

Late Cretaceous - Paleocene deposits in Afikpo sub-Basin, Southeastern Nigeria: Evidence from Palynomorphs

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Abstract

Thirty sediment samples of surface outcrops from Afikpo and Uturu areas in the Afikpo sub-Basin of Anambra Basin has been studied for palynological composition. This investigation was necessitated by the need to reevaluate the stratigraphy of Afikpo sub-Basin using palynomorphs as new outcrops were exposed in road cuts and pits. The samples studied yielded 40 species of palynomorphs at the Afikpo area and 30 species from Uturu axis. The palynological specimens recovered across the studied areas were moderate to low in yield. A total of 1060 specimens were counted from Afikpo samples and 380 from Uturu area. *Longapertities marginatus* assemblage zone and *Apectodinium homomorphum* zone are the two palynological zones that were defined in the studied areas. The new zone (*Apectodinium homomorphum*) defined in the studied area has led to the delineation of Nsukka Formation in Afikpo sub-Basin. The botanical affinity of the recovered palynomorphs shows that the recovered palynomorphs is dominated by palm pollen, and pteridophytic spores (especially taxa related to aquatic fern), and dinocysts. The ecological zones interpreted from the palynological taxa present are tropical rainforest, mangrove/coastal environment, freshwater wetlands and marine ecosystem. The recovered palynomorphs are correlatable to other Cretaceous basins in Nigeria, West Africa, South America, India and other low latitude areas.

Keywords: Palynomorphs; Cretaceous; Paleocene; Anambra Basin; Botanical affinity; paleoecology

1. Introduction

Palynomorphs are known to be crucial tools in the understanding of geological history of a basin. Due to its high preservation potential in sedimentary records and their evolutionary trends, there are invaluable in age determination, paleoenvironmental reconstruction, paleovegetation and paleoclimatic investigations. The Afikpo sub-basin [1] is located within the southern part of Anambra Basin, Southeastern Nigeria. It was previously described as Afikpo Syncline by [2]. The Anambra Basin which Afikpo Sub-basin is part of, was formed as a result of complex tectonic activities associated with Santonian uplift and deformation [3]. The Santonian tectonic activities in the southern Benue Trough created the Abakaliki Anticlinorium, resulting to shifting of the pre-Santonian depocenter in southern Benue Trough to the west and resulting to an extensional basin named the Anambra Basin which the study area constitute the southern portion [3]. The tectonic history of the basin is linked to rifting, subsidence and other Late Cretaceous events that shaped the basin and its sediment depositional pattern.

Sedimentation in the study area started during the Late Cretaceous marine transgression (sea level rise) leading to the deposition of Nkporo Formation as the basal unit which unconformably overlies the pre-Santonian strata [Table 1, 4]. The Nkporo Group comprises of Afikpo Sandstone, Asaga Amagwu shale, Owutu sandstone and Amiyi shale in the study

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area. The group outcrops are common in Afikpo, Owutu, Asaga Amangwu, Ogbu, Ekeje-Amayi road, Enohia, Wowo River, Amigbo and on the dip slope of Awgu-Okigwe Cuesta near Nguzu.

The Nkporo shale is well bedded, laminated but poorly fissile and muddy. The mineralogy is predominantly micaceous clay, though dark organic patches are usually present. Pyrite and gypsum occur as diagenetic minerals.

Table 1 Lithostratigraphic Subdivision Southern Benue Trough [5]

Age		Basin	Lithostrat. Units	Sedimentary Cycles
Tertiary	Eocene	Niger Delta Basin	Ameki Fm./ Nanka Sands	Cycle II
	Paleocene		Imo Fm.	
Upper Cretaceous	Late Maastrichtian	Anambra Basin/Afikpo Sub-basin	Nsukka Fm.	
	Mid-Maastrichtian		Ajali Formation	
	Early Maastrichtian		Mamu Fm.	
	Late Campanian		Nkporo Fm.	
	Santonian	Santonian Unconformity		
	Coniacian	Benue Trough	Awgu Fm.	Cycle I
	Turonian		Eze-Aku Group	
Cenomanian	Odukpani Group			
Lower Cretaceous	Albian		Asu River Group	
Precambrian Basement Complex				

The Mamu Formation overlies the Nkporo Formation; it is characterised by off lap complexes [4] in a paralic sequence that consists of shale, siltstone, mudstone and inter-bedding of siltstone, carbonaceous shales and coal in some locations as observed in Ugwuifere and Eburnwana areas (Figure 1).

Ajali Formation overlies the Mamu Formation; the deposition coincided with marine regression in the Late Cretaceous. Ajali Formation is characterized by cross-beds, Herringbone structures and bioturbations especially of *Ophiomorpha* ichnofacies. It is exposed at the top of Nguzu hill, Ezi Edda sand mine and Ekoli Eddah in the study area.

The youngest Formation in the Afikpo sub-basin is the Nsukka Formation. The Formation begins with coarse to medium grained sandstone and passes upward into the well-bedded blue clays, thin coal seams, fine-grained sandstone and carbonaceous shale [4].

The study areas have been extensively studied in terms of stratigraphic investigations since the works of early researchers such as [6, 2, 7, 8, 9]. The increase in earth scientists and research institutions around the area as well as the need to better understand the basin with new data and capabilities, Afikpo region of the Anambra Basin have received increased investigation. Recent studies cut across biostratigraphy, regional correlation, reservoir characterization and hydrocarbon potentials [10].

