PALYNOZONATION, CHRONOSTRATIGRAPHY AND PALEOENVIRONMENT OF DEPOSITION OF THE ALBIAN TO PLIOCENE SEDIMENTS OF THE NZAM- 1, UMUNA- 1 AND AKUKWA- 2 WELLS ANAMBRA BASIN, SOUTHEASTERN NIGERIA

BY

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ABSTRACT

Anambra Basin is an inland sedimentary basin with oil, gas and coal deposits. Previous palynological studies from the basin were mostly from outcrop samples which are insufficient for detailed palynozonation and paleoenvironmental reconstructions. The aim of this study was to investigatedetailed lithostratigraphy, palynozonation and paleoenvironments of the sediments from Anambra Basin.

Ditch cutting samples from Nzam-1 (390-3672 m), Umuna-1 (24-2310 m) and Akukwa-2 wells (2935-3653 m) were collected for lithological reconstruction and palynological analyses.Two hundred and twenty-six samples were prepared for palynological analysis by treating samples with sixty percent hydrofluoric acid, sieved with 5 μm nylon mesh and the residue separated with zinc bromide. The treated residues were then oxidised with nitric acid and neutralised with potassium hydroxide to form macerals. The macerals were subsequently mounted on glass slides. The prepared slides were then studied under stereoscopic microscope for pollen, spores, dinoflagellates, algae, fungal spores and microforaminiferal wall linings. Palynomorph abundance and diversity were used to identify maximum flooding surfaces (MFS) and sequence boundaries (SB).

Shale, sandstone and siltstone with their heteroliths, intercalated gypsum and strongly diagenised iron shale were the identified lithological units. The lithogical units varied across the wells except the lower partswith correlatable shaly units. Ten correlatable palynological zones were established including *Forma PO 304 Lawal* zone 1, (Albian-Lower Cenomanian); *Cretacaeiporites* spp. acme zone 2, (Upper Cenomanian-Turonian); *Zlivisporitesblanensis* zone 3, (Coniacian) and *Milfordia* spp. acme zone 4, (Campanian). Other recognised biozones were *Foveotriletes margaritae* zone 5, (Lower Maastrichtian); *Longapertites margaritae* zone 6, (Middle Maastrichtian); *Spinizonocolpites bacculatus* zone 7, (Upper Maastrichtian); *Mauritiidites crassibaculatus* zone 8, (Lower Paleocene); *Monoporites annulatus* zone 9, (Middle Eocene) and *Echitricolporites spinosus* zone 10, (Upper Miocene-Pliocene age). In Umuna-1 well, palynological zones 3, 5 and 6 were missing; suggestive of more than one episode of faulting and folding associated with tectonic activity in the basin. Lithostratigraphy sequences varied in the basin and were non-correlatable except at the Albian age stratigraphic interval.This suggested widespread marine inundation in the basin duringAlbian period. The palynological zones ranged from Albian to Pliocene and the sediments were deposited in fluviatile to marine environments.Sequence stratigraphy analysis indicated six sequences of events characterised by five SB and eight MFS.

The Anambra Basin sediments have varied lithology with distinct palynozones that could be used for paleoenvironmental reconstructions for the oil and gas exploration.

Keywords: Lithofacies**,** Palynological zone, Chronostratigraphy, Paleoenvironment,
Anambra Basin
Word count:388

CERTIFICATION

I certify that this work was carried out by Mr. A. O. Ola-Buraimo in theDepartment of Geology, University of Ibadan

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DEDICATION

This PhD thesis is dedicated to Almighty Allah for making it possible for me to complete the program despite all odds; to my lovely wife (Idiat), my lovely children- Temitayo, Luqman and Damilola; finally to my late parents Honorable and Alhaja M. Ola-Buraimo for fulfilling their dream in me towards attaining this status.

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CHAPTER ONE: INTRODUCTION

1.1 Background to Study

Geological and geophysical exploration for hydrocarbonstarted in Anambra Basin in 1938 by Shell BP which led to thedrilling of wells at Ihuo and over 40 more wells up-to-date by Shell-BP and ELF oil companies through the Cretaceous sections in Anambra Basin. Although, none of these wells was found to contain commercial petroleum accumulation. However, tremendous geologic information was gathered during the exploration activities.

Pioneer efforts led to the discovery of sub-bituminous coals near Udi and later traced to major Coal Seams. Reyment (1965) described the lithologic units in the area and proposed “Mamu Formation” to replace the “Lower Coal Measures”.He also described the sandy part of the upper Mamu Formation as a member of the formation. However, Simpson (1954) recognized it as white sandstone. He studied the Cretaceous succession of parts of Onitsha, Owerri and Benue Province coal fields of Nigeria and was able to propose Asu River Group, Eze-Aku shales, Awgu Ndeaboli, Nkporo shale and others. He based his subdivision and dating on the presence of fossils – ammonites, gastropods, pelecypods and cephalopods.

Many workers carried out sandstone studies in different parts of the basin. Nwajide (1979), Nwajide and Reijers (1997)deduced paleoenvironment of deposition based on textural attributes of the strata. Fluvio-deltaic to fluviatile environment was suggested for Ajali Formation by various workers (Hoque and Ezeque, 1977; Nwajide, 1979; Agumanu, 1993; Nwajide and Reijers,1996, 1997).

Three major depositional cycles were recognised; the Campanian to Eocene cycle, assigned to the Anambra Basin and Afikpo Syncline. Murat (1972) later identified these depositional cycles in Lower Benue Trough. Petters (1978) recognized unconformity surfaces bounding depositional sequences in the Benue Trough. These include Albian-Cenomanian, Turonian-Coniacian and Campanian-Maastrichtian depositional sycles. Several outcropped based studies in the Anambra Basin were carried out by Nwajide (1980), Ladipo (1985),and Agagu *et* *al.*(1986). They showed that the depositional environments of the sediments range from tidal to marginal marine settings.

Murat (1972) posited that the sedimentary fills of the southern Nigeria Basins were controlled by three tectonic phases and epeirogenic movement which resulted in major transgressive-regressive phases. Benue-Abakaliki Trough was formed during the first tectonic phase (Albian) and filled by sediments of three major cycles. The second phase causedfolding and upliftment of the Benue-Abakaliki fold belt and resultant subsidence of the Anambra Basin filled by two sedimentary cycles. Niger Delta Basin was formed during the third phase (Upper Eocene).

However, except the work of Reijers (1996), less emphasis was made on detail stratigraphy, sequence stratigraphy and subdivision of these sequences into systems tracts. Nwajide and Reijers (1996a and b), noted that the Post–Santonian fill in the Anambra Basin is bounded at the base by the Santonian (83ma) and at the top by Eocene (38.6ma) unconformities. The sedimentary fill they regarded as second–order cycles (Ca 44Ma) composed of two transgressive-regressive parasequence pairs reflecting relative sea level fluctuations.

The amount and quality of organic matter in the Upper Cretaceous source rocks and quality of organic matter of the Lokpanta oil shale using infrared spectroscope (IR) was investigated. The organic geochemical study of the basin was widelystudied towards determining the hydrocarbon potential and petroleum type likely to be generated by the source rock (Avbovbo and Ayoola, 1981; Akaegbobi, 1995; Akaegbobi and Schmitt, 1998; Akande and Erdtmann, 1998; Akaegbobi *et al.*, 2000).

Notable workers including Reyment (1965), Petters (1978, 1979 and 1980), and Lawal (1982), Lawal and Moullade (1986) carried out biostratigraphic studies of various units of the Benue Trough. Microfossil studies of the Eze-Aku Formation at the Nkalagu quarry was carried out by Fayose and De Klasz (1976); formaminifera forms such as*Heterohelix*sp.,*Hedbergella*sp., some Ostracode genera such as *Brachythera*, *Doxythorida* and *Paracypris* were used to inferenvironment of deposition of sediments.

The Anambra Basin is one of the onshore sedimentary basins in Nigeria. The stratigraphy of the basin was described to contain Post-Santonian sediments in contrary to adjacent sedimentary basins, thus, the research study was intended to evaluate the lithostratigraphy and chronostratigraphy of Nzam-1, Umuna-1 and Akukwa-2 wells through palynological tool. The choice of the 3 wells was predicated on the deepest wells in the basin, wells with complete suite of samples for entire stratigraphic well depth, strategic location of the wells whereby they are well separated-out in such a way that they are fairly distanced from well studied areas. They could as well depict the vertical and lateral variation in the lithofacies and palynofacies assemblages. The total depth variation of the wells was to suggest the structural pattern of the basin.

The Nzam- 1 well is not the deepest but a complete well in terms of sample availability from the top to the total depth (TD), thus, it was used as the reference well for this study. The Akukwa-2 well was also selected based on its strategic location in the eastern side of Nzam-1 well which is very deep; though the samples supplied by the Geological Survey Agency were not complete to the upper part of the well. The Umuna- 1 well is relatively shallow compared to the other two wells; located in the southern part of Akukwa-2 well; consists of complete sequence of samples and its depth ranges from 24-2310 m.

The evolution of the region was based on the fact that Abakaliki, Afikpo Syncline and Benue Trough contain Middle Cretaceous sediments, while Anambra Basin is exclusively Late Maastrichtian (Post-Santonian) in age. Therefore, this study was to elucidate the theory of exclusive post-Santoanian age sediments for Anambra Basin. Hence, both sedimentological and palynological studies were carried out in order to unravel the chronostratigraphy and palynozonation problems in order to determine the age of the oldest sediment present in the Anambra Basin and to profer solutions to the conflicting ages given by ealier reseachers.

Lithological description carried out was based on textural parameters, post depositional diagenetic effect, fossil content, accessory minerals and other important features present in the sediments. Palynological study involved preparation of the samples for palynomorph contents such as pollen, spores, dinoflagellates, algae, fungal, non-pollen palynomorphs(NPP) and other forms that are stratigraphically significant.

1.2 Justification for the Research

Evaluation of literature on biostratigraphic works in general and palynological studies in particular on the Anambra Basin shows that there are research gaps in the studies which include the facts that:

- Earlier biostratigraphy works in the basin were based on foraminifera studies.
- Most of the research studies were carried out on outcrop (surface) samples.
- Most of the research works on foraminifera studies lack marker fossils, especially planktonic forms.
- Where marker forms are present, they are of wide age range.
- In most cases especially in Cretaceous sediments both foraminifera and nannoffossil tools are not suitable and reliable for use because commonly 2/3 of the samples are usually barren of fossils.
- None of the earlier works done depict palyno-chronostratigraphic sequence of the basin and finally
- There is no detail report on the palynological zones

In this regard, the study was justified to be carried out for the following reasons:

- Detail evaluations of the subsurface stratigraphy of the thick sedimentary piles in the basin have not been studied and generated
- Most of the earlier biostratigraphic works in the basin were based on foraminifera and ammonoid studies with few studies on palynology.
- Research studies carried out were mainly on outcrop samples rather than on deep subsurface fresh samples from exploratory oil wells.
- Some of the marker fossils used for relative age calibration were of long ranged and sometimes benthonic foraminifera instead of planktonic forms; where planktics were present most of the fossils are long ranged. In most cases two-third of acquired samples were barren, thereby rendering chronstratigraphy study difficult.

- Earlier formation ages were determined based on identification of gastropods, cephalopods, ammonites and pelecypods instead of modern biostratigraphy age dating tools like palynology, foraminifera and nannofossil studies.
- Most of the geologic ages established for some of the formations are contradictory based on weak marker fossils used
- To date, no sufficient work on chronostratigraphy framework based on palynology for Anambra Basin has been generated compare to adjacent basins like Niger Delta (After Evamy *et al.*, 1978), Benue Trough (After Lawal and Moullade, 1986).

