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Palynological Studies of Upper Createaceous-Paleocene Rocks in Auchi Sheet 266, Benin Flank, Western Extension of the Anambra Basin, Southwestern Nigeria

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Abstract Out crop samples from Mamu and Nsuka Formation at different locations and ditch cutting samples gotten from a water borehole at Ugbekpe-Ekperi road at different intervals collected from Benin Flank, Western extension of the Anambra Basin, were used for sedimentologic and palynology studies with the aim of establishing palynological assemblage zones, age and paleoenvironments of the sediments. Out crops and Ditch cutting samples were lithologically described using a transmitted light microscope in order to obtain their lithofacies and latter subjected to palynological slides preparation to identify the presence of palynomorphs. Lithofacies units identified were clay, sandy clay, silt, sandstone, shale and sandy shale facies. From the analyzed palynological slides, ninety one (91) palynomorphs species were identified in the outcrop samples, eighty three (83) were Miospores (pollen and spores) and seven (7) were Dinocysts while the borehole samples recorded fifty five (55) palynomorph species, forty three (43) were Miospores while fifteen (15) were Dinocyst. Clusters analysis were used to establish four (4) Palynological Assemblage zones which are Palynological Assemblage zones 1, 2, 3 and 4. Late Maastrichtian to Early Paleocene age is suggested for Nsukka Formation because of the presence / abundance of *Spinizonocolpites baculatus* with admixture of *Apectodinium homomorphum and Homotryblium tenuispinosum.* The occurrence of *Monocolpites marginatus, Retidiporites magdalenensis,* and non-occurrence of *Spinizonocolpites baculatus* in the outcrop samples suggests that Mamu Formation did not penetrate Late Maastrichtian. Thus Early to Middle Maastrichtian is suggested for Mamu formation. The occurrence of mangrove palynomorphs *Zonocostites ramonae*, fresh water algae *Botryococcus braunii* and *Concentricyst circulus* indicates sedimentation in coastal to shallow marine environment close to mangrove vegetation.

Keywords: *lithofacies, palynomorphs, Anambra Basin, paleoenvironment, cluster analysis*

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1. Introduction

The Anambra Basin is a Cretaceous/ Tertiary basin which is a structural link between the Benue Trough and the Niger- Delta Basin. The evolution of the Benin flank in South Western Nigeria is known to have started with a series of tectonic activities which accompanied the initial opening of the South- American and African plates in late Jurassic to Cretaceous time [1]. These events created the interior fracture basin of the Benin flank and part of the Benue Trough Complex and the Benin Basin. The later Santonian- Campanian tectonics which produced the Abakaliki Anticlinorium and the other fold sequence along the Benue Trough Complex also produced the Synclinal basins of the Anambra and Afikpo Syncline. The Niger Delta Basin developed as the Benue Trough feed out sediments, just filling the Anambra Basin and led to the outward growth of the delta [1,2].

Field mapping involves the study of 56 outcrops in Auchi Topographic Sheet (266), across Benin Flank in the neighborhood of Edo State. Outcrops where available, remain the best and most direct source of information on the rock record, having played a good role in building the primary data set which largely helped in understanding and establishing a stratigraphic architecture in various depositional settings in the flank.

Field investigation was used to carry out a detailed field mapping with emphasis on lithofacies and palynomorphs distribution and their palaeoenvironmental significance.

Lithofacies can be defined as sedimentary starter that has individual physical characteristics such as grain size, structure and mineral assemblage, sorting variations, which are largely dependent upon depositional processes such as energy conditions and sediment supply source. Lithofacies alone cannot be used solely to reconstruct precise paleoenvironments, but a palynology approach in conjunction with sedimentologic analyses can enable accurate paleoenvironmental appraisal. The use of lithofacie and palynology as tools and components in evaluating sedimentary pile and basin analysis has become increasingly important in recent times as seen in works by [3-8].

Biostratigraphy is an essential tool for dating rocks and identifying the biotic record through time and is necessary for establishing temporal correlation, reconstructing paleogeography as well as recognition of oil and gas deposits and intervals. It is essential to the petroleum industry as a tool for defining geologic constraints on prediction of exploration risk and modeling reservoir simulation.

This study was aimed at analyzing out crops and bore hole sediments from Mamu and Nsuka Formation in other to establish Palynological assemblage zones, Age and Paleoenvironment sediments.

1.1. Location of the Study Area

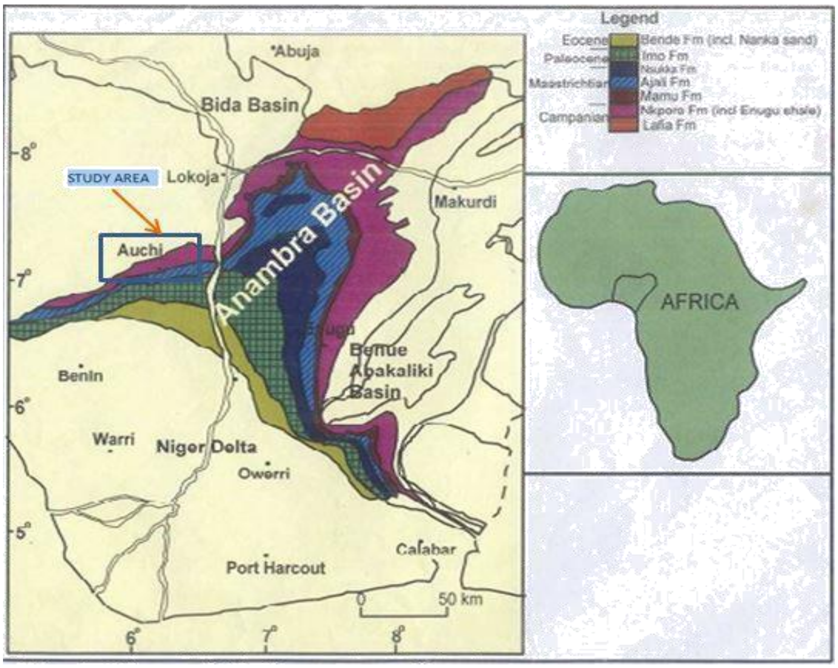

Figure 1. Map of Anambra Basin showing the location of the study area. (Drawn from the Geological Map of Nigeria, GSN 1994)

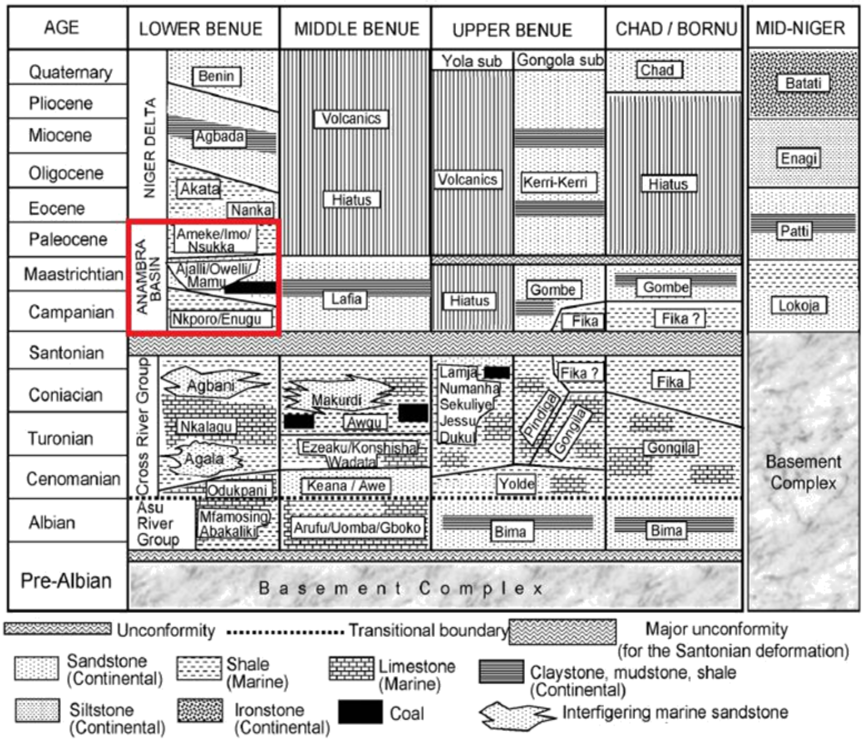

Figure 2. Stratigraphy of the Anambra basin in relation to the Benue Trough complex (Adapted from [9])