[10] studied the Palynostratigraphy and Paleoenvironment of Afikpo Well_3 and delineated two P-zones namely AF-01 *Monocolpites marginatus* assemblage zone and AF-2 *Dinogymnium sp.* assemblage zone. [11] used palynology as one of the proxies for depositional sequences and paleoenvironmental interpretation of the basin. [12] delineated stratigraphic surfaces in northern Afikpo using outcrop and palynological data. While [13] reported on the palynostratigraphy, sequence stratigraphy, and paleoecology of Campano-Maastrichtian sediments from the Afikpo-4 well cuttings and identified four palynological zonation.

These studies and others too numerous to mention above were either localized or of low spatial resolution. For instance, [11] collected only one sample from the two local governments in Afikpo. Similarly, [12] concentrated in Edda area. This sampling method will be difficult to produce a high-resolution stratigraphic interpretation.

The current study sampled recent outcrops exposed within the study area and increased the sampling resolution up to three 3 samples per one outcrop. With this resolution of sampling, this study have provided more detailed stratigraphic analysis resulting to the identification of the new geologic period previously thought to be absent in the sub-Basin.

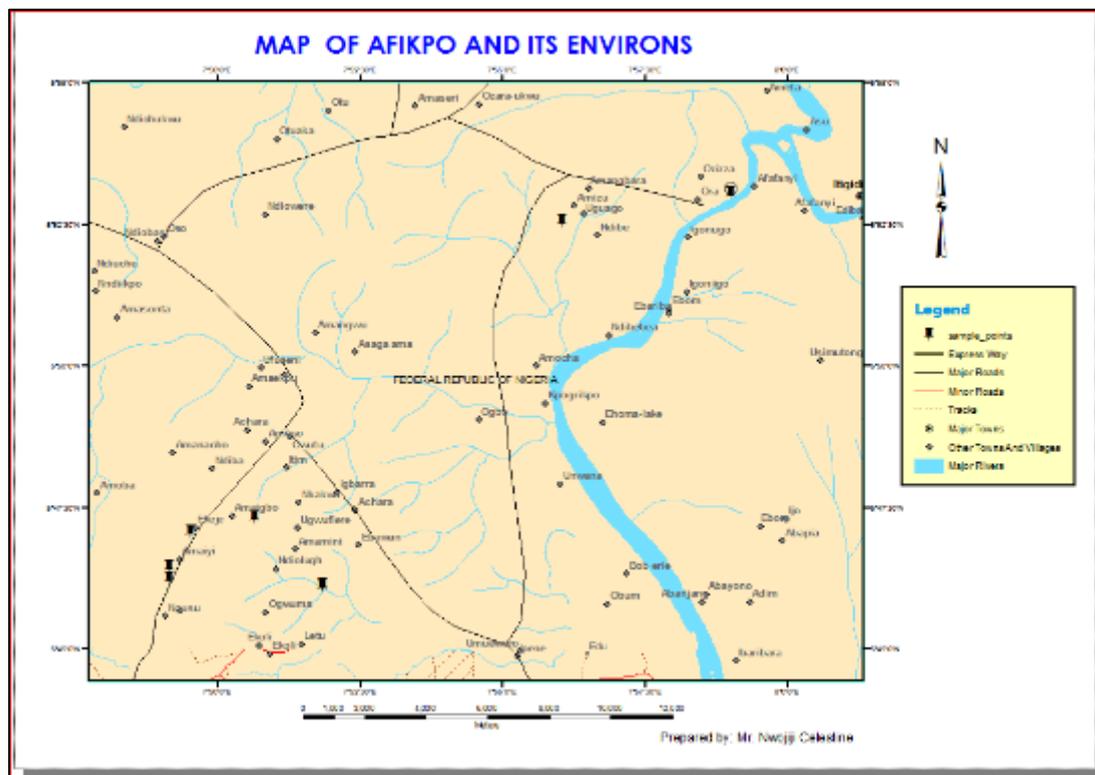


Figure 1 Map of Afikpo sub-Basin showing the study area

2. Materials and methods

The study area is located in the present Afikpo North and Edda Local Government Areas of Ebonyi State, within latitudes $N5^{\circ}45'0''$ – $N5^{\circ}55'0''$ and longitudes $E007^{\circ}48'30''$ – $E008^{\circ}50'30''$ (Figure 1) and Uturu in Abia State. The study sites are mostly outcrops exposed on escarpments, road cuts, mining pits and exposures in Afikpo and Uturu Areas (Figure 1). The outcrops were excavated to expose fresh samples and only shale samples were collected at horizons of interest. The thickness of each outcrops determines the number of sample(s) that was collected. In some locations, only one sample was collected while in thicker outcrops, up to three samples were collected. A total of thirty (30) samples were collected across the study area and analysed for palynological studies. The samples preparation followed standard palynological preparation procedures. The procedure involves preliminary sample administration, cleaning and disaggregation using pistol and mortar. Soaking in 35% HCl for carbonate digestion, soaking in 45% HF for silicate digestion, dissolving the resultant gel with potassium chlorate ($KClO_2$), the oxidation of the organic residue with 70% Nitric acid (HNO_3) and neutralization of the acid with 10% KOH. The wet sieving of the residue was done using $10\mu m$ sieve after which it was treated with 0.5HCl to remove carbonaceous material from the residue and 2.2 specific gravity zinc chloride ($ZnCl_2$) was added to separate the organic from the inorganic substances. Palynological slides were made by spotting the specimen on cover slips and holding it unto a slide using the Norland gel. The prepared slides were analysed for microfloral composition