1.3 Scope of the Research

The scope of the research is to make use of ditch cutting samples from three deep wells in Anambra Basin, Nigeria for Lithological and palynological studies; further to correlate results obtained with existing foraminiferal results where available and applicable.

1.4 Objectives of study

The aim of this study is to carry out lithological description and palynostratigraphic studies on the Nzam-1, Umuna-1, and Akukwa-2 wells located in Anambra Basin.

The objectives of study are to:

- Carry out lithofacies analyses and generate lithostratigraphy of the wells.
- Establish palynozones for the three wells.
- Establish chronostratigraphy for the wells that may represent and serve as palynological zonal scheme for Anambra Basin.
- Determine the paleoenvironment of deposition of sediments in the wells.

1.5 Location of studied wells

The Nzam-1 well is located in Anambra State within the Anambra Basin, situated in the southeastern part of Nigeria with coordinates 6°27'9.79"N and 6º43'35.95"E, within OPL 447. The Nzam – 1 well is about 60 Km from Onitsha town, southeastern, Nigeria (Figure 1.1). The Umuna-1 well has coordinates 5º 45'Nand 7º15' E within OPL 447. The Akukwa-2 well has coordinates of 6º15'N and 7º10'E within OPL 907, Anambra Basin, southeastern Nigeria (Fig. 1.1)

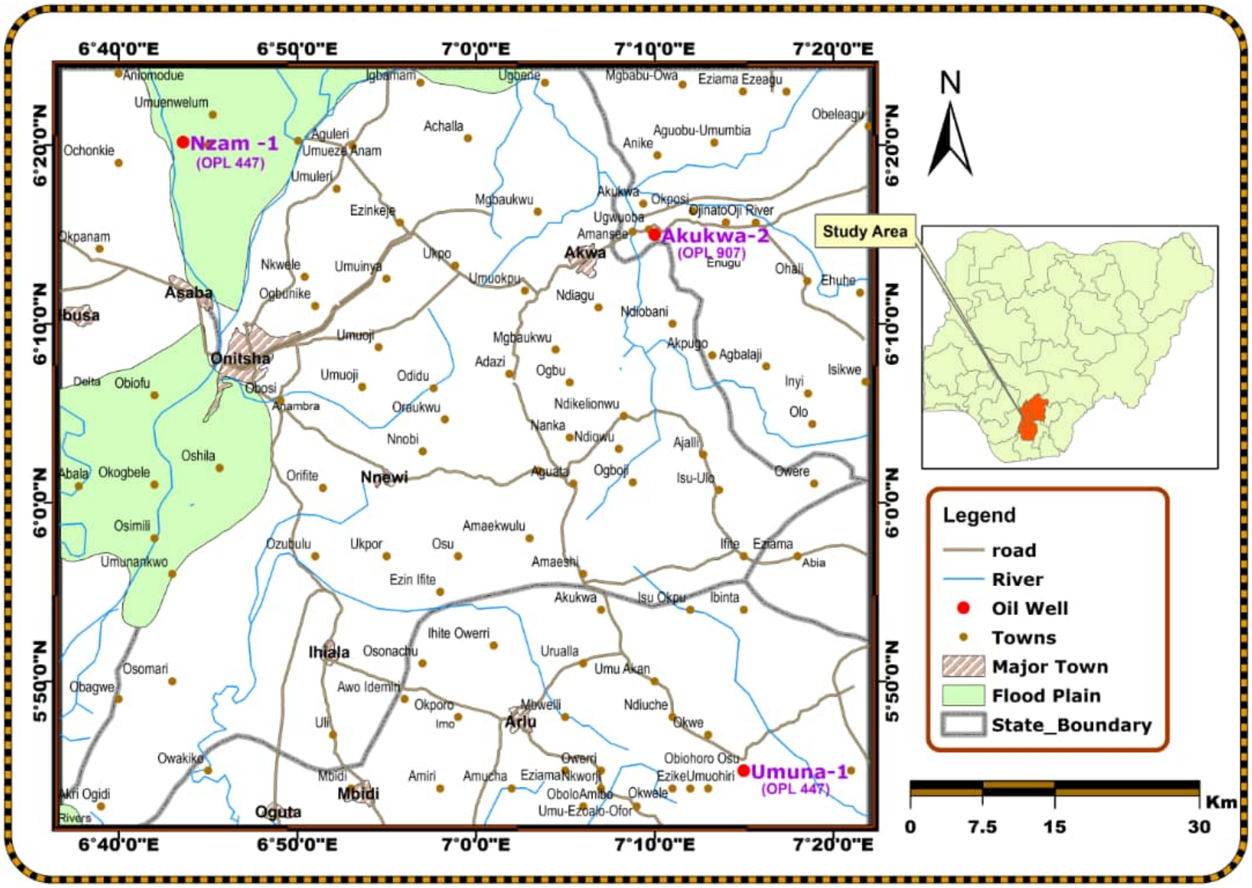


Figure 1.1. Map of Nigeria (inset) showing map of southern Nigeria with the location of Nzam- 1, Umuna-1 and Akukwa-2 wells studied and situated in Anambra Basin

CHAPTER TWO:LITERATURE REVIEW

2.1 Stratigraphy of Anambra Basin

The stratigraphic sequence of the Anambra Basin has been widely discussed by several workers including Reyment (1965), Murat (1972), Dessauvagie (1975), Agagu *et al.* (1986), Ladipo (1986), Nwajide, (1990), Ehinola (2010), Nton and Bankole (2013). Among notable works was that of Umeji (1985) on the subtidal shelf sedimentation of the Turonian Eze-Aku Formation in the Nkalagu area, southeastern Nigeria. Umeji (1988) also studied the trace fossils in the Eze-Aku Formation, Anambra Basin, Nigeria. Lawal (1991) dated the Eze-Aku Formation to belong to Late Cenomanian-Turonian based on palynological content. Umeji (1993) studied the hummocky cross-stratification in the Turonian Eze-Aku Sandstone and related its deposition to tidal effect.

Other palynological studies include the works of Umeji (2003 and 2005); Umeji and Nwajide (2007); Umeji and Edet (2008); Umeji (2011) and Ogala *et al.,* (2009). Umeji (2013) classified the sedimentary succession in Benue Trough, grouped them into Asu-River Group and dated it Neocomian-Cenomanian age. The date given to Asu River Group is in contrary to the work of Ola-Buraimo and Akaegbobi (2013b) who assigned Albian to Early Cenomanian age based on palynological contents such as *Forma PO 304 Lawal*, *Afropollis jardinus, Cretacaeiporites* pollen, *Steevesipollenites binodosus, Galeacornia* sp.and *Hexaporotricolporites emelianovi* deposited in marginal marine, continental and open marine systems. Ola-Buraimo (2013a) dated the Eze-Aku Formation as Upper Cenomanian to Turonian age based on the occurrence of diagnostic palynological marker forms. The Awgu Formation that overlies the Eze-Aku Formation was dated Coniacian in the Nzam- 1 well on the basis of palynomorph contents (Ola-Buraimo, 2013b).

Sequence stratigraphy of Nkporo Shale showed that both the Nkporo Shale and Afikpo Sandstone were deposited by highstand systems tract in near shore environment (Umeji, 2010) Umeji (2011) also studied the palynofacies and palaeodepositional environment of the Campano-

Maastrichtian Nkporo sediments exposed around Leru in Anambra Basin, Nigeria. However, Chiaghanam *et al.,* (2012) assigned Late Campanian age to Nkporo Shale at Leru and Early to Middle Maastrichtian to Mamu Formation at Uturu while Nsukka Formation at Ihube was dated Late Maastrichtian. Ola-Buraimo and Akaegbobi (2013a) studied the Nkporo Shale which overlies the Awgu Shale stratigraphically to be Campanian to Lowermost Maastrichtian age based on palynological contents.

Aja and Igwe (2015) dated Nkporo Shale to be Late Campanian to Maastrichtian, while the environment of deposition was described to be open marine to estuarine. In the work of Adebayo *et al.* (2015), Nkporo shale located at Orekpekpe-Imiegba area was dated Early-Late Campanian age while sequence stratigraphy study classified the sequence into TST which suggested inundation of the marine responsible for deposition of Nkporo shale in the Early Campanian. A more detailed study was carried out on a section of Ubiaja-1 well whereby the section was delineated into Eze-Aku dated Turonian; Awgu Formation, dated Coniacian to ? Santonian and Nkporo Shale dated Early Campanian; deposited in marginal marine environment (Ola-Buraimo *et al.,* 2016).

Ogala *et al.* (2009) studied Mamu Coal facies which overlies the Nkporo Shale for palynological age dating and paleoenvironment of deposition. The age of the Mamu coal was put at Middle to Upper Maastrichtian and suggested to have been deposited in marine to brackish environment. The work of Chiaghanam *et al.* (2012) put the age of Mamu Formation at Middle Maastrichtian and suggested shallow marine paleoenvironment of deposition.

Bankole and Ola-Buraimo (2017) dated the Nsukka Formation to be Late Maastrichtian based on the occurrence of *Spinizonocolpites baculatus, S. echinatus, Constrructipollenites ineffectus, Periretisyncolpites* sp, *P. giganteus, Foveotriletes margaritae, Syncolporites marginatus, Anacolocidites luidonisis, Mauritiidites crassibaculatus, Retistephanocolpites williamsi, Proteacidites dehaani, Echitriporites trianguliformis, Proxapertites cursus, Retidiporites magdalenensis, Retitricolpites gigeoneti,* and *Araucariacites* sp.; while the paleoenvironments of deposition vary alternately from marginal marine to continental setting based on the presence of land-derived miospores and dinoflagellates. Imo Formation overlies the Nsukka Formation; it was dated to belong to Selandinian to Aquitanian based on abundant ocurrence of dinoflagellates (Umeji, 2016).

Umeji (2012) used the presence of *Podocarpus millanjianus* to date Ogwashi-Asaba Formation as Pleistocene age. However, the same Ogwasi-Asaba Formation was dated to be of Late Miocene to Pliocene based on dinoflagellate constituents such as *Selenopemphix nephroides, Multispinula quanta, Tuberculodinium vancampoae, Polysphaeridium zoharyi* and *Impagidinium* spp.; accompnied with diagnostic pollen forms such *as Nymphae lotus, Elaeis guineensis, Cypracaepallis* sp.*, Podocarpus mullanjianus, Retistephanocolpites gracilis, Arecipites* sp.and *Echitricolporites spinosus* (Ola-Buraimo and Akaegbobi, 2012).