The study area is geographically located in the Southwestern Nigeria, and defined by Latitudes 07°00' N and 07°15' N and Longitudes 006°00' E and 006°30' E, which constitutes part of the Auchi Sheet 266 (1:100,000). It covers an area of about 2,400km^2. Major access roads into the area include Auchi-Fugar Road, Auchi-Igarra Road, Ayogwiri-Apana Road, Iyora-Uzaire Road, Apana-Iyora Road, Auchi Ukpilla Road, Ugbekpe-Ekperi Road, Ogbonna-Okpekpe Road, Auchi-Ohame Road, as well as Ogbonna-Imiegba Road. The major towns are Auchi, Fugar, Jattu, Imiegba, and Okpekpe; (Figure 1).

1.2. The Stratigraphic Fill of the Anambra Basin

Sedimentation within the Anambra Basin consists of deltaic complexes (2500m thick) ranging from Late Cretaceous to Late Eocene in age. Two major transgressions occurred within the basin resulting in the Nkporo depositional cycle during the Late Campanian to Early Maastrichtian, and the Nsukka depositional cycle during the Late Maastrichtian to Late Paleocene [10]. The formations that make up the Nkporo cycle are the Agbani, Owelli, Mamu and Ajali Formations. The Ajali Formation marks the height of the regression before the beginning of the Nsukka depositional Cycle. The Enugu Shale and Nkporo Shale sequences represent brackish marsh and fossiliferous prodeltaic facies, respectively. The Nsukka Formation marks the beginning of the Nsukka cycle, and is interpreted to be a fluvio-deltaic phase of deposition. This cycle ended with the deposition of the Imo Shale, which is interpreted to be shallow marine shelf sediments. The deposition of the Ameki Group and its laterally equivalent Nanka Formation represents the start of the Eocene regression.

The shape, closeness of sediment source areas, transgression and regression cycles, and paleo-circulation patterns are all factors that had major impact on the depositional patterns in the Anambra Basin [10].

1.3. Nkporo Shale

The Nkporo shale is the basal sedimentary unit that was deposited following the Santonian folding and inversion in south eastern Nigeria. It represents deltaic sedimentation and indicates a Late Campanian age, based on the presence of Afrobolivina Afra [11]. Nkporo shale comprises of a coarsening upward sequence of shales and interbedded sands with laminae of gypsum. Shales are Carbonaceous, gypsiferous and contain siderite.

1.4. Enugu Shale

This is a lateral equivalent of Nkporo shales. (Upper Campanian). The formation consists mainly of carbonaceous bluish shales with coal seams in the upper part. Interbeds of greyish siltstones and thin bedded fine sandstones, gypsum and pyrite grains are also present. The shales are found north of Awgu, thus restricting them to the central and northern parts of the basin. Environment of deposition ranges from lower flood plains, comprising overbank and crevasse splay [11].

1.5. Owelli Sandstone

It comprises thickly bedded sandstones pebbly to medium grained, characteristically tabular and trough bedded and poorly sorted. Its age is Late Campanian. The Owelli sandstone is typically massive, hard and often ferruginous. It is cross bedded, generally medium to coarse grained and contains pebble bands, occasional thin silty or argillaceous layers [11]. Paleo- current direction is generally to the SE, generally texturally immature and Kaolinitic. It is composed of shoestring sand body elongated to the NE and outcrops at the Enugu- Port Harcourt expressway.

Table 1. Lithostratigraphic framework for the Early Cretaceous-Tertiary period in Southeastern Nigeria after [12]

AGE		ABAKALIKI – ANAMBRA BASIN	AFIKPO BASIN
m.y 30	Oligocene	Ogwashi-Asaba Formation	Ogwashi-Asaba Formation
549	Eocene	Ameki/Nanka Formation/ Nsugbe Sandstone (Ameki Group)	Ameki Formation
65	Palaeocene	Imo Formation	Imo Formation
		Nsukka Formation	Nsukka Formation
	Maastrichtian	Ajali Formation	Ajali Formation
73		Mamu Formation	Mamu Formation
83	Campanian	Npkoro Oweli Formation/Enugu Shale	Nkporo Shale/ Afikpo Sandstone
87.5	Santonian	Agbani Sandstone/Awgu Shale	Non-deposition/erosion
88.5	Coniacian		
93	Turonian	Eze Aku Group	Eze Aku Group (incl. Amasiri Sandstone)
100	Cenomanian – Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Units	
Precambrian		Basement Complex	

1.6. Lokoja Basa'Nge

The Lokoja Basa'Nge formation is cartographically represented east of the River Niger and South of the confluence as directly overlying the Basement. It is also classified with the coal measures as the basal unit. It is thus ill defined in both stratigraphic position and aerial extent. Its contact with the basement should rather assign it the Nkporo Group.

1.7. Mamu Formation

Mamu Formation overlies the Nkporo Shales in the south, the Owelli Sandstone and Enugu Shales in the Central and Lokoja Sandstone in the Northern dip of the basin. The estimated thickness of the formation varies across the basin, ranging from 75m- over 1000m. [11,13]. It is accompanied by both vertical and lateral facies changes. The sequence comprises of inter- bedded fine to medium grained sands, carbonaceous and pyritic mudstones. The sand beds are several meters thick and show mainly lenticular, ripple sets, flaser and wavy bedding.

1.8. Ajali Sandstone

The Ajali sandstone overlies the Mamu formation in the Anambra basin and has a diachronous age from south to north (Middle- Upper Maastrichtian). The Ajali sandstone occur as a sheet like sand body spread across the entire Anambra basin with a thickness of about 300m to over 1000m at the center of the basin [14]. The unit is compositionally mature (quartz arenite), medium to coarse grained, well to moderately sorted, friable, intercalated with kaolinite beds. Structures include planar and occasionally herringbone cross bed. Dominant sedimentary structures are cross bedded associated with reactivation surfaces, mud drapes, tidal bundles, back flow ripples, channel cut and fills, and lateral accretion surface [13].

1.9. Nsukka Formation

The Nsukka Formation which is called the upper coal measures [15,16] overlies the Ajali sandstone. It begins with a coarse to medium grained sandstones and passes upward into well- bedded blue clays, fine grained sandstones and carbonaceous shale with thin bands of limestone [11,17]. [17] used sedimentological evidence to suggest that the Nsukka Formation represents a phase of fluvio- deltaic sedimentation that began close to the end of Maastrichtian and continued during the Paleocene. It contains interbeds of coal seams. The formation is poorly fossiliferous and consists of some palynomorph species. Nsukka formation is Maastrichtian to Danian in age [11]. It was deposited under paralic conditions which prevailed during the second Post Santonian transgressive cycle. The Nsukka formation marks the onset of another transgression and documents the return of a paludal condition. Sedimentation was mainly of fluvial origin though punctuated at the height of transgressive phases by marine flooding.

1.10. Imo Shale

This formation overlies the Nsukka Formation. The Imo shales reflect shallow- marine shelf conditions in which foreshore and shoreface sands are occasionally preserved. It consists of blue grey clays and shales, black shales with bands of calcareous sandstone, marl, and limestone [11]. Ostracods and foraminiferal biostratigraphy [11], and microfauna recovered from the basal limestone unit, [18]. Surface outcrop of this formation occur in a belt extending from North OF Umuahia to North of Benin City. Akata Formation is the subsurface equivalent of the Imo shale in the Niger Delta, [19]. Lithology and trace fossils of the basal sandstone unit reflect foreshore and shoreface [10].