3. Results

The analysis of shale samples yielded 40 species of palynomorphs from the Afikpo area and 30 species from Uturu axis. The specimen recovery was moderate to low in palynomorph yield. A total of 1060 specimens were counted at Afikpo

samples and 380 at Uturu. In both locations, the pollen grains dominated the palynomorph assemblages followed by spores and dinoflagellate cyst (Figures 2 and 3; Tables 2 and 3). The recovered palynological species (Figure 2) are typical of low latitude flora with strong similarity to African – South American palynoflora province [14, 15, 16, 17]. Some of the key events in Afikpo area include restricted occurrence of *Aglaoreidia foveolata*, *Momipites africanus*, *Racemonocolpites racematus* and *Tricolpopollenites Sp.* within sample 1-11 and *Distaverrusporites simplex*, *Echitriporites trianguliformis*, *Longapertites marginatus* and *Apectodinium homomorphum* within sample 12 – 20. *Apectodinium homomorphum* which is a key fossil for dating Paleocene strata made its first appearance in sample 20 (Figure 2 and Figure 5).

At Uturu area, key events include the occurrence of *Ephedripites Sp.*, *Smilacipites echinatus*, *Liliacidites sp.*, *Crototricolpites crotonoisculptus*, *Periretisyncolpites magnosagenatus*, *Proceadites dehaani*, *Triporopollenites sp.*, *Ctenolophonidites costatus*, *Leiosphaeridia sp.*, *Polypodiaproteacidites dehaani*, *Azolla sp.*, *Palaeperidium pyrophorum*, *Echitriletes sp.*, *Foveotriletes margaritae*, *Echitriporites trianguliformis*, *Smilacipites echinatus*, *Gnetaceapollenites sp.*, *Monocolpites marginatus*, *Leiotriletes adriensis* and *Leiotriletes sp.* (Figure 3 and Figure 6)

Table 2 Palynological Species diversity, abundance and percentage distribution across the studied section in Afikpo area

Sample	Species diversity			Total	Percentage (%)			Species abundance			Total	Percentage (%)		
	Terrestrial		Marine		Terrestrial		Marine	Terrestrial		Marine		Terrestrial		Marine
	Pollen	Spore	Dino		Pollen	Spore	Dino	Pollen	Spore	Dino		Pollen	Spore	Dinocyst
20	8	3	7	18	44	17	39	79	26	33	138	57	19	24
19	7	2	3	12	58	17	25	81	315	9	405	20	77	3
18	1	1	0	2	50	50	0	2	2	0	4	50	50	0
17	2	1	0	3	67	33	0	2	2	0	4	50	50	0
16	1	1	0	2	50	50	0	1	1	0	2	50	50	0
15	4	3	0	7	57	43	0	5	8	1	14	35.7	57	7
14	4	2	0	6	67	33	0	5	9	0	14	35.7	64	0
13	2	4	0	6	33	67	0	4	24	0	28	14.3	85.7	
12	7	7	1	15	47	47	7	31	160	5	196	15.8	81.6	2.6
11	6	6	2	14	43	43	14	36	80	3	119	30.3	67.2	2.5
10	-	-	-	0	0	0	0	0	0	0	0	0	0	0
9	2	1	0	3	67	33	0	3	1	0	4	75	25	0
8	3	3	1	7	43	43	14	3	3	1	7	42.9	42.9	14.3
7	-	-	-	0	0	0	0	0	0	0	0	0	0	0
6	2	1	1	4	50	25	25	2	8	1	11	18	73	9
5	5	4	1	10	50	40	10	8	21	1	30	27	70	3
4	6	2	2	10	60	20	20	11	3	2	17	67	18	12
3	6	2	1	9	67	22	11	14	19	3	37	39	53	8
2	5	4	1	10	50	40	10	14	18	1	33	42.5	54.5	3
1	7	3	2	12	58	25	17	10	52	3	66	15	80	5
Total								311	752	63	1126			

