received more acceptance than the use of sporomorphs (pollen and spores). Several authors have demonstrated the use of these cysts to delineate different palynozones as well as determine the age of sediments (Jain and Millepied, 1975; Boltenhagen, 1977; Schrank, 1987). However, Oboh-Ikuenobe et al. (1998) reported that the upper Cretaceous areas with low latitudes lacked detailed and globally accepted dinoflagellate cyst zones. Therefore, in-depth intervals where marker dinoflagellate cysts are absent, key marker sporomorphs (pollen and spores) are integrated. As a result, the well AFK_03 was divided into two (2) assemblage zones.

The age of the studied interval is based on the occurrence and stratigraphic distribution of age-diagnostic species such as *Monocolpites marginatus*, *Echitriporites trianguliformis*, *Proteacidites sigalii*, *Longapertites marginatus*, *Cerodinium diebelii*, *Ephedripites* sp. and *Dinogymnium euclaense*, with reference to the previous published works of Lawal and Moullade (1986) and Salard-Cheboldaeff (1990).

Monocolpites marginatus Zone

Assemblage zonal code: AF-1

Depth interval: 1500–1320 ft

Assigned age: Late Cretaceous (Campanian)

Definition: The base of this zone coincided with the last sample analyzed at 1500 ft, as did the top occurrence of Droseridites senonicus (Salard Cheboldaeff, 1990), which usually marks the top of the Campanian and was not encountered at 1500 ft. The top of the Campanian is defined by the base occurrence of *Cerodinium diebelii* at 1320 ft. Kirsch (1991) and Antonescu et al. (2001) recorded the first occurrence of *Cerodinium diebelii,* which marks the Campanian/Maastrichtian boundary. The zone is generally characterized by common records of palynoflora such as *Echitriporites trianguliformis*, *Cyathidites minor*, *Monocolpites marginatus*, *Gleicheniidites* sp., and *Cleistosphaeridium* sp., which is consistent with Salard Cheboldaeff (1990). However, *Paleocystodinium* spp., *Proteacidites* sp., *Cleistoshaeridia* spp., and Auriculiidites reticulatus occurred once within the zone. Moreso, the zone witnesses the rare occurrence of *Cyathidites* sp., *Longapertites* spp., *Retimonocolpites* spp., and Leiospaeridia spp. The assemblage zone correlates with the *Echitriporites trianguliformis* and *Scabratriporites annellus* palynological zones described by Salard Cheboldaeff (1990) and *Longapertites* sp. 3 described by Lawal and Moullade (1986). As a result, the interval is dated as Campanian.

Dinogymnium sp. Zone

Assemblage zonal code: AF-2

Depth interval: 1320–50 ft

Assigned age: Late Cretaceous (Maastrichtian)

Definition: The base occurrence of *Cerodinium diebelii* at 1320 ft marks the base of this interval. The first sample analyzed at 50 ft coincided with the top occurrence of *Proteacidites sigalii*, which normally defines the top of this interval. This suggests that the actual top of this interval was not penetrated by the well at 50 ft. This interval is characterized by Maastrichtian events such as common downhole occurrences of *Dinogymnium* sp., *Dinogymnium euclaense*, *Proteacidites sigalii*, *Ephedripites* sp., *Zlivisporites blanensis*, *Echitriporites trianguliformis*, and the occurrence of *Tubistephanocolpites cylindricus*, which is consistent with Salard Cheboldaeff (1990). Therefore, the interval is dated as Maastrichtian age. The interval falls within the *Longapertites* sp. 3-*Spinizonocolpites baculatus* palynological zone of Lawal and Moullade (1986). Also, the sediments did not contain any Danian or Paleocene species like *Damasadinium californicum*, *Carpatella* *corntaus*, *Proxapertites operculatus*, or *Proxapertites cursus*. Instead, they did contain Dinogymnium species in the upper part of the section, which suggests that the sediments were not older than Maastrichtian. Stover et al. (1999) reported that the Dinogymnium lineage became extinct during the Maastrichtian age. Invariably, the last occurrence of Dinogymnium species at a depth of 140 ft reveals that the zone did not exceed Maastrichtian. Furthermore, Nohr Hansen (2012) reported that the occurrence of *Cerodinium diebelii* within the sediments suggests an age not older than the early Maastrichtian. Again, the occurrence of *Palaeocystodinium cf. golzowense* and *Odontochitina costata,* which are Maastrichtian marker species (Habib et al., 1989), confirms the age of the interval as Maastrichtian.