Table 2.1. Chart for Early Cretaceous strata in southeastern Nigeria (After Nwajide, 1990)

AGE		ABAKALIKI-ANAMBRA BASIN	AFKPO BASIN
M.Y 30	Oligocene	Ogwashi-Asaba formation	Ogwashi-Asaba formation
54.9	Eocene	Ameki/Nanka formation/ Nsuebe sandstone(Ameki group)	Ameki formation
65	Paleocene	Imo formation Nsukka formation	Imo formation Nsukka formation
73	Maastrichtian	Ajali formation Mamu formation	Ajali formation Mamu formation
83	Campanian	Nkporo Oweli formation/Enugu shale	Nkporo shale/Afikpo sandstone
87.5	Santonian	Agbani sandstone/ Awgu shale	Non-deposition/erosion
88.5	Coniacian		
	Turonian	Eze Aku Group	Eze Aku Group (include Amasiri sandstone)
93 100	Cenomanian-Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Group	
PRECAMBRIAN		BASEMENT COMPLEX	

CHAPTER THREE: METHODOLOGY

3.1 Sample collection

Ditch cutting samples of three wells- Nzam-1, Umuna-1, and Akukwa-2 wells were collected from the Nigeria Geological Survey Agency, Kaduna. Limitations encountered were the inavailability of composite logs and geologic map of the location of the three wells. A total of one thousand and thirty two (1032) samples were collected and lithologically described. Five hundred and fifty six (556) samples were lithogically described for Nzam-1 well, two hundred and seventy two (272) samples for Umuna-1 well and two hundred and four samples (204) samples were lithologically described for Akukwa-2 well. These were carried out on the three wells inorder to investigate the lithologic sequence and palynological contents. The samples were treated under three aspectsin order to achieve the desired objectives. The aspects include:

- Lithological description
- Palynological slide preparation and
- Palynological slide analysis

3.2 Lithological description

The samples were described using standard laboratory method. The samples were arranged serially in order of depth. Samples from the wells were observed under scientific binocular microscope.They were described by considering their characteristics such as composition, colour, texture, fossil content, sand /shale ratio; presence of calcite or evaporates, presence of accessory minerals, authigenic mineral such as glauconite or pyrite and other noticeable forms that might be important for sedimentological interpretation

3.3 Palynological slide preparation

The collected samples were treated for chemical preparation in the laboratory. The samples were selected at varyinginterval of ninety feet (27 m) except where samples were not present sequencially; next available sample depth was then selected for use. Therefore, one hundred and thirty two samples (132) were prepared into palynological slides for Nzam-1 well; fifty five samples (55) for Umuna-1 and thirty nine samples (39) for Akukwa-2 well. Thus, a total of two hundred and twenty six samples were prepared in the Palynology Laboratory of Archeology

Department of University of Ibadan for palynological studies. The selected samples were subjected to various standard laboratory palynological preparation procedures as follows:

3.3.1 Stage 1- Treatment with dilute HCl

The first stage under chemical treatment is addition of dilute hydrcchloric acid (HCl) to the samples in plastic beakers in order to eliminate the effect of carbonate presense in the samples.

3.3.2 Stage 2- Digestion

The next stage after treatment with dilute hydrochloric acid is called digestion stage. This is a fundamental process that leads to palynological slide preparation. At this stage 60 % grade of hydrofluoric acid (HF) was added to the samples in the fume cupboard. The samples were soaked overnight, stirred intermittently with plastic rod in order to achieve complete digestion. After overnight soaking, the supernatant liquid was decanted gently without pouring the sample along; then, samples were rinsed with distilled water and ready for sieving.

3.3.3 Stage 3- Sieving

A 5µ mesh was used to sieve the rinsed samples in order to remove presence of clay particles in them. This was done towards achieving clean slides that will be easy for analysis and able to produce clear photos that are not obscured by clay particles.

3.3.4 Stage 4- Oxidation

This stage involves the use of nitric acid (HNO_3). Oxidation stage is the lightening of pollen and spores, few drops of the nitric acid were put in the residue for bleaching of the macerals. The reaction was stopped by addition of potassium hydroxide (KOH).

3.3.5 Stage 5- Heavy liquid separation

This stage involves the addition of heavy liquid such as zinc chloride ($ZnCl_2$) with specific gravity of about 2.0 - 2.1g /cc. The heavy liquid was added to set of test tubes containing the residue which were measured to the same level before they were placed in the centrifuge. However, caution was exercised by making sure that the heavy liquid in the test tubes were of equal volume, otherwise, the centrifuge machine would become unbalanced, thus, leading to breakage of the test tubes or spillage. The centrifuge was adjusted to 2000 revolution/min. for 15minutes towards achieving effective liquid phase separation.

The organic matter lighter than 2.1g /cc floats while, the residue heavier than 2.1 g /cc settled at the bottom of the tubes. Floated material was carefully decanted into clean-labeled test tubes without allowing mixture with the heavy materials at the bottom of the tube. The collected organic residue was rinsed with distilled water.

3.3.6 Stage 6- Alcohol treatment

Ethanol liquid (Alcohol) was finally used to rinse the collected residue before mounting the slides for permanent slide preparation. The essence of alcohol liquid is to allow removal of water, which might become trapped with the organic residue.

3.3.7 Stage 7- Mounting of slide

The alcohol-rinsed organic residue was dropped on a cover slip placed on warm temperature hot plate. The residue was spread on the cover slip and allowed to dry. Enough drops of DPX mountant liquid was put on the glass slide; spread to about the size of the cover slip. The cover slip was quickly placed on the glass slide, pressed gently with tip of finger in order to expel likely trapped oxygen. Slides were allowed to dry for about 1-2 days, ready for microscopic analysis.

3.4 Palynological slide analysis

The prepared palynological slides were analysed petrographycally using Will microscope and attached Nikon Coolpix 13.7Mp with an in-built GPS P6000 model camera for photography of pollen, spores, dinoflagellates, algae, fungal and microforaminiferal wall linings. Absolute counts of palynomorphs were plotted on checklist which shows the appearance and distribution of important palynomorphs with depth. Other statistical parameters were derived from generated analysis sheets for delineation of paleoenvironment of deposition.

3.5 Data gathering

Data was collected from the analysed palynological slides. This was achieved by noting the total count of each species encountered. In order to determine the age of the sediments, assemblages of fossils recovered were noted both qualitatively and quantitatively. For this study Akukwa -2 well served as a control well section for the other two wells (Nzam-1 and Umuna- 1) because it is the oldest well among the three wells studied. However, observed pollen, spores and organic wall microplankton under the microscope were compared with published illustrated forms materials within the country and other regions in West Africa, Africa, South America, North America, Europe and other parts of the world.

3.6 Qualitative study

This involved the determination of the reliability of the sample. In this study, the samples are reliable because they are not surface samples that might have surffered degradation and contamination. The data collected were enough for comparism and the fossils are fairly well preserved in most instances. Other qualitative parameters noted are the vertical range of the floral in terms of evolution and extinction, morphological variation within the species and quantitative occurrence of the species. Therefore, a checklist was made to show the order of appearance of the pollen, spores and microplanktons with depth.

3.7 Quantitative study

Palynological study also involved quantitative account of palynomorphs encountered during slide analysis. An account of each taxon is given in absolute number. The quantitative data was presented in terms of:

- Each taxon present.
- Total number of palynomorphs present
- Total number of diverse forms
- Total number of miospores
- Total number of dinoflagellates
- Total number of algae
- Total number of fungi and
- Total number of chitinuous microforaminiferal wall linings.

The importance of this exercise is to give the estimate of the dominant forms present. Ecological changes may as well be responsible for the relative change in composition of the floral assemblage; increase or decrease in species frequency.

3.8 Data presentation

The data generated from the slide analysis were presented in tables, charts and graphs for better understanding. The data were plotted on checklist using stratabug. However, presentation of the data in bar or pie charts are pictorial but these are only appreciable in the case of plot of depth against total palynomorph recovered per sample, diversity of palynomorph, and relative frequency of angiosperm to gymnosperms in the well sections analysed.

3.9 Interpretation of data

Data interpretation is the essence of the whole exercise. The identified taxa were compared with well established assemblages of species that indicate stratigraphic importance in terms of age, paleoenvironment and ecology. The sequential depth stratigraphic dating will indicate the chronostratigraphy of the well and unveil other geologically important features such as unconformity, diastem, and faults as the case may be. Ranges of different taxa, their stratigraphic time equivalence were used for correlation.

CHAPTER FOUR: RESULTS, INTERPRETATION AND DISCUSSION

4.1 Lithological and Palynological results

Two major forms of analyses such as lithological description and palynological analysis were engaged. The data obtained from them were presented as lithologic description data and palynological analysis data.

4.2 Lithological description data

The lithological description of the wells- Nzam- 1, Umuna- 1 and Akukwa- 2 wells were based on their characteristics such as composition, colour, textural parameters such as grain size, roundness and sorting. Post depositional effects are also considered along with sand to shale ratio, presence of carbonate or evaporate, presence of accessory minerals, authigenic minerals such as glauconite or pyrite and other noticeable forms that are stratigraphically important were taken into consideration during the analysis. Nzam-1 well has a total number of five hundred and fifty six (556) samples; Umunah- 1 well has a total of two hundred and seventy two (272) samples, while the Akukwa- 2 well has a total of two hundred and four (204) samples that were lithologically examined.

The results of the lithologically analysed samples for the 3 wells were summarized and tabulated in Tables 4.1, 4.2 and 4.3 for Nzam- 1, Umunah- 1 and Akukwa- 2 wells respectively.

Table 4.1. Summary of the lithologic description of Nzam-1 well

Depth (m)	Lithology	Description
390	Shale	Light grey fissile shale, whitish-pinkish sand grains; fine to coarse, angular to rounded, rrarely ferrugunised
457	Sandy shale	Light grey fissile sandy shale, fine to coarse, angular to rounded in shale, well sorted; slightly ferruginised
475	Shale	Light to dark grey fissile shale, rarely ferruginised
1109	Sandy shale	Fine to medium sand grains, angular to subangular in association withfissile dark shale; rarely ferruginised
1116	Shale	Dark grey fissile shale
1423	Siltstone	Milky-brownish siltstone, stongly lithified and well sorted
1448	Gypsiferous shale	Black coloured fissile shale, associated with milky colloured gypsum
1506	Sandy shale	Medium to coarse sized grains, moderately sorted sands with dark fissile shale
1511	Gypsiferous shale	Dark grey fissile shale in association with gypsum
1905	Shaly gypsum	Dark grey fissile shale with greater amount of gypsum
1932	Gysiferous shale	Lower quantity of gypsum to shale
2106	Shaly gypsum	Same as above with higher quantity of gypsum to shale
2906	Shale	Dark grey fissile shale

Table 4.2. Summary of the lithologic description of Umuna-1 well

Depth (m)	Lithology	Description
24	Shale	Black fissile shale, slightly ferruginised
524	Sandy shale	Black fissile sandy shale
536	Shale	Black fissile shale, rarely ferruginised
774	Sandy shale	Whitish –pinkish fine to coarse angular to subrounded , moderately sorted sand grains in association with dark grey fissile shale
786	Silty shale	Black fissile silty shale; whitish coloured silt particles; very well sorted
841	Shall sand	Whitish shaly sand, fine to very coarse, angular to rounded, moderately sorted sand
861	Sitstone	Light grey to whitish siltstone. Fine to medium, angular to subrounded, well sorted
863	Sandstone	Well sorted, lithfied sandstone
927	Sandy shale	Black fissile sandy shale
1058	Shaly micaceous iron	Reddish brown, fissile shaly micaceous iron grains
1064	Ferruginised shale	Reddish brown, strongly ferruginised, rarely pebbly with sand grains
1180	Shale	Black fissile shale, rarely ferruginised
1259	Shaly siltstone	Black fissile shaly siltstone. Whitish siltstone, very well sorted, rarely ferruginised
1283	Silty Shale	Black fissile silty shale; well sorted siltstone, rarely ferruginised
1375	shale	Black fissile shale
1698	Ferruginised shale	Black to reddish ferruginised shale
1844	Micaceous ferruginised shale	Black to reddish brown fissile micaceous ferruginised shale
1875	Ferruginised gypsiferous shale	Black to reddidh brown ferruginous gypsiferous shale
1893	Ferruginised shale	Black to reddish brown ferruginised shale
2310	Shale	Dark grey fissile shale

Table 4.3. Summary of the lithologic description of Akukwa-2 well

Depth (m)	Lothology	Description
2935	Shale	Dark grey fissile shale
3039	Gypsiferous shale	Dark coloured fissile shale associated with light coloured gypsum
3042	Shale	Dark coloured shale
3653	Shale	Black fissile shale

4.3 Palynological analysis data

Palynological analysis was carried out with the use of scientific linear binocular microscope on the three wells selected for the study. Point counts of encountered taxa or species were recorded in terms of abundance and diversity. The data obtained are presented below in Figures 4.1, 4.2 and 4.3 for Nzam- 1, Umuna- 1, and Akukwa- 2 wells respectively. The data obtained were in-turn computed on Stratabug software spread sheet to indicate the order of appearance of palynomorphs with depth and summary of palynomorph abundance, palynomorph diversity, palynozones, their characteristics, deduced ages and their associated paleoenvironment of deposition.