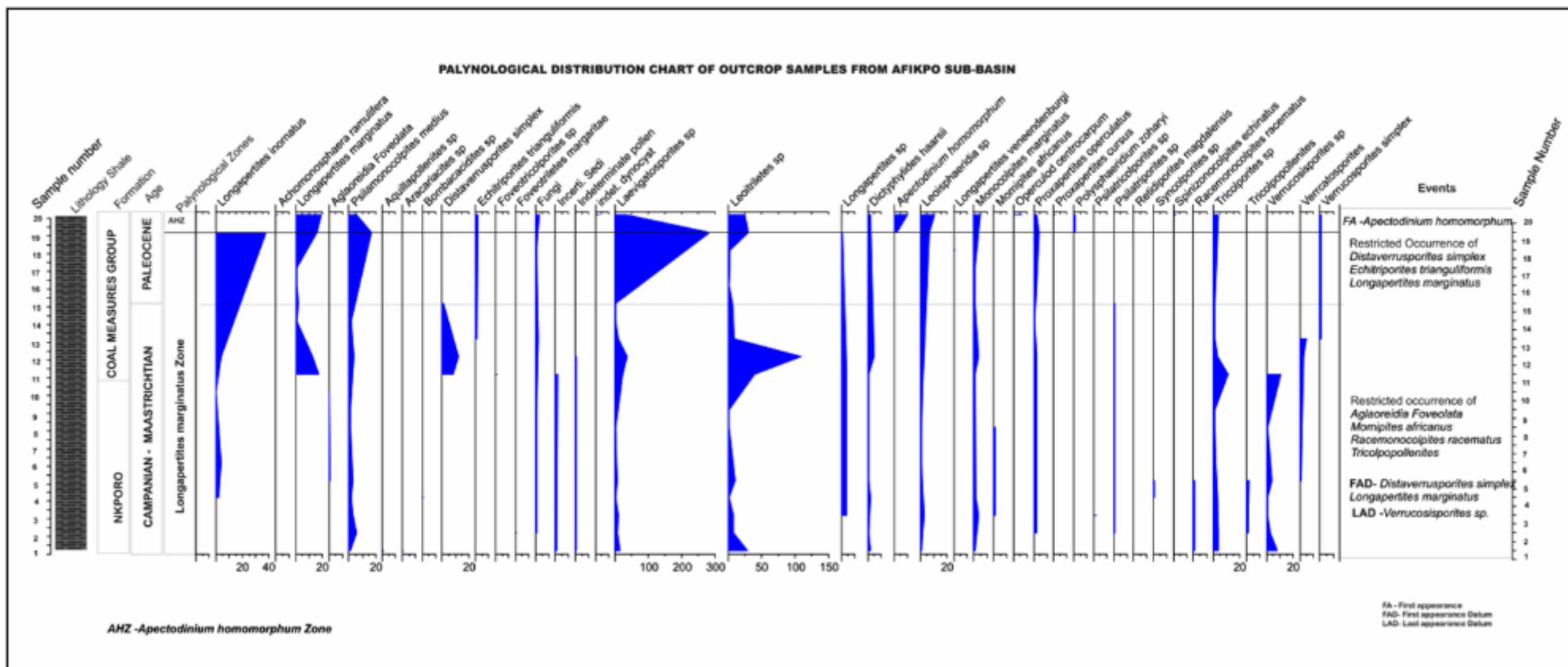


Figure 2 A distribution chart showing the palynomorphs recovered from the studied sections in the Afikpo area. The twenty samples cut across Nkporo and Coal Measure Groups, dating Campanian – Paleocene. The palynomorphs were grouped into two zones with key palynological events

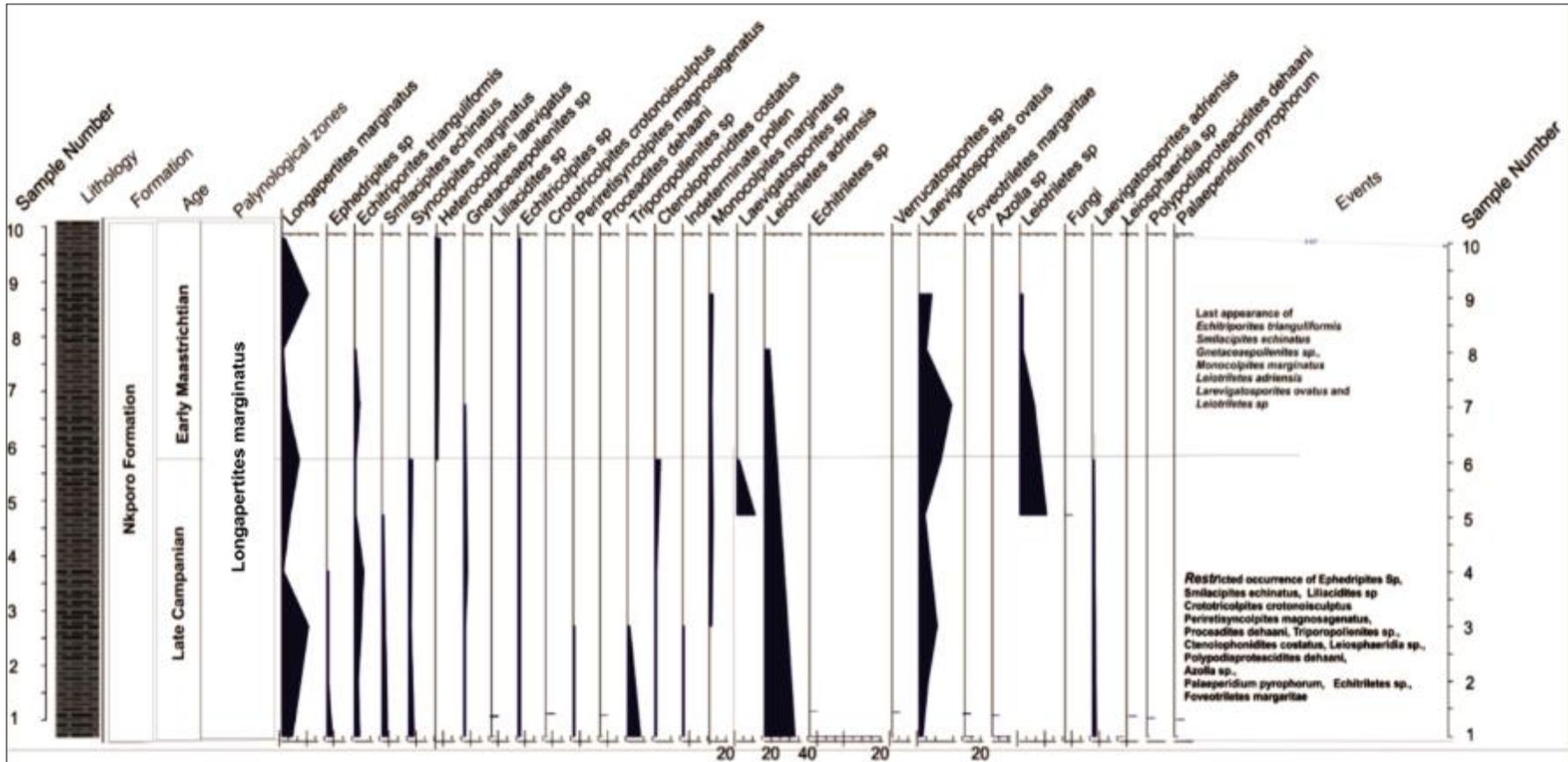


Figure 3 A distribution chart showing the palynomorphs recovered from outcrop sections in Uturu area. The ten samples came from Nkporo Formation. Late Campanian – Early Maastrichtian in age. One palynological zone was interpreted for the recovered palynomorphs