PALEOENVIRONMENT OF AFK_03

The interpretation of the paleoenvironment of deposition for this well is based on the presence of environmentally significant palynomorphs, and the integration of a new hybrid technique whereby the total miospore value derived from land is combined with the two main types of dinoflagellate, that is, gonyaulacinoids and peridinoids. The gonyaulacinoids are characterized by short spines, indicative of marine environments, while the peridinoids have longer spines and inhabit marginal marine environments. Also, the relative abundance of terrestrial sporomorphs and marine species of dinoflagellate cysts, architarch, and microforaminifera wall lining is used in the paleoenvironment reconstruction.

Based on these, the co-occurrence of moderately recorded land-derived sporomorphs (Fig. 5) with few occurrences of marine dinoflagellate cysts such as *Dinogymnium* sp. *Paleoperidinium pyrophorum*, *Cleistosphaeridium* sp., *Odontochitina* sp., *Leoisphaeridia* sp. (Acritarch), *Subtilisphaera* sp., *Dinogymnium euclaense, Paleocystodinium australinium*, *Cerodinium* sp. and *Dinogymnium* spp., amongst others, suggest a predominantly brackish swamp environment with inner to middle marine incursions. Generally, there are more terrestrial palynomorphs (pollen, spore, and fungal spore) than marine ones (dinoflagellate and microforaminiferal wall lining). The terrestrial pollens are dominated by the palmae pollen, suggesting a brackish water environment. Some of these palmae pollens include *Spinozonocopites baculatus, Echitriporites trianguliformis, Longapertites marginatus, Monocolpites marginatus*, and *Longapertites* spp. However, the high recovery of Cyathide minor across the section connotes a freshwater swamp. Terrestrially, the co-occurrence of palmae pollen and freshwater swamp within the section suggests a brackish water swamp environment. Again, the rare occurrence of gonyaulacinoids forms within the section, and the dominance of the peridinoids reveals a marginal marine environment. This is complemented by the frequent occurrence of Subtilisphaera spp. and Senegalinium spp., which indicate a shallow marine environment. Equally, the fair representation of the microforaminifera wall lining signifies a shallow marine environment.

Additionally, the high proportion of terrestrial sporomophs within depths 50 ft, 140 - 260 ft, 340 - 620 ft, 680 ft, 776 - 920 ft, 980 - 1010 ft, 1110 ft, 1210 - 1220 ft, 1298 ft, 1410 - 1500 ft, relative to the marine assemblages suggest marginal marine (proximal estuaries), whereas the high proportion of marine forms within depths 80 ft, 650 ft, 740 ft, 950 ft, 1130 ft, 1260 ft, 1320 ft, relative to the terrestrial forms suggest marginal marine (distal estuaries). However, the complete absence of marine species at depths of 320 ft suggests a nearshore brackish water environment. Invariably, a brackish swamp environment to a shallow marine environment can be proposed for the section. The nearshore setting is equally affirmed by the overwhelming occurrence of *Leiosphaeridia* spp. as well as the representation of *Palaeocystodinium* spp. that thrive in the environment, as reported by Berggen et al. (2012).

CONCLUSION

The detailed palynostratigraphy and paleoenvironment investigation conducted on the sediments of Afikpo well_3 within the Afikpo Syncline revealed two palynozones within the well. These include zone AF-01 (*Monocolpites marginatus* assemblage zone), which ranges from depths of 1500–1320 ft and is Campanian in age; and zone AF-2 (*Dinogymnium sp.* assemblage zone), which extends from depths of 50 ft–1320 ft and is Maastrichtian in age. Also, the predominance of palmae pollen, together with the subordinate occurrence of dinoflagellate cysts and the moderate occurrence of spores (*Cyathidite minor*), suggest nearshore brackish water to shallow marine (inner neritic) environment.

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