4.3.1 Summary of the Palynological analysis of Nzam- 1 well

Summary of palynological analysis of the Nzam- 1 well is presented as distribution chart in Figure 4.1 below. Here for each depth analysed are the list of palynomorphs recovered and their respective abundanceand other important parameters .

4.3.2Summary of the Palynological analysis of Umuna- 1 well

Summary of palynological analysis of the Nzam- 1 well is presented as distribution chart in Figure 4.2 below. Here for each depth analysed are the list of palynomorphs recovered and their respective abundanceand other important parameters .

4.3.3Summary of the Palynological analysis of Akukwa- 2 well

Summary of palynological analysis of the Akukwa- 2 well is presented as distribution chart in Figure 4.3 below. Here for each depth analysed are the list of palynomorphs recovered and their respective abundance and other important parameters.

4.4 Lithologic Description

Lithologic description of the three wells was carried out in the laboratory; detailed results and interpretation of the wells are given below:

4.4.1 Lithostratigraphy of Nzam-1 well

Nzam-1 well ranges in depth from 390-2960 m, containing five hundred and fifty six samples.Six broad lithofacies units were established, made-up principally of shale, sandy shale, siltstone, gypsiferous shale, sandy gypsiferous shale, and shaly gypsum. This was based on the fact that either of the components constitutes more than 10 % of mineral framework of the rock body (Folk, 1974). However, based on non-conventional higher classification refinement, two informal lithologic facies units were recognisedat the lower part of the well section.These include-shale with minor sand grain component and shale with minor gypsum grain content.

Lithologic unit 1 is a dark grey to black coloured fissile shale facies,the shales are rarely ferruginised, mild effervescence on acid test which indicated presence of carbonate mineral like calcite. The unit was found at different levels and occurred in the three formations encountered in the analysed section (Table 4.1). The shale facies is of various paleoenvironment of deposition such as continental, marginal marine and open marine systems. Shale deposits of continental environment are associated with coarse to pebbly sand grains, while those deposited in marginal and open marine are devoid of sand grains or with negligible sand content less than two percent (<2%); with or without gypsum intercalations.

Lithologic unit 2 is sandy shale. It is light to dark grey in colour; sand content is milky to pinkish in colour, medium to pebble in size, subangular to rounded, slightly ferruginised, It occurs mainly in the upper part of the well, at some levels the sand grains vary in size from fine to medium (1110-1113 m).

Lithologic unit 3 is siltstone; it occurs as thin bed and intercalated by shale within the well section. It is milky to brownish in colour, well sorted and strongly lithified. It ranges in depth from 1423-1454 m and constitute part of the Mamu Formation (Table 4.1,Fig. 4.4).

Lithilogic unit 4 is gypsiferous shale; it occurs at various intervals within the well section. It is light grey in colour and at times contain minor sand grains. This facies occurred at about the middle part of the well and make-up fairly thick interval ranging from 1448-1850 m (402 m thick). This facies was dated Middle Maastrichtian in this study and correlable to Mamu Formation. Therefore, Mamu Formation contains evaporite mineral like gypsum unlike coal that it is well noted for in the Anambra Basin.

Lithologic unit 5 is made-up of sandy gypsiferous shale.It is light grey in colour, whitish to milky in colour; sand grainsare medium to coarse, rounded to subangular, moderately sorted in nature. The facies unit 6 is shaly gypsum formed within the gypsum dominated interval but characterised by lower proportion of gypsum to shale (Table 4.1). This facies still forms part of the Mamu Formation.

The informal lithofacies classification is composed mainly of shale with minor sand grain content that varies from 1 to 8% (Table 4.1, Fig. 4.4). The shale is light to dark gray in colour, fissile in nature.The associated sand grains are brownish to milky coloured, range in size from coarse to small pebble, moderately to poorly sorted and slightly ferruginised. The lithofacies unit 6 is more prevailent at the lower part of the well section (Table 4.1). It was suggested that unconformity surfaces may be present within this lithofacies especially those associated with lag particles. The paleoenvironment of this unit was also suggested to belong to fluviatile setting probably prograding delta (Fig. 4.4).

Lithologic unit 7 is composed of shale with minor percentage of gypsum. The gypsum content varies from 5-8% and the facies is concentrated between intervals 2744 to 2759 m (Table4.1). The gypsum is milky in colour and shows no effervescence on acid test. The sediment was suggested to be deposited in shallow marine environment. This was based on its constituent that is evaporitic and known to form in marginal marine environment. It was as well based on palynological inference showing occurrence of microplankton which are dominated by peridinacean forms, known with marginal marine system (Fig. 4.4).

Depth (m)	Age	Lithology	Description	Paleo-environment
370 3672	Pliocene Albian	_-_----_- _-_-_-_- _-_-▪▪▪_- _▪▪-_-_-_- _-_--_.- ._-_-_-_- ▪▪▪▪▪▪▪▪▪▪▪▪▪▪ ▪▪▪▪▪▪▪▪▪▪▪▪▪▪ _--__-__- ___--__-_-- _---_--__-_- __-----_- Gp_-_------_- ___--_-_-_- _-_-_--__- Gp_--____- ___-_Gp_ ____-_-_- _-_Gp-_- _-_-_-_- _-_-_-_- _-Gp_-_- _-_-_-_- _-_-_Gp- _-__--_-_-_- ___-_-sst_- _sst-___-_- _-_-sst- ____-_-___- _-_-_-_- _-sst_--_-- _-_--_-_-_- _-_-_sst- _-_--_-_- _-_-_--_- _-_-_-_-- _-_--_-_- _-_-_-_-_- _-__--_---_--- ---_--_--_----- _--	Black fissile shale Black fissile shale intercalated with gypsum Black fissile shale with minor sand grians Black fissile shale	Open marine Continental Open marine Marginal marine Continental Open marine Marginall marine

Figure 4.4. Litho-log and paleoenvironment of Nzam-1 well

4.4.2 Lithostratigraphy of Umuna-1 well

The lithostratgraphy of Umuna-1 well at the lower section has similarity with that of Nzam-1 well by containing basal shale at 1689 m in Umuna- 1 well. The well section also contains sandy shale, siltstone and sandstone facies. The lithofacies show the same property with those described for Nzam-1 well. The lowermost part of the well is defined by intercalation of gypsum and shale leading to heterolith of various degrees depending on the dominance of either the shale or gypsum (Fig. 4.5, Table 4.2).

However, interval 952-1990 m is composed of ferruginised shale (Fig. 4.5, Table 4.2). The facies was formed as a result of post depositional diagenesis process or due to hydrothermal mineralisation of iron within the basin.

4.4.3 Lithostratigraphy of Akukwa-2 well

The lithostratigraphy of Akukwa-2 well (2935 to 3261 m) is composed of shale. The shale facies is dark gray to black, almost monotonous throughout the well section with minor sand grains at few intervals. The shale is intercalated with gypsum at depth 3042 m (Fig. 4.6, Table 4.3). Differentiation of the sequence into various formations was difficult except through formation ages derived from palynological means.

Depth(m)	Age	Litho-log	Description	Paleo-environment
24	Late Miocene	--____----___----___-- __--___--- ___▪▪▪___▪▪▪___---___- ____--_-___---___----- ___---_---__-__-Fe___--- --___▪▪▪___▪▪▪_---___-- ▪▪▪_---__-▪▪▪▪__--___-Fe- --___--	Black fissile shale	Marginal marine
86		▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪ ▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪ _--__▪▪▪_-__-_▪▪▪__-_- __---_▪▪▪______--▪▪▪_- __-__Fe--_--__-_--_--_-- _-_-_--_-___-_-Fe--_-_-	Silty to sandy sandstone	Continental
1247		_-_-Fe_--_-_-_-_-_-_-- ---_-_---_---_---_-_-_-Fe- -_-▪▪▪__--_--▪▪▪_-_--- ___----▪▪▪_----_-- __▪▪▪▪▪▪_--_-___--_-__-- __---__----Fe--__--___--	Ferruginised shale	
		_-____-__▪▪▪▪_-__--___- -_--___---___----_--__--- ___--__Fe_--___--__--- ___---___-___--_Fe--_- _--___--___---__--__-- ___--___--___--_____---- __-----__--___----__--__- -_____-----___-----__----		Open marine
		__---__-----__----__--- __--__--Fe▪▪▪_--Fe---- ___--Fe--___--__Fe---- __-----__Fe_---Fe---__-- ______---__--Gp__--__-- _)_--______--__--__---- ___---__--Fe_--___---- ___--Fe--___--Fe--__--		Marginal marine
		___--Fe▪▪▪---___--__-Fe- -__--Fe--__--__Fe▪▪▪__-- _---_-Fe_---__--_-__-- Fe--__------_-Gp---__-- __--__--__--Fe--__--__--	Ferruginised sandy shale	
		_--_---Gp----__--_---__-- _---_------Fe---____--Gp- ---_Fe-----__------- ___Gp----__--__------ ___-Gp-----------__---	Gypsiferous shale	
2310	Albian	___---__---__--__--___-- __--__----_-__--__-- _____--__----__---__---__		Marginal marine

Figure 4.5. Litho-log and paleoenvironment of Umuna-1 well

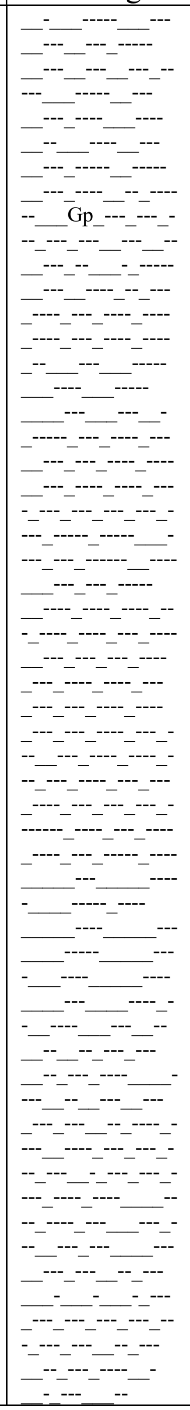
Depth(m)	Age	Litho-log	Description	Paleoenvironment
2935	Early Maastrichtian		Black fissile shale with intercalated gypsum at the upper part	Continental Marginal marine Continental Marginal marine Open marine Marginal marine
3653	Albian			

Figure 4.6. Litho-log and paleoenvironment of Akukwa-2 well

4.4.4 Lithology synthesis

The Nzam-1 well is the second deepest well with complete samples, interval ranges from 113-2906 m, followed by Umuna-1 well; though shallower but with complete well samples ranging from 24-2310 m, while the Akukwa-2 well is the deepest well but samples available ranged from 2935-3261 m.

Comparative lithology shows that the Nzam-1 well is sandy at the upper part but mostly composed of shale at the lower part of the well section (Table 4.1, Fig. 4.4). The Umuna-1 well is composed mostly of ferruginised shale, while the upper part consists of sandstone facies with rare intercalations of gypsum at the lower part of the section (Table 4.2, Fig. 4.5). Akukwa-2 well is generally shaly in nature with minor content of evaporate, absence of mineralised iron (Fe) and intercalation of gypsum at the upper part of the analysed well section (Table 4.3, Fig. 4.6).