Table 3 Palynomorphs species, diversity and percentage distribution across the studied section in Uturu area

Sample	Species diversity			Total	Percentage (%)			Species abundance			Total	Percentage (%)		
	Terrestrial		Marine		Terrestrial		Marine	Terrestrial		Marine		Terrestrial		Marine
	Pollen	Spore	Dino		Pollen	Spore	Dinocyst	Pollen	Spore	Dinocyst		Pollen	Spore	Dinocyst
10	3	0	0	3	100		0	5		0	5	100		0
9	2	2		4	50	50	0	17	9	0	26	65	35	0
8	2	3	0	5	40	60	0	2	9	0	11	18	82	0
7	4	2	0	6	67	33	0	8	26	0	34	23	76	0
6	5	3	0	8	62.5	37.5	0	17	13	0	30	57	43	0
5	5	4	0	9	55.5	44.5	0	10	32	0	42	24	76	0
4	5	0	0	5	100		0	10	0	0	10	100		0
3	8	1	0	9	89	11	0	25	10	0	35	71	29	0
2	2	1	0	3	67	33	0	3	5	0	8	37.5	6.5	0
1	15	10	3	28	54	36	10	92	82	5	179	54.5	45	0.5
Total								189	186	5	380			

4. Discussion

4.1. Palynological Zones

Two palynological zones were identified from the studied areas based on palynomorphs assemblage and presence of some age diagnostic taxa. They are *Longapertites marginatus* assemblage zone and *Apectodinium homomorphum* zone (Figure 2).

4.1.1. *Longapertites marginatus* Assemblage Zone

This zone is characterized by the occurrence of *Longapertites marginatus*, *Aquillapollenites sp.*, *Aracariacites sp.*, *Dictyophylides haarsii*, *Distaverrusporites simplex*, *Longapertites inornatus*, *Longapertites sp.*, *Syncolporites sp.*, *Echitriporites trianguliformis*, and *Monocolpites marginatus* (Figure 2). Similar palynological assemblage have been used by other authors to describe this zone. [15] was the first to designate this zone in the Upper Benue Trough, N.E. Nigeria and dated it Early Maastrichtian – Early Campanian. Other authors that describe this zone in Nigeria include [17, 18, 19]. The *Longapertites marginatus* assemblage Zone is part to West African pollen zones (WAPZ) established by early researchers like [14] and [20]. The zone could be correlated to *Echitriporites trianguliformis* zone in (South America; [21]) and *Aquillapollenites bengalensis* [Asia, 22].

Apectodinium homomorphum zone: This zone is characterized by significant increase in the abundance and diversity of marine dinoflagellate taxa (Figure 2). It is marked by the appearance of *Apectodinium homomorphum*, *Operculod centrocarpum* and *Polysphaeridium zoharyi*, peak and last appearance of *Longapertites inornatus*, acme of *Laevigatosporites sp.*, and *Psilamoncolpites medius*. This zone is particularly important because it confirms the presence of Paleocene section in the Afikpo area of Anambra basin. *Apectodinium homomorphum* have been used to characterize a global hyper thermal event - the Paleocene-Eocene Thermal Maximum [PETM, 23]. The zone is a globally recognized zone in the northern hemisphere [24, 25], and Southern hemisphere [26]

4.2. Age Determination

The age of the sections studied in Afikpo area range from Campanian – Paleocene (Figure 2). The presence of *Aquillapollenites sp.* and *Tricolpopollenites Sp.* suggest that shale units deposited within Afikpo town represented by sample 1- 4 in Oziza coal seam, Enohia beach and shale outcrop opposite Egescos hotel belong to Campanian period. These species along with other taxa present such *Distaverrusporites simplex* and *Echitriporites trianguliformis* in the assemblage have reported in other Cretaceous basins in Nigeria [10, 27, 28 and 17], and Tano Basin in Ghana [20]

The Maastrichtian deposits are dated based on the presence of *Aracariacites sp.*, *Echitriporites trianguliformis*, *Foveotriletes margaritae*, *Longapertites marginatus*, *Monocolpites marginatus*, *Operculod centrocarpum*, *Proxapertites operculatus*, *Retidiporites magdalensis*, *Spinizonocolpites echinatus*, *Racemonocolpites racematus* and other taxa. The sections dated Maastrichtian occur from samples 5- to 16 covering Ekeje, Amaiyi, Eburnwana and the base of Nguzu escarpment. These palynomorphs correlate well with Maastrichtian assemblage from other basins in Nigeria [14, 15, 16, 17, 27] and other low latitude basins across the world [29, 30, 31, 32].