1.11. Ameki Formation

The Eocene Ameki group marks the return to regressive conditions. This formation is observed to overlie the Imo shale. Two lithologic units are observed. They include: (a) the upper unit which consists of coarse cross bedded sandstone with sandy clay interbeds and (b) the lower unit which consists of fine to coarse grained sandstone with inter- beds of calcareous shale and thin shaly limestone.

2. Materials and Method

2.1. Field Investigation

This involves field mapping and lithologic logging of outcrop sections to provide data for lithofacies studies and palynofacies studies which will aid in identifying the kerogen types and source rock maturity.

Outcrops were studied lithologically with their attributes and characteristics recorded with representative samples taken in places. Selected ditch cutting samples collected from the Out crop were utilized for palynology slide preparation.

2.2. Facies Analysis

Facies analysis is a rigorous, scientific approach to the study and interpretation of the characteristics of a sedimentary unit [20]. These characteristics include depositional geometry, sedimentary structures, grain sizes and types, and biogenic content of the sedimentary units. These are determined by physical and chemical processes of transport and deposition, as well as the paleoecology during and after deposition of sediments. By interpreting the sediments in terms of these physical, chemical and ecological conditions at the time of deposition, it is possible to reconstruct the paleoenvironment and the paleogeography of the sedimentary body [20,21]. The word facies is used in both descriptive and an interpretative sense. The facies analyses used in this work include lithofacies and palynofacies.

A lithfacies is a rock unit defined on the basis of its distinctive lithological features which include grain size, sedimentary structures, composition, bedding characteristics [20]. Each lithofacies represents an individual depositional event. Lithofacies may be grouped into lithofacies associations or assemblages, which are characteristics of particular depositional environment [22]. These assemblages form the basis for defining lithofacies and depositional model.

Palynofacies (or palynological facies) is most widely used applied in a general way to mean organic matter that is recovered from a rock or unconsolidated sediments. It involves the preparation of slides for identification of palynomorphs and palynodebris that was association with the sediments during the time of deposition and diagenesis. Both Terrestrial and Marine palynomorphs were identified. The types of palynomaceral were also identified. The interpretation will be fully documented in chapter six of this research work. The laboratory procedures are described below.

2.3. Palynology Sample Preparation

Twenty four (24) samples were treated for palynological slide preparation. The slides were analyzed under the microscope for palynological content.

Palynological Sample Preparation: The sample preparation was carried out following the international standards given below: 10g of sample was crushed between aluminum pie dishes, collected and tested for limestone ($CaCO_3$) using HCl, while effervescence occurred, the limestone was eliminated by further addition treatment with concentrated HCl. After two or three hours, the sample was decanted and the waste solution transferred to one special waste container bottle. The broken down mineral material and fossils were removed and centrifuged for about 1-2 minutes and decanted repeatedly until a neutral reaction was reached. Concentrated HNO_3 was used for oxidization and heated over bunsen burner. KOH of 10% solution was added to the sample and transferred to styrofoam cups and HF added and let to stand overnight. The sample was then washed with water until a neutral reaction was reached and decanted. Sodium hypochlorite (Purex) as well as some drops of HCl was added, agitated and let for about 15 minutes. Two drops of Ammonium Hydroxide concentrate was added and diluted with water. At this stage, separation of the organic matter from the inorganic material (silica) was done by floatation using diluted zinc bromide (ZnBr). The samples were transferred to a flexible plastic tubes, already prepared (cut and mount immersed into warm water); such plastic tubes are set into centrifuge tubes with water around them. Zinc bromide has a specific gravity of 2.2 thus, everything with a specific gravity of more than 2.2 will settle down. The process of centrifugation using zinc bromide took about 15 minutes. A small portion of the supernatant liquid was observed under the microscope. Then, a clip across the flexible plastic tube was inserted so that the supernatant liquid would be easy to take out by pipette decantation or eye dropper.

2.4. Cluster Analysis

A cluster analysis was made for grouping the samples depending on similarities in species abundance and distribution. A hierarchical agglomerative clustering with Ward's linkage method and Euclidean distance measure was used, as recommended by [22]. Ward's clustering is recognized as a very effective method that gives distinct clusters and has been used and recommended to interpret biostratigraphical data [23]. The results are presented as dendrograms scaled by the distance between merged groups in this case, the sample between sample compositions. The cluster analysis was made using statistical software called SPSS.

3. Result and Discussion

3.1. Lithofacies

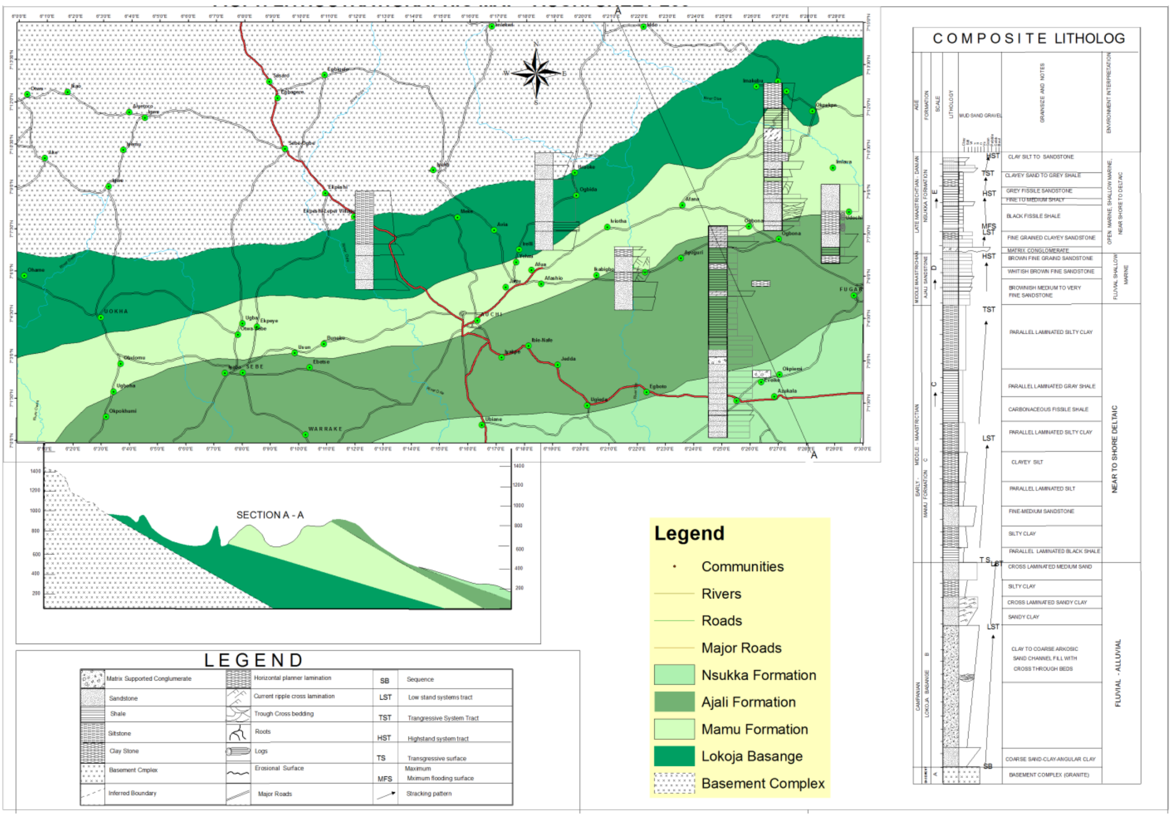

Figure 3. Lithostratigraphic Map of Auchi sheet 226 (ONYEACHONAM .N and FREGENE T.J In present study)