Lithologies of the three wells vary tremendously and these conforms with the dynamism surrounding the lithofacies variation in the Anambra Basin. This phenomenon might be due to factors such as different depocenters responsible for the sedimentation in the basin, mineral composition, provenance and structural style of the basin. Therefore, the basal section of the three wells were correlatable because they are shaly in nature due to marine inundation during the Middle Cretaceous as a result of rifting. The silty and sandy facies recognized in Nzam-1 and Umuna-1 wells were also correlatable lithologically (Figs. 4.4 and 4.5) while other sections of the three wells were not correlatable except through palynological tool employed in this study.

Based on the established palynonological zones in this study, stratigraphic boundaries were erected for the encountered formations which helped in delineating and determining estimated formation thicknesses in the three wells (Table 4.4). The Table 4.4 shows that for every formation encountered in the wells they have different thicknesses which was suggested to be due to structural control and sea level changes. It was noted that during the Pre-Santonian, formations such as Eze-Aku Formation in the Umuna-1 well have thickness value of 509 m compared to Akukwa-2 well with 61 m.

Table 4.4. Formation thicknesses in Nzam-1, Umuna-1, and Akukwa-2 wells in Anambra Basin, southeastern Nigeria

Formation	Nzam-1 well (Thickness in meters)	Umuna-1 well (Thickness in meters)	Akukwa-2 well (Thickness in meters)
Ogwashi/Asaba	277	305	No Data
Ameki	128	152	No Data
Imo	329	43	No Data
Nsukka	525	Not Present	No Data
Ajali	Not Present	Not Present	No Data
Mamu	844	241	283
Nkporo	500	415	317
Awgu	190	Not present	125
Eze-Aku		509	61

The conspicuous disparity in formations thicknessis suggests that Umuna-1 well initially sited in a structurally depressed (synclinal) depocenter during the Pre-Santonian period compared to the overlying wells- Nzam-1 and Akukwa-2. During the Santonia, there was structural reversal leading to uplifment of the Umuna depocenter (horst) and structural depression of both the Nzam-1 and Akukwa-2 wells (graben) due to tectonic activity; thereby the two wells have more thicker formations during the Post-Santonian period as a result of increase in sediment supply and accommodation of the depocenters (Table 4.4). Similar view had been expressed for the increase in sediment supply during post Santonian period due to structural control by deep faults which led to formation of horst and graben structure (Oluwajana and Ehinola, 2016).

4.5 Palynology result

Palynology analyses of the three wells were carried out; detailed results and interpretation of the wells are given below:

4.5.1 Palynozonation of Nzam-1 well

One hundred and thirty two samples of the Nzam-1 well, ranging in depth from 390 m at the top to 2906 m at the bottom were subjected to standard palynological analysis. Ten palynozones were erected, some modified after the work of Germeraad *et al.* (1968); Evamy *et al.* (1978); Lawal and Moullade (1986). The zones erected for Nzam-1well were compared with palynologial zones established for sedimentary basins in different parts of the world(Jardine and Magloire, 1965; Kotova, 1984; Schrank, 1984; Muller *et al.,* 1987; Kaska, 1985; Umeji, 2003-2005, 2011, 2013; Ehinola, 2010; Ola-Buraimo, 2012, 2013; Oluwajana and Ehinola, 2016).

Definition of zones

- An assemblage zone is defined as a body of strata representing an assemblage or assemblages of sporomorphs that existed at the same time, but characterised by a striking marker form.
- An acme zone is defined as a body of strata characterised by a maximum abundance or maximum development of a taxa or a taxon

Thus, the bases of establishment of the nine zones are given as follows:

ZONE 1 :*Zlivisporites blanensis* Zone 1

The zone is present within interval 2716-2906 m., dated Coniacian- ? Santonian. The lower part of the interval is characterized by paucity of palynomorphs, disappearance of *Cretaceaiporites* spp. (Fig. 4.1) and break in the continuous appearance of *Odontochitinacostata.* The interval is defined by preponderance of monosulcate, tricolp(or)ate grains of angiosperms (Figs. 4.7 and 4.8) and continuous uphole occurrence of *Zlivisporitesblanensis* (Plate 4, no. 1)

The upper part of the interval is characterized by high abundance of fossils (Fig. 4.1). *Perimonolitesperireticulatus* (Plate 4.1, no. 2,5) and *Longapertites* sp. 3 (Plate 4.1, no. 6) evolved at the base of the interval. The lower part of the interval is deficient in dinoflagellate cysts compared to its upper part (Fig. 4.1). Recovered dinoflagellate cysts are *Andalusiella* sp. *Andalusiella polymorpha, Senegalinium* sp*, Odontochitina costata*, Forma M, Forma N, and Forma J, (*Subtilisphaera* sp.1). Miospores in the interval include *Tricolpites* sp. *Monosulcites*sp.,*Retimonocolpites* sp. 2, *Tricolporopollenites* sp., *Cyathidites* sp.,*Araucaricites* sp., *Monocolpopollenitessphaeroidites*, *Inaperturopollenites* sp. and *Peromonolites peroreticulatus*. Stratigraphically important pollen that define Senonian sediments such as *Droseridites senonicus, Syncolporites subtilis, Tricolpites gigantoreticulatus and Bacutricolporites manifestus* were not recovered in the analysed samples of the interval. However, other important fossils that appeared in the interval are presented in Figure 4.1

Zlivisporites blanensis Assemblage Zone 1 of this well is similar to Sequence VI – IV for Senegal Basin, dated Senonian (Jardine and Magloire, 1965). Palynomorph assemblage for the interval is also similar in part to *Droseridites senonicus* Acme Zone IV in Upper Benue trough, Nigeria (Lawal and Moullade, 1986). *Subtilisphaera* sp.recovered from Coniacian sediment in Upper Benue Trough was found in this interval. The Coniacian age given to Awgu Shale in this study agrees with the age given by Umeji (2007). Ehinola (2010) assigned Middle Turonian to Coniacian age to Awgu Shale on the basis of recovery of foraminifera *Hetohelicids* sp. which this study partly corroborate the established age.

The presence of *Longapertites* sp. 3 at the top of the interval marked the base of Campanian age. Santonian sediment is unlikely to be present in the well because of lack of diagnostic forms that indicate theage. Therefore, the Santonian sediments deposited in the basin were likelyto have been removed; thereby, an unconformity exists between Zone 1 and the younger overlying Zone 2.

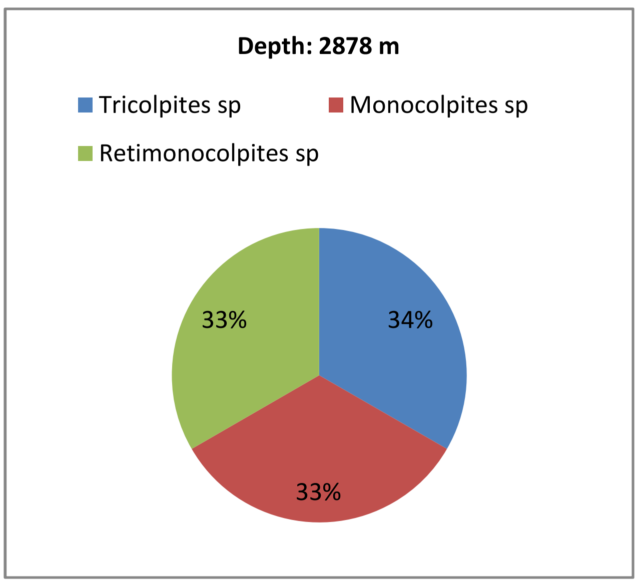


Figure 4.7. Relative percentage of angiosperm formsat depth 2878m

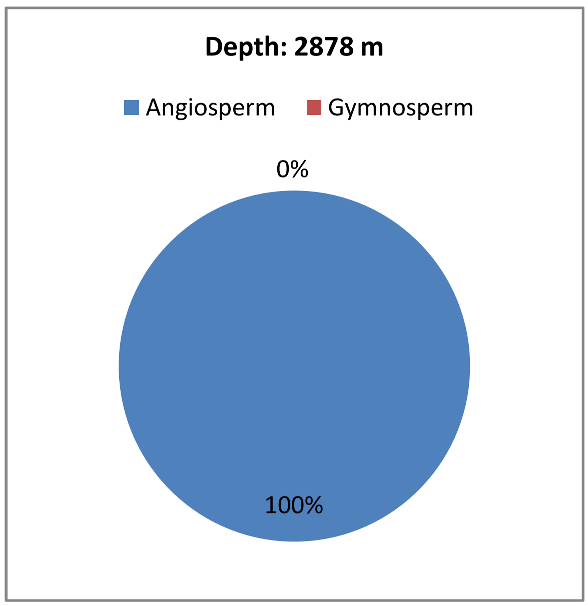


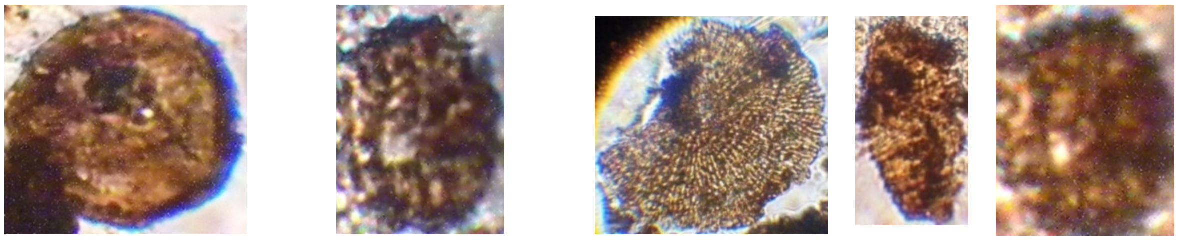
Figure 4.8. Dominant relationship between angiosperm and gymnospermpollen

The erosional structural break might be due to combined tectonic activity and weathering. However, a conformable relationship existsbetween the Awgu Shale and the underlying older Eze-Aku Formation becausethe interval hashomogenous shale sequence. Umeji (2006) observed similar phenomenon for the Turonian/Campanian boundary between the Abakaliki and Anambra Basins in an outcrop at Leru, Southeastern Nigeria. It is also similar to observation made by Ehinola *et al.* (2003) in the western limb of the Abakaliki Anticlinorium.

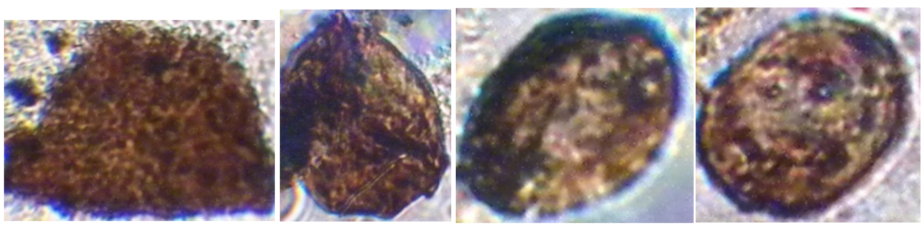
It is here suggested that the sedimentary pile that are contained in the Abakaliki Anticlinorium in actual fact extend laterally and become deeply buried in the Anambra Basin; depicting contemporenous sedimentation in Anambra Basin, Abakaliki Anticlinorium and Benue Trough as a result of rifting (Fig. 4.9).

Therefore, it is convenient to say that Anambra Basin contains pre-Santonian (Middle Cretaceous) sediments in some parts of the basin unlike earlier concept that it particularly containsonly post-Santonian (Late Cretaceous) sediments.

Magnification ×800



1 2 3 4 5



6 7 8 9

Plate 4.1. Palynomorph assemblage of interval 2716-2906 m

1	*Zlivisporites blanensis*
2, 5	?*Peromonolites peroreticulatus*
3	*Trichothyrites* sp. (microthyriaceous fungal fruiting body)
4	*Retimonocolpites* sp. (Liliacidites sp.)
6	*Longapertites* sp. 3
7	*Andalusiella laevigata*
8	*Monocolpopollenites sphaeroidites*
9	*Milfordia* sp.