The upper part of the section from samples 17- 20 at the upper part Nguzu escarpment is dated Paleocene in age due the presence of late Paleocene marker- *Apectodinium homomorphum*, other associated species include *Longapertites spp.*, *Spinizonocolpites echinatus*, *Proxapertites operculatus*, *Polysphaeridium zoharyi*, *Leoisphaeridia sp.*, *Momipites africanus*, *Psilamonocolpites medius*. *Apectodinium homomorphum* originated in the Paleocene and its abundance peaked during the Paleocene – Eocene thermal maximum [23]. *Spinizonocolpites echinatus* and *Proxapertites operculatus* were reported by [33, 34] as key Paleocene mangrove system markers in northern South American while *Verrucasporites simplex* was reported in the Paleocene section of the Niger Delta by [35].

Late Campanian to Maastrichtian age was interpreted for the analysed sections in Uturu area. The restricted occurrence of *Ephedripites Sp.*, *Similacipites echinatus*, *Crototricolpites crotonosculptus*, *Periretisyncolpites magnosagenatus*, *Triporopollenites sp.*, *Palaeperidium pyrophorum* and *Echitriletes sp.* (Figure 2) suggest the Campanian age for sample 1 – 6. *Similacipites echinatus*, *Periretisyncolpites magnosagenatus* and *Palaeperidium pyrophorum* are key Campanian markers. They have been reported by [36] in Gabon, [37] in Europe and North America, [38, 39] in Global dinoflagellate zonations respectively. Other species in the assemblage have been reported to range from the Campanian to Maastrichtian [40]

The Maastrichtian deposit in Uturu area is dated using the last appearance datum of *Similacipites echinatus*, *Ctenolophonidites costatus* and *Leiotriletes adriensis*. Other Maastrichtian assemblages in the sections include *Longapertites marginatus*, *Monocolpites marginatus*, *Leiotriletes sp.*, and *Heterocolpites laevigatus*. These species and other associated taxa have been reported in the deposits of Maastrichtian age in Nigeria, West Africa and South America [41, 15; 40, 42, 43, 37].

4.3. Paleocological Interpretation

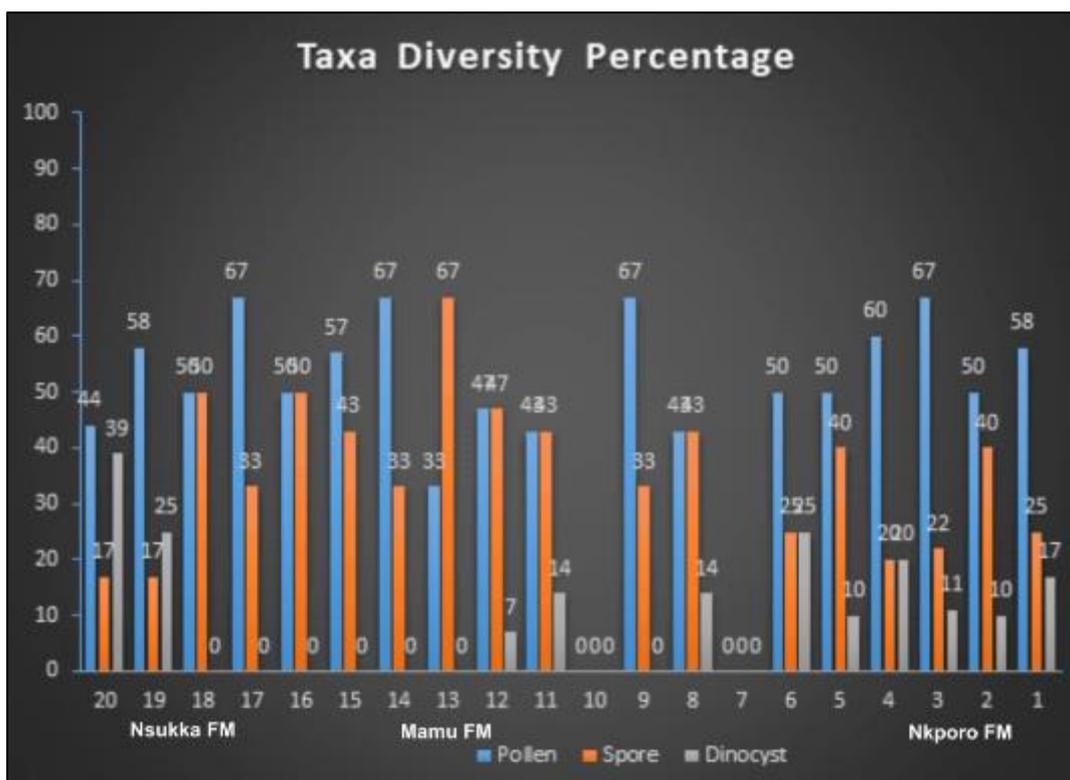


Figure 4 Distribution of different groups of palynomorphs percentage diversity from each sample in a bar chart

Paleoecologic and paleoenvironmental interpretation of the studied sections were guided by changes in the compositions of palynomorphs assemblages. The changes in palynofloral composition, abundance and diversity of the terrestrial plants (pollens and spores) and Marine flora (dinoflagellate cysts) are driven by factors such as depositional environment; base level changes (sea level fluctuations) and change in climatic conditions. Abundance of miospores (spore and pollen) species depicts terrestrial or fluvial influence while the presence of dinocysts and acritarchs depicts marine environment. In the Afikpo area, there is a co-occurrence of both terrestrial and marine taxa in sample 1, 2, 3, 4, 5, 6, 8, 11, 12, 19 and 20 (Figure 4).