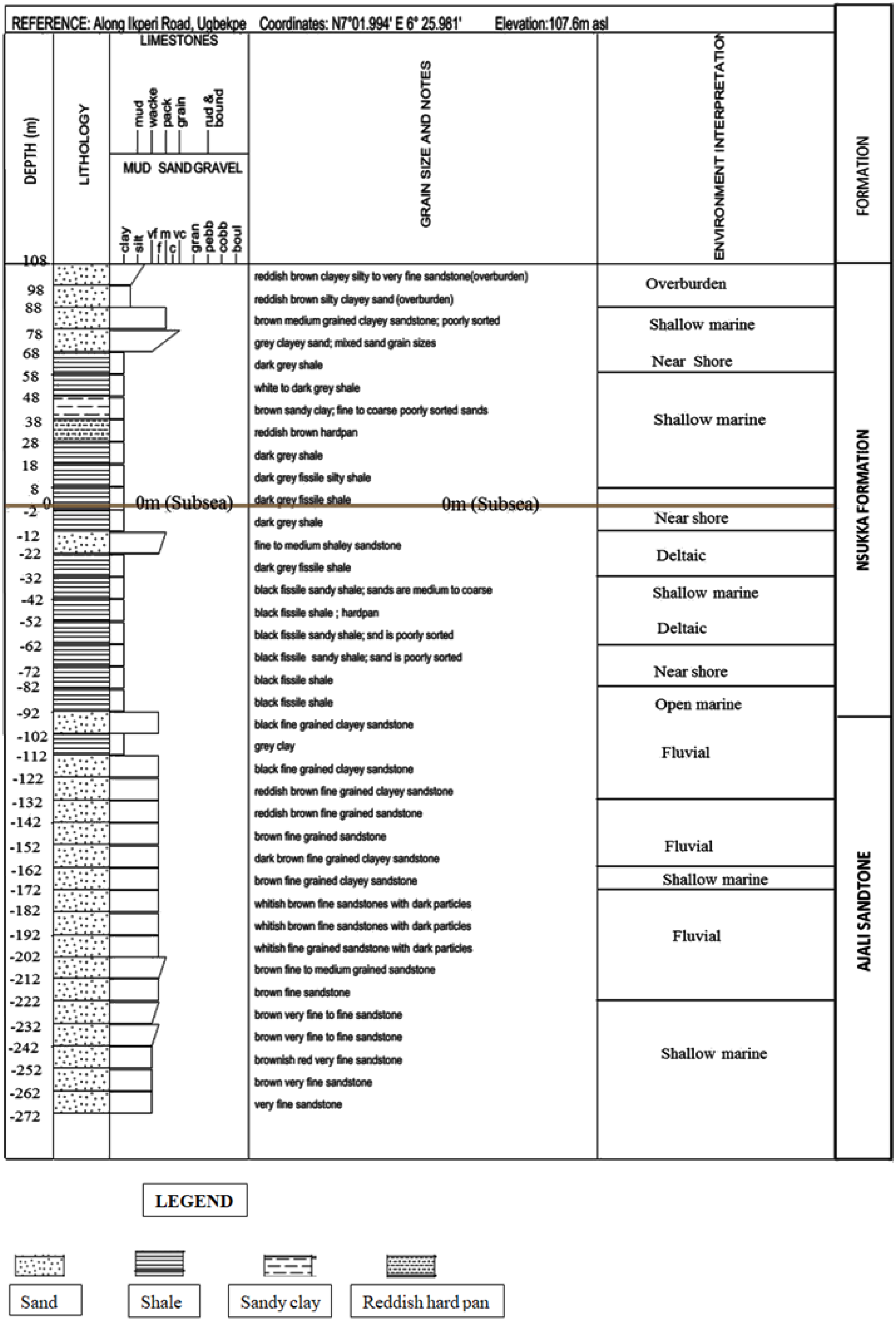

Figure 4. Lithology of Ugbekpe well showing the various lithofacies penetrated by the drill and depositional environments

A lithostratigraphic map identifying the various formations in the study area, their sedimentary structures as well as roads and rivers within the area was established.

The ditch cutting samples used for this study are from a water borehole at Ugbekpe- Ekperi road in the Benin Flank of Anambra Basin. Thirty Eight (38) horizons in the well were sampled at 10 meter intervals with coordinates N07°01.994' and E006°25.981'. The lithology sections were drawn for the intervals sampled. The lithofacies identified were clay, silt, sandstone, shale and sandy shale. From the thirty eight ditch cutting samples, (10) ten samples were selected for palynological analysis along side (11) eleven other samples gotten from out crops of Mamu and Nsuka formation.

3.2. Palynology

Palynomorphs that were stratigraphically significant recovered in the analyzed samples were plotted in order to interpret for the Palynostratigraphy, Age Dating and Paleo-depositional environment of the intervals (8-68m asl, 2-92m bsl). The miospores are relatively moderate in abundance and diversity, moderately rich in dinoflagellate cysts.

3.3. Palynological Count

From the analyzed palynological slides, ninety one (91) palynomorphs species were identified in the outcrop samples. Eighty three (83) were Miospores (pollen and spores) and seven (7) were Dinocysts. From the borehole sample, fifty five (55) palynomorph species were identified. Forty three (43) were Miospores while fifteen (15) were Dinocyst.

Table 2. Occurrence and distribution of pollen, spores and dinocysts in Ugbekpe outcrop samples

S/N	LOCATION/DEPTH	MIOSPORES	POLLEN	SPORES	DINOCYS	TOTAL PALYNOMORPHS	PERCENTAGE OF THE PALYNOMORPH		
							(%) POLLEN	(%) SPORES	(%) DINOCYST
	LOCATION								
1	L3C	204	117	87	1	205	57	42	1
2	L6C1A	0	0	0	0	0	0	0	0
3	L6C1B	0	0	0	0	0	0	0	0
4	L6D1	209	116	92	1	210	55	44	1
5	L6D4	5	0	5	0	5	0	100	0
6	L7A1	16	10	6	2	18	56	33	11
7	L7E3	73	56	17	1	74	76	23	1
8	L7E5	8	4	4	0	8	50	50	0
9	L7F1	147	71	76	0	147	28	52	0
10	L7F5	37	24	13	0	37	65	35	0
11	L7H2	67	56	11	3	70	80	16	4
12	LOKOJA CLAY	1	0	1	0	1	0	100	0
13	SHALES 25cm	11	9	2	0	11	82	18	0
14	SHALES 35cm	102	70	32	1	103	68	31	1
15	SHALES 45cm	225	160	65	3	228	70	29	1
16	SHALES 93cm	130	101	29	2	132	76	22	2
17	AJALI IDAH	4	3	1	0	4	75	25	0
18	GWOLIGWO	5	5	0	2	7	71	0	29
19	FERRUGISED Okpatse	43	37	6	1	44	84	14	2
20	OKPATSE 263cm	26	23	3	1	27	85	11	4
21	BURROW PIT SHALES 55cm	55	25	30	0	55	45	55	0
22	COALY SHALE IYEGUW	145	103	42	0	145	71	29	0
23	RIPPLE SHALES 50cm	164	104	60	0	164	63	37	0
24	SILTY CLAY 110cm	316	259	57	5	321	80	18	2

Table 3. Occurrence and distribution of pollen, spores and dinocysts in Ugbekpe well samples

S/N	LOCATION/DEPTH (m)	MIOSPORES	POLLEN	SPORES	DINOCYS	TOTAL PALYNOMORPHS	PERCENTAGE OF THE PALYNOMORPH		
							(%) POLLEN	(%) SPORES	(%) DINOCYST
1	BH58-68	100	73	27	2	102	72	26	2
2	BH48-58	8	6	2	5	13	46	15	39
3	BH18-28	14	7	7	10	24	29	29	42
4	BH8-18	113	61	52	54	167	37	31	32
5	BH2-12	16	9	7	0	16	56	44	0
6	BH22-32	42	18	24	3	45	40	53	7
7	BH32-42	56	29	27	24	80	36	34	30
8	BH52-62	38	15	23	1	39	38	59	3
9	BH62-72	21	14	7	2	23	61	30	9
10	BH82-92	26	13	13	83	109	12	12	76