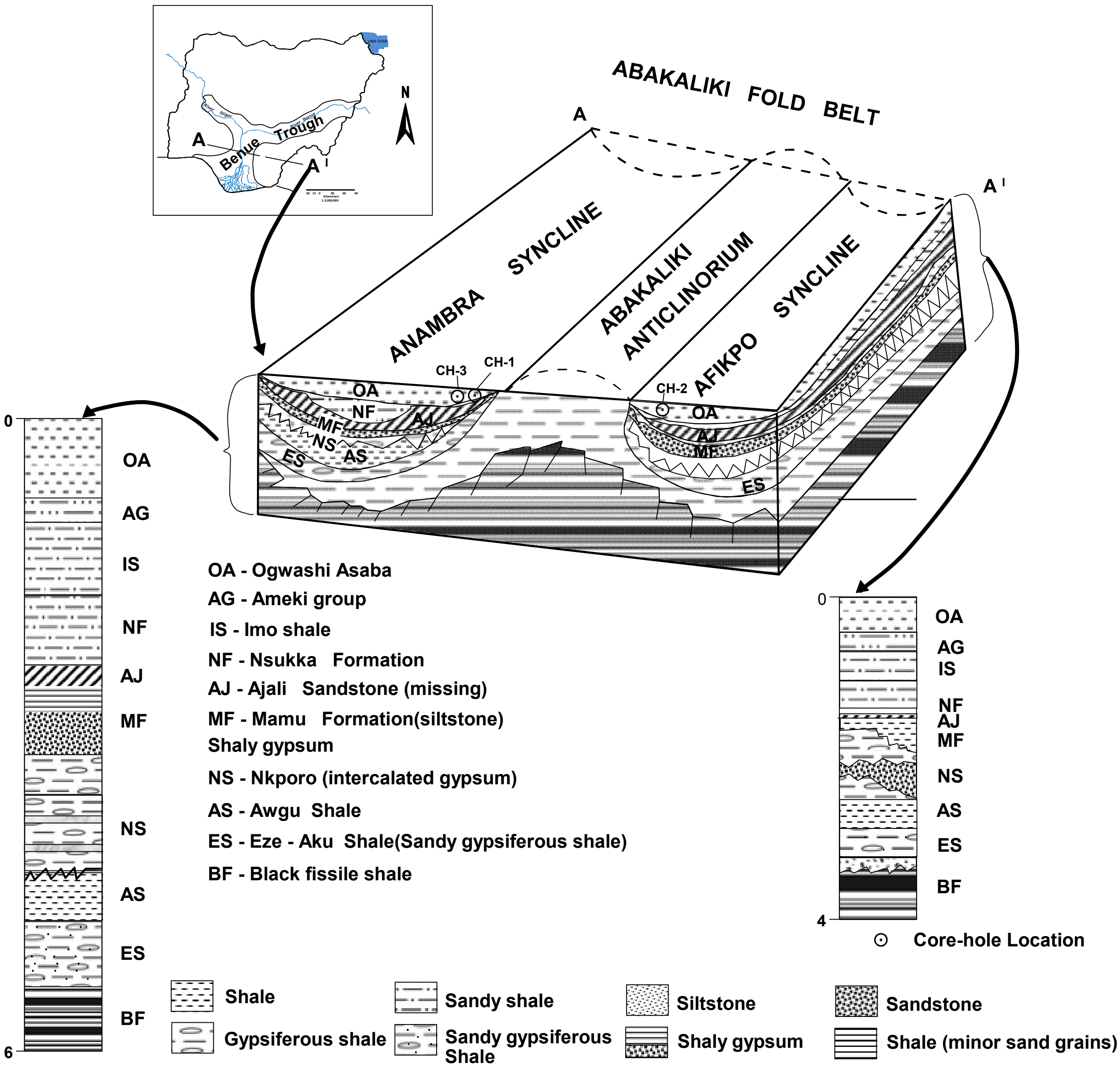


Figure 4.9. Depositional model of Abakaliki and Anambra Basin Contemporaneous sediment deposits (Modified from Ehinola *et al*., 2010)

ZONE 2:*Milfordia* spp. Acme Zone

The zone is located in interval 2216-2716 m, dated Capanian to Lowermost Maastrichtian. The basal part of the interval at 2716 m is characterised by the first occurrence of *Longapertites* sp. 3(Plate 4.2, no. 2; Lawal and Moullade, 1986), continuous occurrence of *Zlivisporites blanensis*, stephanocolporate pollen (Plate 4.2, no. 3),*Verrucatosporites* sp., *Monocolpites* sp.and *Cyathidites* sp. (Plate 4.2, no. 6). At the lower part of the interval was appearance of new forms such as *Milfordia* spp. (Plate 4.2, no. 5),*Syncolporites subtilis*(Plate 4.2, no. 9), *Cingulatisporitesornatus*(Plate 4.2, no. 10) and *Monocolpites marginatus* (Plate 4.2, no. 11). The top of the interval is characterised by the disappearance of *Milfordia* spp. and *Cupanieiditesreticularis* (Plate 4.2, no. 12). Within this zone, there is a variety of *Milfordia* taxa showing a continuous occurrence along with *Cupanieidites reticularis*(See Figures 4.1 and 4.10). They are both quantitatively restricted within the interval.

The top of the interval is marked by the disappearance of *Cupanieidites reticularis,Tricolpites gigantoreticulatus*(Jardine and Magloire, 1965), *Retitricolpite gageonnetii* (Boltenhagen, 1976), *Milfordia jardine* (Plate 5.23, nos.5 and 6) and appearance of Stephanocolporate pollen.

Many forms that are Maastrichtian markers have their offshoot within this zone, these include *Buttinia andreevi* (Plate 4.3, no. 9), *Retidiporites magdalenensis* (Plate 4.2, no. 14), *Periretisyncolporites* sp.(Plate 4.3, nos. 12), *Proxapertites cursus*(Plate 4.3, no. 11)and *Cingulatisporites ornatus* (Plate 4.2, no. 10).However, some forms became extinct within this zone such as *Milfordia* spp., *Cupanieidites reticularis, Triorites africaensis, Ephedripites multicostatus, Auriculiidites reticularis*and *Cicatricosisporites* sp. (Plate 4.5, no. 14).

Other miospores present within the interval are *Constantinisporites jacquei, Tricolporopollenites* sp.(Plate 4.4, no. 1) (S. 152 of Jardine and Magloire, 1965), *Ulmoideipites* sp.(Plate 4.4, no. 2), Tricolpate pollen, *Monoporites* sp., *Leiotriletes* sp., *Inaperturopollenites* sp., *Verrucosisporites* sp., *Gemmatricolpites* sp., *Laevigatosporites* sp., and dinoflagellate cysts. The organic wall organisms include *Senegalinium* spp.(Plate 4.4, nos. 3),*Andalusiella* spp.(Plate 4.4, no. 4), *Spinidium* sp. 1(Plate 4.4, no. 5)*,Cribroperidium* sp. *(*Plate 4.4, no.6) (Lawal, 1982), *Spiniferites* sp.(Plate 4.4, no. 7),*Oligosphaeridium*sp.(Plate 4.4, no. 8) and *Dinogymnium* sp. Other stratigraphically important palynomorphs recovered from the interval are presented in Plates 4.2-4.6.

Magnification ×800

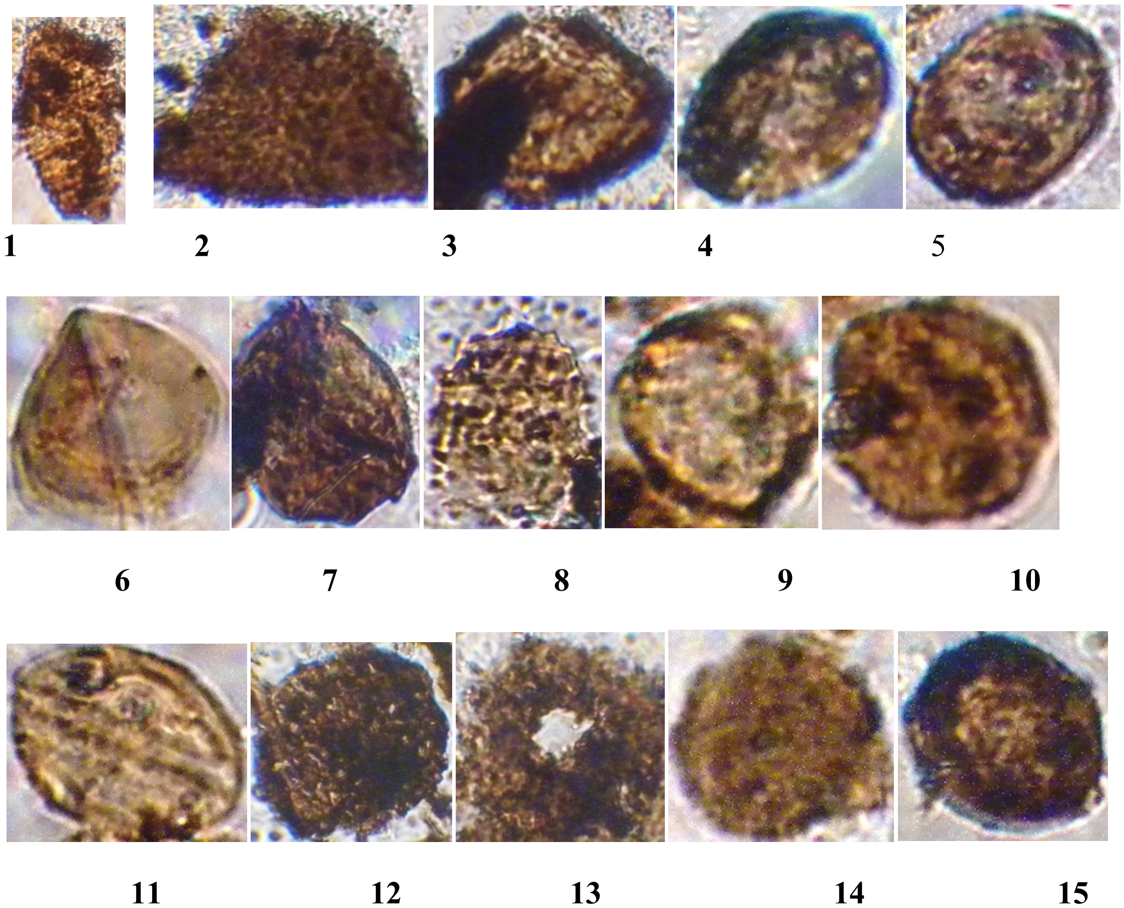


Plate 4.2. Palynomorph assemblage of interval 2216-2716 m

1 *Monosulcites* sp.
2 *Longapertites* sp. 3
3 Stephanocolporate pollen
4 *Monocolpopollenites sphaeroidites*
5 *Milfordia* sp.
6 *Cyathidites* sp.
7 *Andalusiella laevigata*
8 Dinogymnium sp.
9 *Syncolporites subtilis*
10 *Cingulatisporites ornatus*
11 Monocolpites marginatus
12 *Cupanieidites reticularis*
13 Milfordia jardinei
14 Retidiporites magdalenensis
15 Milfordia sp. 3