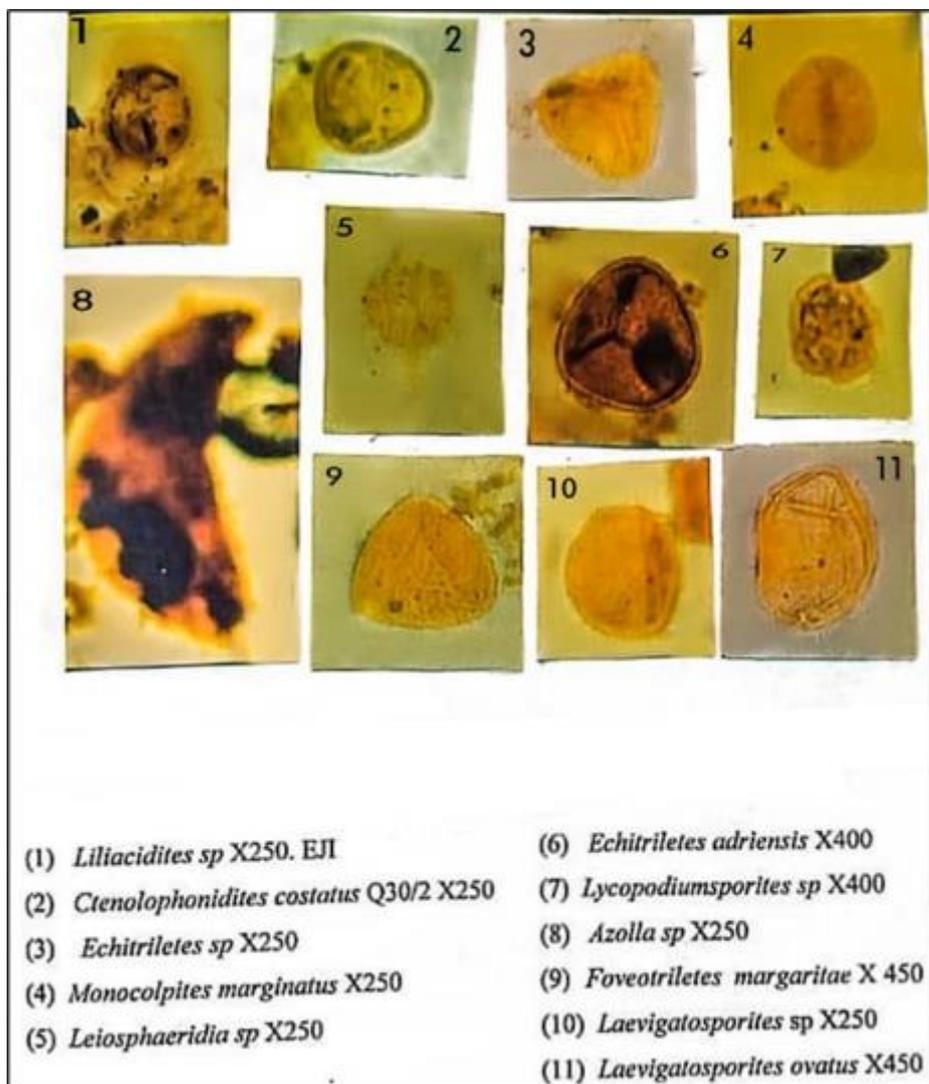


Figure 5 Photomicrographs of some selected palynomorphs with the magnification

In scenarios such as in these sections, where both marine and terrestrial species coexist, the depositional environment is interpreted to be shallow marine or deltaic with marine incursions. All the sections contain pollen and spores except samples 7 and 10 that is totally barren of palynomorphs. The prevalence of dinoflagellate cyst at the basal part of the sections (sample 1-6) indicates strong marine influence during the Late Campanian – Early Maastrichtian that deposited the Nkporo and part of Mamu Formation. The palynomorphs bareness in samples 7 and 10 (Figure 4) could be attributed to oxidation or high fluvial input in the sections. Terrestrial deposition persisted from sample 13 – 18 as indicated by total absence of marine dinoflagellate taxa. The reappearance of marine taxa in sample 19 and 20 marks the onset of marine condition in the upper part of the section. The palynological assemblages indicate that the lower sections (Nkporo Formation) were deposited in shallow marine setting specifically at the shore face. This correlates with previous studies such as [44, 12, 11]. The Mamu Formation was deposited in a fluvio-deltaic setting with coal swamps due to a high percentage of spores and low to absence of dinocysts in the palynomorphs assemblage. This interpretation is supported by earlier studies such as [16, 15, 32]. The resurgence of marine dinoflagellates at the upper part of the section in samples 19 and 20 indicate the return to marine setting during the deposition of Nsukka Formation. The most

significant outcome of this study is the evidence of the Paleocene – Eocene thermal Maximum in the last section (peak of Nguzu hill) indicated by presence of *Apectodinium homomorphum* [23] and expansion of mangrove due high abundance of palynofloral [34]. With this, there is a need for more research to unravel the existence of this important climatic event in Anambra Basin. The transgressive and regressive cycles experienced across the studied sections could also be linked to climatic changes during the late Cretaceous - Paleocene.

The botanical affinity of the recovered palynomorphs shows that the study is dominated by Palm pollen such as *Longapertites inornatus*, *Longapertites marginatus*, *Longapertites sp.*, *Longapertites veneendenburgi*, *Arcariacites sp.*, *Aquillapollenites sp.* *Monocolpites marginatus*, *Momipites africanus* [41, 44, 45] and pteridophytic spores especially taxa related to aquatic fern such as *Laevigatosporites ovatus* and *Laevigatosporites adriensis* [46]. Four ecological zone were interpreted from the palynological taxa present - 1. Tropical Rainforest identified due to the presence of *Bombacacidites* and *Ctenolophonidites* taxa; 2. Mangrove/Coastal environment based on the occurrence of *Spinizonocolpites* and *Longapertites*; 3. Freshwater Wetlands interpreted with the presence of *Azolla* *Laevigatosporites* taxa and 4. Marine ecosystem based on the presence of *Apectodinium*, *Polysphaeridium* and other Dinoflagellates cysts taxa, [47, 41, 48, 25].