3.4. Palynological Range Chart

A palynological range chart showing the vertical distribution, abundance and diversity were established for the well. They were established based on the first appearance datum (last downhole occurrence) and last appearance datum (first downhole occurrence) of each palynomorph identified in the well section. The recovered palynomorphs are stated below:

Miospores recovered are: *Echitriporites trianguliformis, Arecipites exilimulatus, Retitriporites spp., Retimonocolpites spp., Psilastephanocolpites sapotaceae, Proteacidites spp., Longapertites marginatus, Spinizonocolpites baculatus, Psilatricolporites spp., Indeterminate pollen, Echiperiporites spp., Arecipites spp., Proxapertites operculatus, Triorites takahashii, Retitricolpites spp., Proxapertites anisosculptus, Tetracolpites reticulatus, Tetracolporites quadratus, Retibrevitricolporites Obodoensis, Marginipollis concinnus, Zonocostites ramonae, Germmamonocolporites spp., Psilamonocolpites scabratus, Classopollis spp., Arecipites crassimuratus, Ephedripites spp., Echiperiporites spinosus, Striatricolporites spp., Verrucatosporites spp., Cyathidites spp., Funga spore, Acrostichum aureum, Laevigatosporites spp., Deltodospora spp., Polypodiaceoisporites spp., Cingulatisporites ornatus, Crassoretitriletes vanraadshooveni, Selaginella myosorus, Lycopodium spp., Dictophyliidites harrishi.*

Dinocysts recovered are: *Polyshaeridium subtile, Operculodinium centrocarpum, Lejeunecysta spp., Tenua rioultii, Dinocyst indeterminate, Spiniferites ramosus, Oligoshaeridium complex, Glyphyrocysta retiintexta, Hystrichogonyaulaux cornigera, Cannosphaeropsis utinensis, Apectodinium hormomorphum, Eocladoppyxis peniculatum, Homotryblium tennuispinosum.*

Table 4. Range chart of Miospores (pollen and spores) recovered from bore hole sample

S/N	DEPTH (m)	POLLEN	*Echitriporites trianguliformis*	*Arecipites exilimuratus*	*Retitriporites sp.*	*Retimonocolpites sp.*	*Psilastephanocolpites sapotaceae*	*Proteacites sp.*	*Longapertites marginatus*	*Pandanus*	*Spinizonocolpites baculatus*	*Psilatricolporites sp.*	*Indeterminate pollen*	*Echiperiporites sp.*	*Arecipites sp.*	*Proxapertites operculatus*	*Triorites takahashii*	*Retitricolpites sp.*	*Proxapertites anisosculptus*	*Tetracolpites reticulates*	*Tetracolporites quadratus*	*Retibrevitricolporites obodoensis*	*Marginipollis concinnus*	*Zonocostites ramonae*	*Gemmamonoporites sp.*	*Psilamonocolpites marginatus*	*Cretacaeiporites scabratus*	*Classopollis sp.*	*Arecipites crassimuratus*	*Ephedripites sp.*	*Echiperiporites spinosus*	*Striatricolporites sp.*	SPORES	*Verucatosporites sp.*	*Cyathidites sp.*	*Fungal spore*	*Acrostichum aureum*	*Laevigatosporites sp.*	*Deltodospora sp.*	*Polypodiaceoisporites sp.*	*Cingulatisporites ornatus*	*Crassoretitriletes vanraadshooveni*	*Selaginella myosorus*	*Lycopodium sp.*	*Dictophyliidites harrisii*	Auxilliary microfossil	*Botryococcus brauni*	*Concentricyst circulus*	*Charred Graminae cuticle*	*Species Abundance*	*Species Diversity*	Age	Formation
1	58-68		63	2	1	4	1	1	1																									2	7	3	6	7	2										48	148	14	Paleocene	Nsukka Formation
2	48-58			1						1	1	1	2																								1			1									1	9	8		
3	18-28					1					3			1	1	1																				1		3	4		1	1								17	10		
4	8-18.		6			5			10		13	1	6		1	7	1	1	3	1	1														22	2		19	8			1							7	115	19		
5	2-12.			1	1						3	1										1	1	1										1	1		2	2				1							1	17	13	Maastrichtian - Early	
6	22-32		2			2					1		2	1		3									1	1								2	3	2	2	10					2	2	1					37	16		
7	32-42		10			6	1		3		1			1		1		1									1	4	1						2	2	6	12		1				1			1			54	17		
8	52-62					2			2		2	2	7																						3	2		12	1					3			1	1		36	10		
9	62-72		1			5					2												1							1	1							3					1	1					1	17	10		
10	82-92		6						1							2																1		1	2			10												23	7		

Table 5. Range chart of Dinocysts recovered from bore hole sample

S/N	DEPTH (m)	*Polysphaeridium subtile*	*Operculodinium centrocarpum*	*Lejeunecysta sp.*	*Tenua rioultii*	*Diatom frustule*	*Kiokansium unituberculatum*	*Indeterminate dinocyst*	*Spiniferites ramosus*	*Oligospheridium complex*	*Glaphyrocysta retiintexta*	*Hystrichogoyaulaux cornigera*	*Cannosphaeropsis utinensis*	*Apectodinium hormorphum*	*Homotryblium tenuispinosum*	*Eocladoppyxis peniculatum*	*Species Abundance*	*Species Diversity*	Age	Formation
1	58-68	1	1														2	2	**Maastrichtian to Early Paleocene**	**Nsukka Formation**
2	48-58		10	2	1	1	1										15	5		
3	18-28	6						1		1							8	3		
4	8-18.	25		6				1	3		7	2					44	6		
5	2-12.																0	0		
6	22-32										3						3	1		
7	32-42	2	12						2				1	1	1		19	6		
8	52-62															1	1	1		
9	62-72																0	0		

3.2. Palynomorph Distribution of Outcrop Samples

- **Mamu Formation at Imiegba Road**

This facies consists of carbonaceous shale, greyish to black fissile laminated shale. Palynological analysis of sample from this facies (L7A1, L7E3, L7E5, L7F1, L7F5, L7H2) yielded relatively high abundance of non-marine and poor marine palynomorphs.

Some of the Palynomorphs recovered are *Longapertites marginatus, Longapertites microfoveolatus, Cingulatisporites ornatus, Proteacidites signali, Rugulatisporites caperatus, Tubistephanocolporites cylindricus, Echitriporites trianguliformis, Cyathidites spp., Deltoidospora spp., Retidiporites magdaleneesis,* and spot occurrence of dinocyst species such as *Operculodinium centrocarpum, palaeocystodinium gabonense*.

- **Mamu Formation at Okpekpe Road**

This facies consists of light grey to black fissile shale. Palynological analysis of samples from this facies (L6C1A, L6C1B, L6D1, and L6D4) yielded high abundance of terrestrial palynomorphs. Dinocyst were poorly recovered from the samples. Samples L6C1A and L6C1B were barren, poorly fossiliferous. The rarity of palynomorphs might have occurred as a result of weathering and transportation of sediments.

Some of the palynomorph species such as *Cyathidites spp., Echitriporites trianguliformis, Longapertites marginatus, Retidiporites magdalenensis, Cingulatisporites ornatus* and spot occurrence of dinocyst such as *Operculodinium centrocapum*.