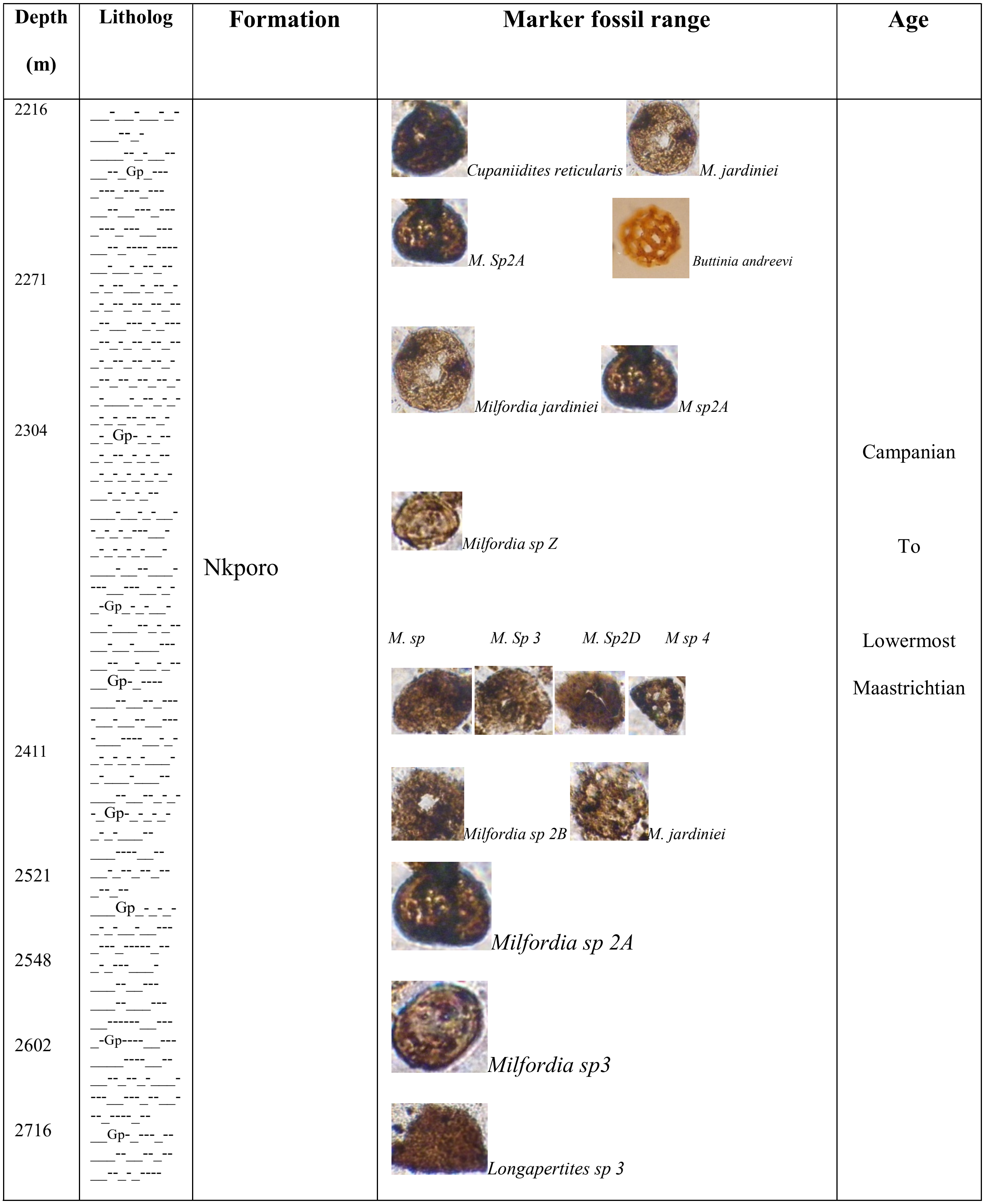


Figure 4.10: Trend of appearance and evolutionary changes in *Milfordia* taxa.

Magnification ×800

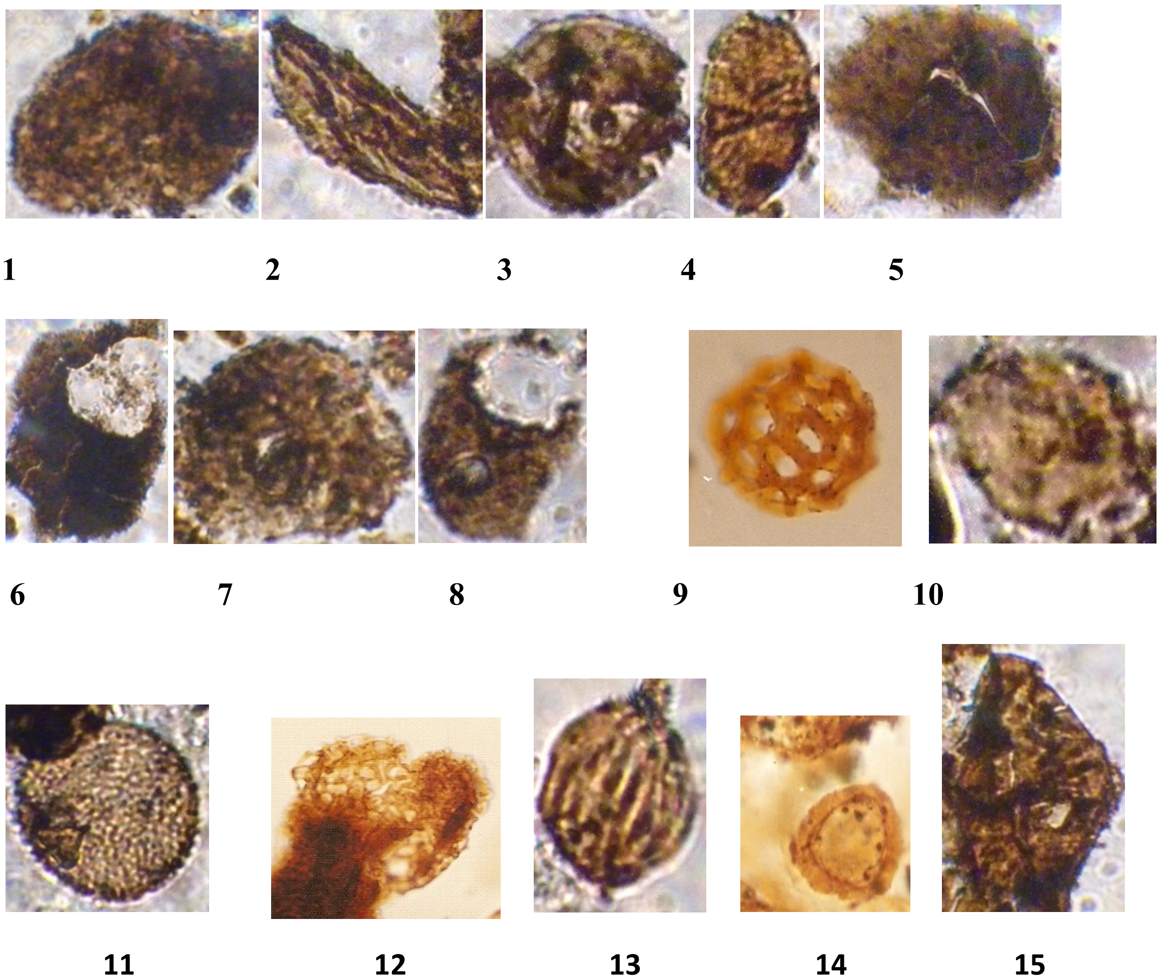


Plate 4.3. Palynomorph assemblage of interval 2216-2716 m

1 *Milfordia* sp.
2 *Ephedripites* sp.
3 *Araucariacites australis*
4 *?Psilaticolporites divisus*
5 *Milfordia* sp. 2D
6,8 Forma Y
7 *Milfordia* sp. 3**Lawal (1982).**
9 *Buttinia andreevi*
10 *Retidiporites magdalenensis*
11 *Proxapertites cursus*
12 *Periretisyncolpites* sp.
13 Ephedripites sp
14 *Cingulatisporites ornatus*
15 *Cupanieidites reticularis*

The *Milfordia* spp. acme zone is similar to *Longapertites* sp 3. Assemblage Zone erected by Lawal and Moullade (1986). This zone is well represented in Nzam- 1 well of this study. The *Milfordia* spp. were reported in the works of Van de Hammen (1954); Van der Hammen and Wijmstra (1964); Paeltova (1961); Van Hoeken Klinkenberg (1964, 1966); Jardine and Magloire (1965). *Cupanieidites reticularis* and *Cingulatisporitesornatus*have been reported by Boltenhagen (1967, 1976); Sole de Porta(1971, 1972a, 1972b); Herngreen (1972, 1975a, 1975b);Jan du Chene (1977); Jan du Chene *et al.* (1978a, 1978b); Salard-Cheboldaeff (1979); Baksi and Deb (1981); Salami (1983,1984,1985,1986,1988); Schrank (1987); Oloto (1987); Edet and Nyong (1994);Umeji (2006); Ogale *et al.* (2009); Ikhane *et al.* (2012); Ola-Buraimo *et al*. (2012); Ola-Buraimo (2012); Ola-Buraimo *et al*. (2014); Adebayo *et al*. (2015); Ola-Buraimo and Adebayo (2015); Ola-Buraimo *et al*. (2015); Bankole and Ola-Buraimo (2017).

The *Milfordia* spp. acme zone 4 has similarity to other zones observed in Senegal and Cote d' Ivoire; palynomorph assemblages from Campanian sediments of Egypt described by Sultan (1985), Schrank (1987) and Upper Senonian sediment described from Brazil (Herngreen, 1972, 1975a, 1975b).