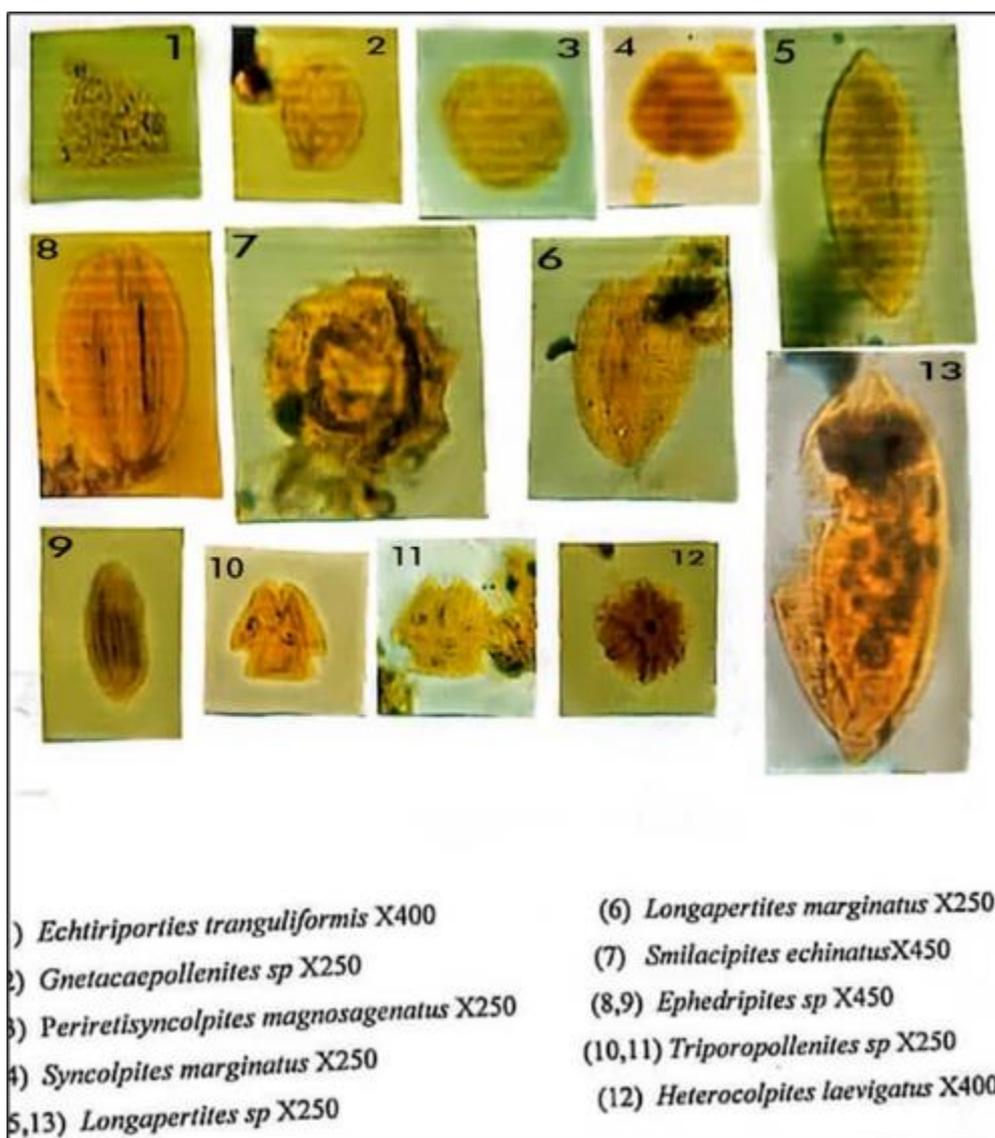


Figure 6 Photomicrographs of some selected palynomorphs with the magnification

5. Conclusions

The palynological assemblage from the outcrop sections in the Afikpo, Edda and Uturu areas of Anambra Basin were delineated into two Palynological zones namely *Longapertities marginatus* assemblage Zone and *Apectodinium homomorphum* Zone. This confirms that the sediments deposited in the Afikpo sub-basin of the Anambra Basin is of Late- Campanian – Paleocene period. The Nkporo and the basal part of Mamu formations was deposited in shallow marine/ deltaic setting with marine incursions. The upper part of Mamu Formation and Ajali Formation were deposited in a terrestrial setting with more fluvial influence, this was interpreted due to the paucity of marine dinoflagellate in these sections. The Nsukka Formation was deposited in the Marine setting with the preponderance of dinoflagellate cysts in the upper part of the studied section. The highlight of this work is the identification of Paleocene deposit (Nsukka Formation) for the first time in Afikpo sub-Basin at the peak of Nguzu hill interpreted due to the presence of *Apectodinium homomorphum*. The botanical affinity of the recovered palynomorphs suggest that they were derived from tropical rainforest, mangrove/coastal, freshwater wetlands and shallow marine settings.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors, Dr. Celestine Nwite Nwojiji, Dr. Auwalu Yola Lawal and Dr. Aitalokhai Joel Edegbai hereby declare that there is no conflict of interest with publication of this manuscript.

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