Table 6. Palynomorph Distribution of Outcrop Samples

S/N	PALYNOMORPHS	L3C	L6C1A	L6C1B	L6D1	L6D4	L7A1	L7E3	L7E5	L7F1	L7F5	L7H2
	RECOVERED	**SHALE**	**SHALE**	**SHALE**	**SHALE**	**SHALE**	**SHALE**	**SHALE**	**SHALE**	**SHALE**	**SHALE**	**SHALE**
	POLLEN											
1	*Marginipollis concinnus*	20	0	0	3	0	1	0	0	0	0	0
2	*Retitriporites sp*	1	0	0	0	0	0	0	0	0	0	0
3	*Retimonocolpites asabaensis*	3	0	0	*0*	0	0	0	0	0	0	0
4	*Retidiporites magdaleneesis*	2	0	0	1	0	0	0	0	0	0	0
5	*Cyperaceaepollis sp*	4	0	0	0	0	0	0	0	0	0	0
6	*Retstephanocolporites sp*	1	0	0	0	0	0	0	0	0	0	0
7	*Proxapertites cursus*	3	0	0	0	0	0	0	0	0	0	0
8	*Psilatricolporites sp*	3	0	0	0	0	0	0	0	0	0	0
9	*Arecipites crassimuratus*	2	0	0	1	0	0	0	0	0	0	0
10	*Retibrevitricolporites obodoensis*	4	0	0	0	0	0	0	0	0	0	0
11	*Canthium sp*	1	0	0	0	0	0	0	0	0	0	0
12	*Retitricolpites gageonneti*	3	0	0	1	0	1	0	0	0	0	0
13	*Echitriporites trianguliformis*	5	0	0	8	0	1	0	0	0	0	0
14	*Spinizonocolpites echinatus*	1	0	0	0	0	0	0	0	0	0	2
15	*Zonocostites ramonae*	24	0	0	0	0	0	0	0	0	0	0
16	*Proxapertites dehaani*	1	0	0	0	0	0	0	0	0	0	0
17	*Spirosyncolpites sp*	2	0	0	0	0	0	0	0	0	0	0
18	*Retitricolpites irregularis*	4	0	0	0	0	0	0	0	0	0	0
19	*Psilamonocolpites sp*	1	0	0	7	0	0	0	0	0	0	0
20	*Longapertites marginatus*	3	0	0	4	0	1	7	0	0	7	0
21	*Proteacidites cooksonni*	2	0	0	1	0	0	0	0	0	0	0
22	*Arecipites exilmuratus*	3	0	0	0	0	0	0	0	0	0	0
23	*Retimonocolpites obaensis*	7	0	0	0	0	0	1	0	0	0	0
24	*Proxapertites operculatus*	3	0	0	0	0	1	1	0	0	0	0
25	*Retibrevitricolpites triangulatus*	2	0	0	0	0	0	0	0	0	0	0
26	*Pachydermites diederrixi*	1	0	0	0	0	0	0	0	0	0	0
27	*Gemmamonoporites sp*	1	0	0	0	0	0	0	0	0	0	0

28	*Peragrinipollis nigericus*	2	0	0	0	0	0	0	0	0	0	0
29	*Indeterminate striate pollen*	1	0	0	0	0	0	0	0	0	0	0
30	*Psilatricolpites crassus*	2	0	0	0	0	0	0	0	0	0	0
31	*Retitricolporites sp*	3	0	0	6	0	0	0	0	0	0	0
32	*Psilastephanocolporites sapotaceae*	2	0	0	0	0	0	0	0	2	0	0
33	*Psilamonocolpites marginatus*	2	0	0	8	0	0	0	0	20	0	0
34	*Retitricolpites sp*	1	0	0	0	0	0	0	0	0	0	0
35	*Racemonoclpites hians*	2	0	0	0	0	0	0	0	0	0	0
36	*Ctenolophonidites costatus*	1	0	0	0	0	0	0	0	0	0	0
37	*Syncolporites marginatus*	2	0	0	0	0	0	0	0	0	0	0
38	*Retimonocolpites sp*	0	0	0	25	0	3	0	0	9	1	1
39	*Crontotricolpites crotonoisculptus*	0	0	0	2	0	0	0	0	1	0	0
40	*Glaeicheniidites senonicus*	0	0	0	2	0	0	0	0	0	0	0
41	*Thymelipollis retisculpturius*	0	0	0	1	0	0	0	0	0	0	0
41	*Syncolporites sp*	0	0	0	2	0	0	0	0	0	0	0
43	*Monoporites annulatus*	0	0	0	1	0	0	0	0	0	0	0
44	*Arecipites sp*	0	0	0	0	0	1	0	0	0	0	0
45	*Tricolporopollentes sp.*	0	0	0	0	0	0	4	0	0	7	12
46	*Auriculiidites sp*	0	0	0	0	0	0	0	0	0	1	0
47	*Monosulcites sp*	0	0	0	0	0	0	0	0	0	1	1
48	*Inaperturopollenites sp*	0	0	0	0	0	0	4	0	0	1	8
49	*Proteacidites sigalii*	0	0	0	0	0	0	0	0	0	1	1
50	*Moncolpites marginatus*	0	0	0	0	0	0	4	0	0	1	5

- **Mamu Formation at Ukoh –Udochi**

This facie consist of light grey shale, well laminated and highly fissile. This sample yielded the highest abundance of non- palynomorphs compared to other locations.

Some of the Palynomorphs recovered are *Longapertites marginatus, Cyathidites spp., Echitriporites trianguliformis, Retidiporites magdalenensis, Cingulatisporites ornatus*.

3.3. Palynological Assemblage

3.3.1. Palynological Assemblage 1

The abundance of marine palynomorphs is greater than that of terrestrial palynomorphs. *Operculodinium centrocarpum* dominates the marine assemblage with 65% of total dinoflagellate relative abundance. The abundance was at the basal part of the analyzed section (82-92m below sea level). The occurrence of mangrove elements *Zonocostites ramonae* fresh water algae *Botryococcus braunii* and *Concentricyst circulus* indicates sedimentation in coastal to shallow marine environment close to mangrove vegetation [4,24].

3.3.2. Palynological Assemblage 2

The abundance of marine palynomorphs is approximately equal to terrestrial palynomorphs. Most of them occurred single and at a depth interval of 32-42m below sea level. This zone shows important Paleocene marker forms which include *Apectodinium homomorphum and Homotryblium tenuispinosum.*

3.3.3. Palynological Assemblage 3

The abundance of terrestrial palynomorphs are greater than marine palynomorphs. Assemblage 3 is composed of palms (*Echitriporites trianguliformis*, *Longapertites marginatus*, *Spinizonocolpites baculatus*), ferns (*Laevigatosporites spp.*) and Fungal spores representing coastal swamps (palm/fern swamps). They are abundant at the depth of 8-18m above sea level.

3.3.4. Palynological Assemblage 4

The abundance of marine palynomorphs is approximately equal to terrestrial palynomorphs. The occurrence of palm pollen *Proxapertites operculatus* and some dinocysts such as *Spiniferites ramosus* and *Oligosphaeridium complex* suggests sedimentation in coastal to shallow marine environment.

As shown on the dendrogram Figure 4, cluster analysis was used in grouping the samples on the basis of similarities in species abundance and distribution.

Table 7. Palynological Assemblage

Palynomorphs	**Palynological Assemblage**
Eocladoppyxis peniculatum	Palynological Assemblage 1
Concentricyst circulus	
Botryococcus braunii	
Echiperiporites	
Lycopodium spp	
Psilamonocolpites marginatus	
Dictophyliidites harrishi	
Gemmamonoporites ssp	
Ephedripites ssp	
Echiperiporites spinosus	

Selaginellamyosorus	
Retibrevitricolporites Obodoensis	
Zonocostites ramonae	
Marginipollis concinnus	
Arecipites exilimulatus	
Retitriporites spp	
Verrucatosporites spp	
Acrostichum aureum	
Psilastephanocolpites sapotaceae	
Proteacidites spp.	
Polypodiaceoisporites spp.	
Operculodinium centrocarpum	
Diatom frustule	
Kiokansium unituberculatu	
Pandanus	
Lejeunecysta	
Tenua rioultii	
Striatricolporites spp	
Apectodinium hormomorphum	
Homotryblium tennuispinosum	Palynological Assemblage 2
Cretacaeiporites scabratus	
Arecipites crassimuratus	
Cannosphaeropsis utinensis	
Classopollis spp	
Psilatricolporites spp	
Spinizonocolpites baculatus	
Cyathidites spp	
Laevigatosporites spp	Palynological Assemblage 3
Echitriporites trianguliformis	
Longapertites marginatus	
Retimonocolpites spp	
Funga spore	
Deltodospora spp	
Polyshaeridium subtile	
Tetracolporites quadratus	
Hystrichogonyaulaux cornigera	
Triorites takahashii	
Proxapertites anisosculptus	
Tetracolpites reticulatus	
Retitricolpites spp	
Spiniferites ramosus	
Proxapertites anisosculptus	
Tetracolporites quadratus	
Hystrichogonyaulaux cornigera	
Triorites takahashii	Palynological Assemblage 4
Proxapertites anisosculptus	
Tetracolpites reticulatus	
Retitriporites spp	
Spiniferites ramosus	
Proxapertites operculatus	
Glyphyrocysta retiintexta	
Cingulatisporites ornatus	
Oligoshaeridium complex	
Arecipites spp	
Crassoretitriletes vanraadshooveni	

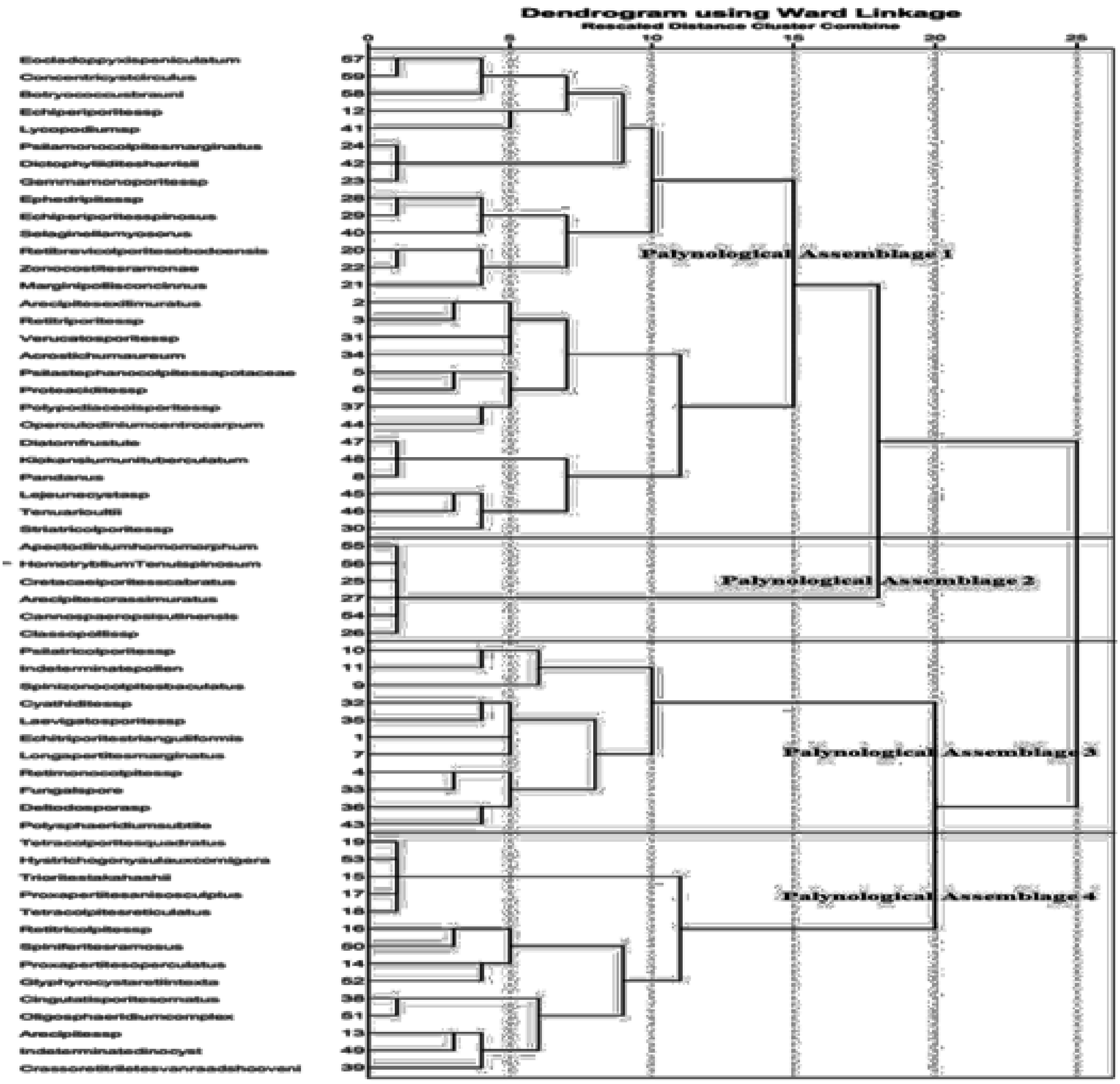

Figure 5. Dendrogram-clustering of palynomorphs in the well section showing four assemblages after [25]

3.4. Age Determination

The high occurrence of palm pollen such as *Longapertites marginatus, Echitriporites trianguliformis, Spinizonocolpites baculatus, Proxapertites operculatus, Proxapertites cursus*, Spinizonocolpites echinatus and Retidiporites magdalenensis characterize Cretaceous to Early Tertiary palm province of [26] while the high occurrence of *Spinizonocolpites baculatus* indicate late Maastrichtian age [27,28]. The high occurrence of *Apectodinium homomorphum* and *Homotryblium tenuispinosum* in the analyzed borehole intervals suggest Late Maastrichtian to Early Paleocene age is suggested for Nsukka Formation. The occurrence of *Monocolpites marginatus*, *Retidiporites magdalenensis*, and non-occurrence of *Spinizonocolpites baculatus* in the outcrop samples indicate that Mamu Formation did not penetrate Late Maastrichtian. Thus Early to Middle Maastrichtian age was suggested for Mamu formation.

4. Conclusion

The sedimentologic and Palynological analysis of the studied Out crops and Bore hole samples was used to determine the lithofacies, Palynological Assembly zonation, age and paleoenvironment of the sediments. Lithofacies units identified were clay, Sandy Clay, silt, sandstone, shale and sandy shale facies. Ninety one (91) palynomorphs species were identified in the outcrop samples, Eighty three (83) were Miospores (pollen and spores) and seven (7) were Dinocysts while the borehole samples recorded Fifty five (55) palynomorph species, forty three (43) were Miospores while fifteen (15) were Dinocyst. Clusters analysis were used to establish four (4) Palynological Assemblage zones which are Palynological Assemblage zones 1, 2, 3 and 4. Late Maastrichtian to Early Paleocene age was suggested for Nsukka Formation because of the presence / abundance of *Spinizonocolpites baculatus* with admixture of *Apectodinium homomorphum and Homotryblium tenuispinosum.*

The occurrence of *Monocolpites marginatus, Retidiporites magdalenensis* and non-occurrence of *Spinizonocolpites baculatus* in the outcrop samples suggests that Mamu Formation did not penetrate Late Maastrichtian. Thus Early to Middle Maastrichtian age was suggested for Mamu formation, coastal to shallow marine environment close to mangrove vegetation was suggested for the sampled sediments.

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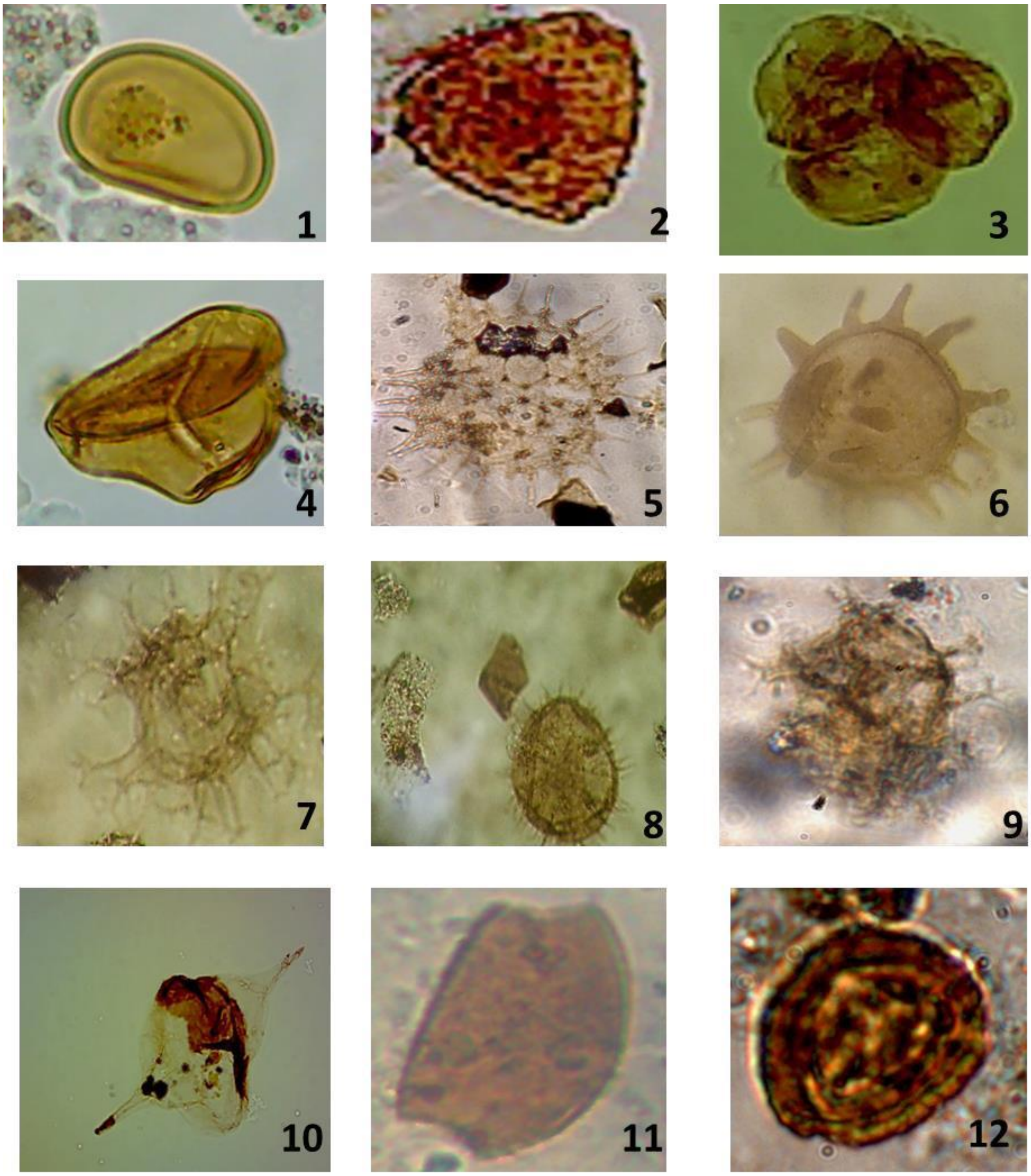

Plate 1. Light photomicrographs of some of the marine and terrestrial palynomorphs present in the studied section (1. *Laevigatosporites sp.*, 2. *Echitriporites trianguliformis*, 3. *Classopollis sp.*, 4. *Cyathidites sp.*, 5. *Polyspharidium subtile*, 6. *Spinozonocolpites baculatus*, 7. *Oligospaeridium complex*, 8. *Operculodinium centrocarpum*, 9. *Spiniferites ramosus*, 10. *Paleocystodinium sp.*, 11. *Retidiporites magdalenensis*, 12. *Cingulatisporites ornatus*)

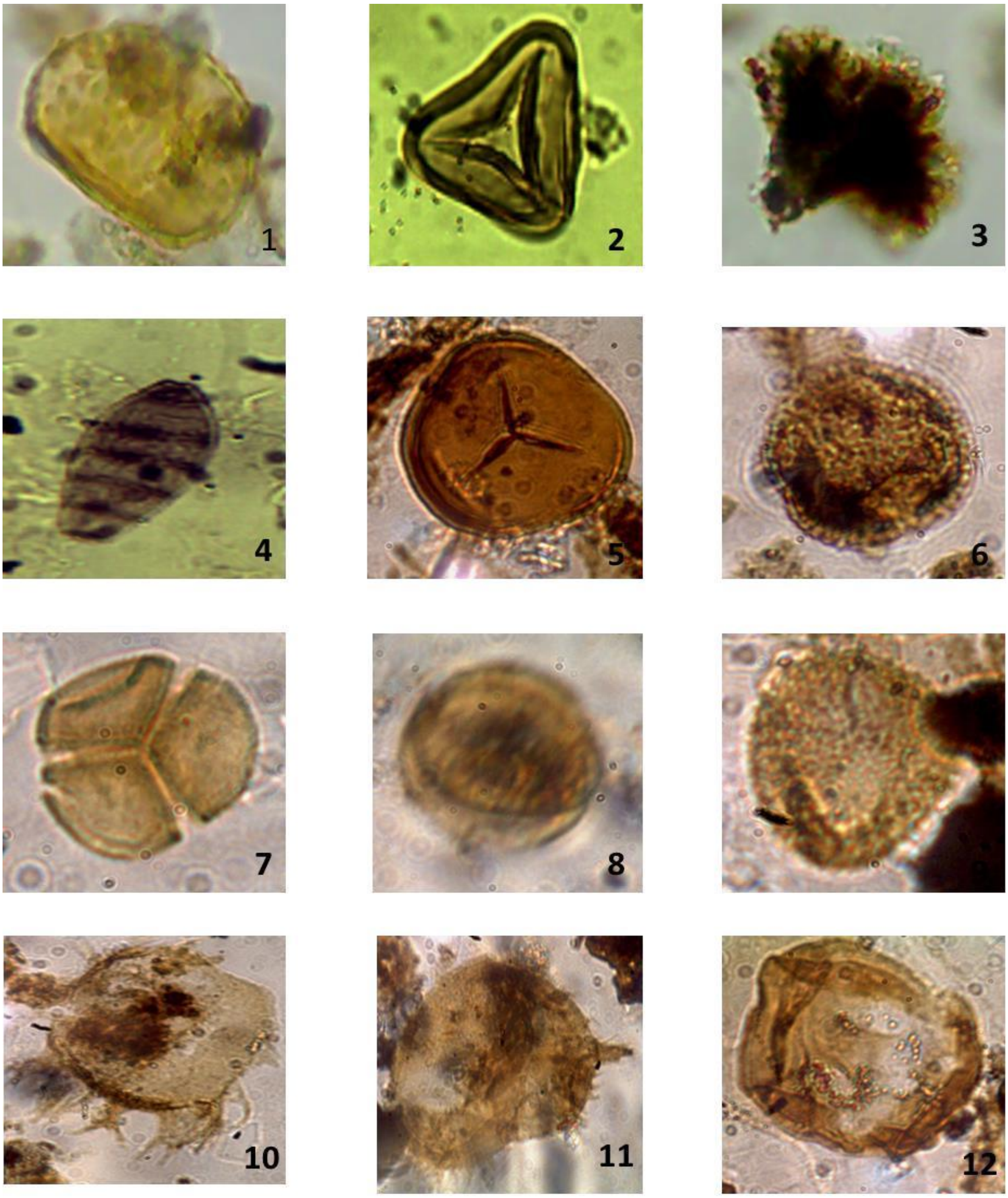

Plate 2. Light photomicrographs of some of the marine and terrestrial palynomorphs present in the studied section (1. *Verrucatosporites sp.*, 2. *Polypodiaceosporites sp.*, 3. *Botryococcus braunii*, 4. *Fungal spore*, 5. *Acrostchum aureum*, 6. *Proxapertites cursus*, 7. *Syncolpites marginatus*, 8. *Proxapertites operculatus*, 9. *Arecipites exilimuratus*, 10. *Glyphyrocysta retiintexta*, 11. *Hystrichogonyaulax cornigera*, 12. *Lejuenecyta sp.)*