Magnification ×800

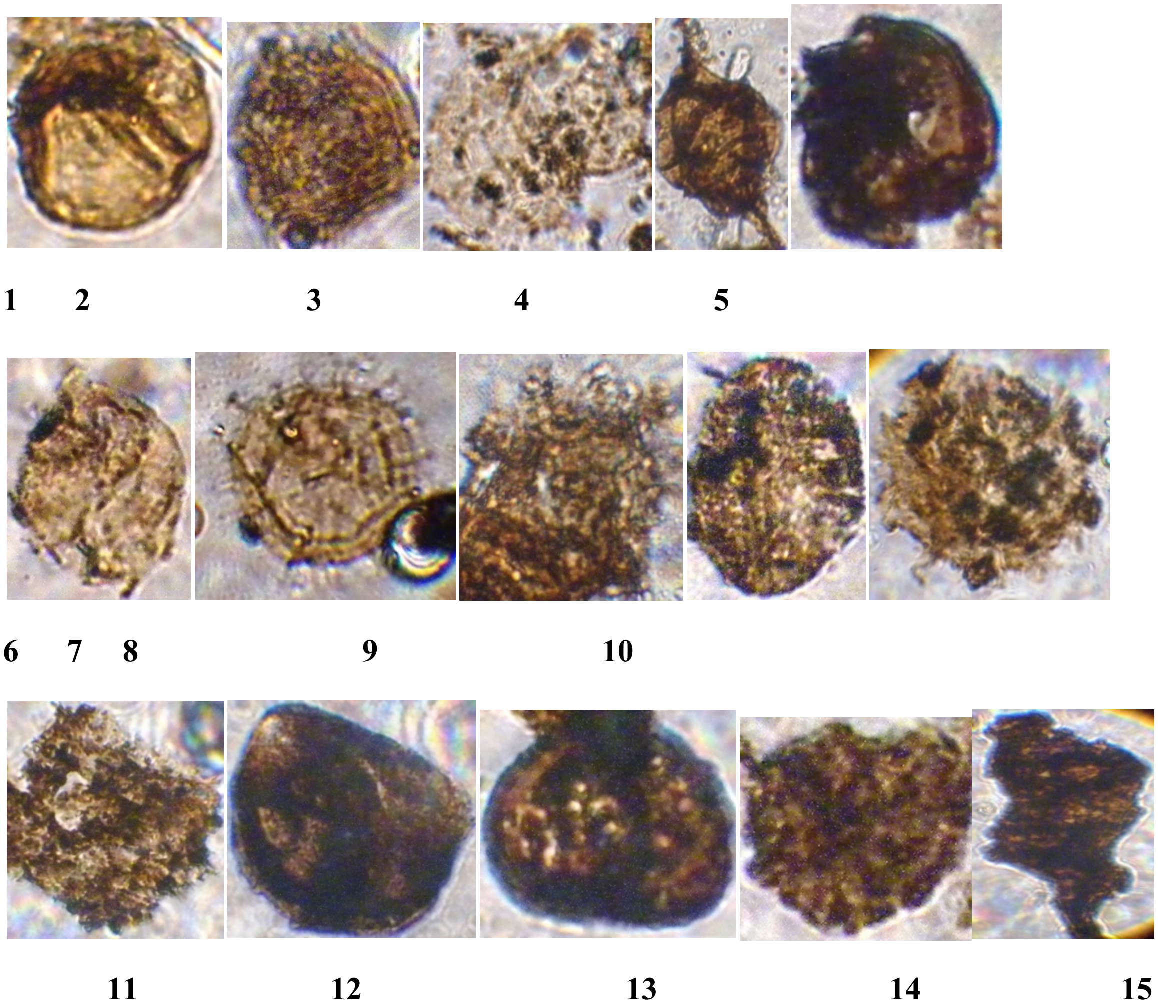
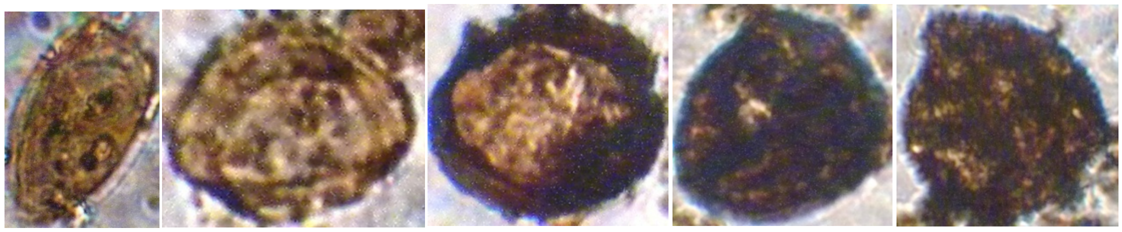


Plate 4.4. Palynomorph assemblage of interval 2216-2716 m

1 *Tricolporopolleniteses* sp.**Jardine & Magloire(1965).**
2 *Ulmoideipites krempii***(Anderson, 1960); Elsik (1968).**
3 *Senegalinium sp.*
4 *Andalusiella polymorpha***Malloy(1972).**
5 *Spinidinium* sp.
6 *Cribroperidium* sp. 2**Lawal(1982).**
7 *Spiniferites mirabilis*
8 *Oligosphaeridium* sp.
9 *Retimonocolpites* sp.
10 *Homotryblium* sp. A**Oloto(1987).**
11 *Pheloddinium bolonienae***Riegel (1974).**
12 *Phelodinium belonienae* **Riegel(1974).**
13 *Milfordia* sp. 2A
14 *Milfordia* sp. 2B
15 *Botryococcus braunii*

Magnification ×800



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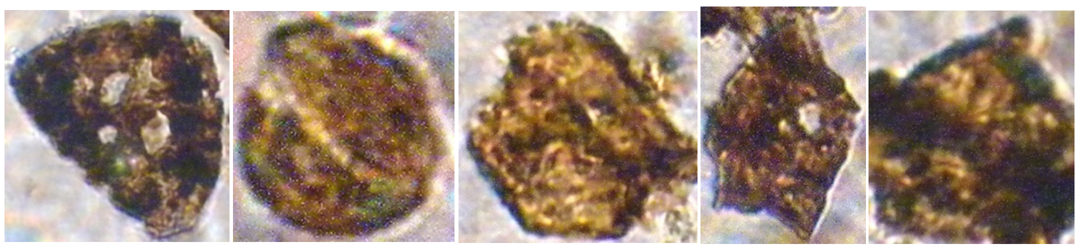

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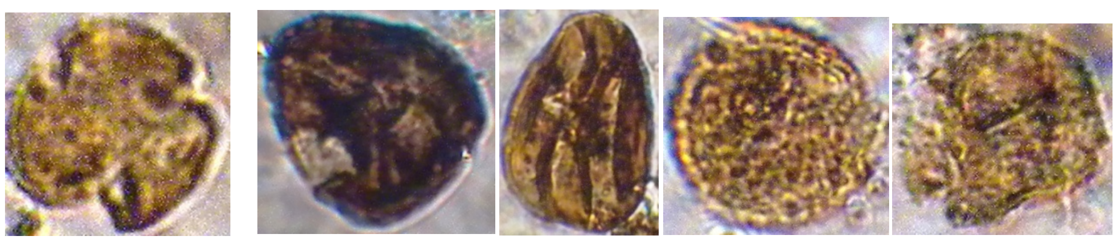
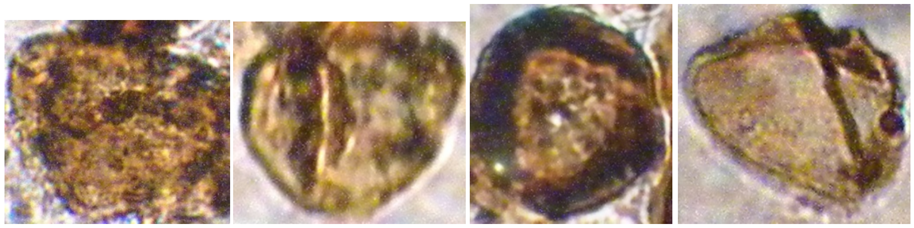


11 12 13 14 15

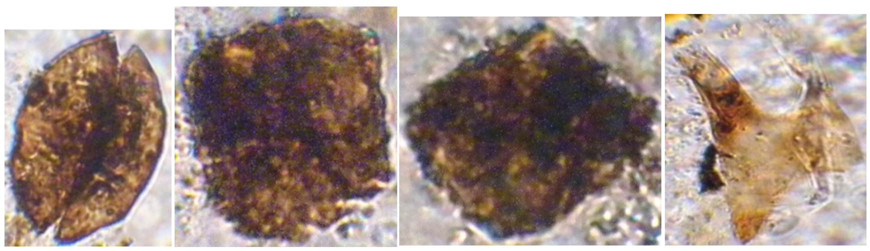
Plate 4.5. Palynomorph assemblage of interval 2216-2716 m

1 *Longapertites* sp. 3**Lawal and Moullade (1986).**
2 *Milfordia* sp. Z
3 *Milfordia* sp. 2A
4 *Cupanieidites reticularis*
5 *Milfordia* sp.
6 *Milfordia* sp. 4
7 *Stephanocolpites* sp.
8 *Tricolpites* sp. 1in **Reyre(1970).**
9 *Senegalinium* sp.
10 *Senegalinium* sp. 8**Lawal(1982).**
11 Tricolpites sp. 1
12 *Cyathidites* sp.
13 Tricolpites sp. 2
14 ? *Cicatricosisporites* sp.
15 Cf *Cupanieidites reticularis*

Magnification ×800



1234



5 678

Plate 4.6. Palynomorph assemblage of interval 2216-2716 m

1	*Syncolporites ifeensis* **Jan du Chene (1977).**
2	*Cupanieidites reticularis*
3	*Milfordia* sp.2A
4	Cf *Graminidites* sp.
5	*Monosulcites* sp.
6-7	*Phelodinium bolonienae*
8	*Deflandre* sp.

The first appearance of *Buttinia andreevi* and *Auriculiidites* sp. in the Upper part of the intervalconforms with observations of Jardine and Magloire (1965); Petrosgrants and Trofimov (1971); Herngreen (1975a), in dating their sediments Campanian–Lower Maastrichtian age.

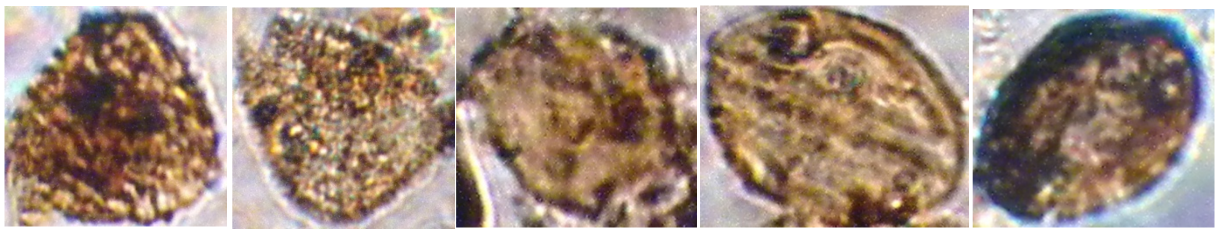
Nyong and Ramanathan (1985) assigned Late Campanian age for the Nkporo Shale on the basis planktonic foraminiferal assemblages including*Globotruncana fornicate* (Plumer), *Rugoglobigerina rugosa* (Plummer), *Heterohelix pulchra* (Brotzen) *and H. globulosa* (Ehrenberg). However, Reyment (1965) used *Libycoceras crossense,L. afikpoense*and*Sphenoidiscus lobatus*(ammonites) respectively in assigning Late Campanian age. Umeji (2007, 2011) assigned Campanian age to the Nkporo Shale. However, Chiaghanam *et al*. (2012); other workers put the age of Nkporo shale at Late Campanian (Aja and Igwe, 2015). Nkporo Shale did not generate much controvercy on its age dating compared to other formations in the basin.

However, the work of Adebayo *et al.* (2015) suggested Early to Late Campanian age for the Nkporo Shale. The Early Campanian dating for Nkporo Shale conforms to this study and that of Umeji (2007, 2011) and the work of Ola-Buraimo and Akaegbobi (2013c). However, the study carried out by Aja and Igwe (2015) on Nkporo Shale totally correlate with Campanian to Early Maastrichtian age suggested for Nkporo Shale in this study.Therefore, the interval 2215-2603 m of the *Milfordia* spp.acme zone 2 is here conveniently dated Campanian to Lowermost Maastrichtian age.

ZONE 3:*Foveotriletes margaritae* Assemblage Zone

The Zone 3 issituated in interval 1844-2216 m, dated Early Maastrichtian. The basal part of the interval is marked by the extinction of *MIlfordia* spp. and *Cupanieidites reticulatus*.However, the near base is characterised by the appearance of *Trichotomosulcites* sp. 1(Plate 4.7, nos. 1) and *Monocolpopollenites sphaeroidites*(Plate 4.7, no. 5).

Magnification ×800



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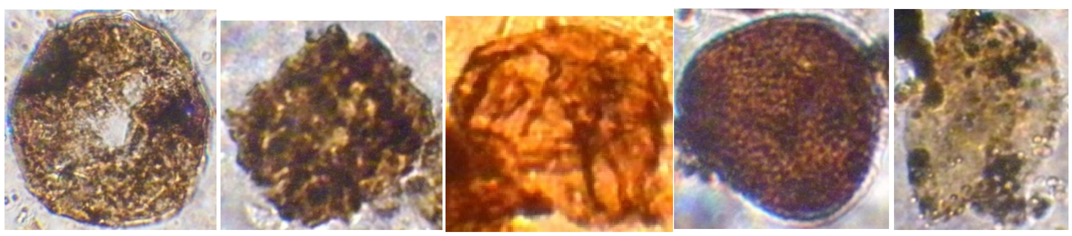
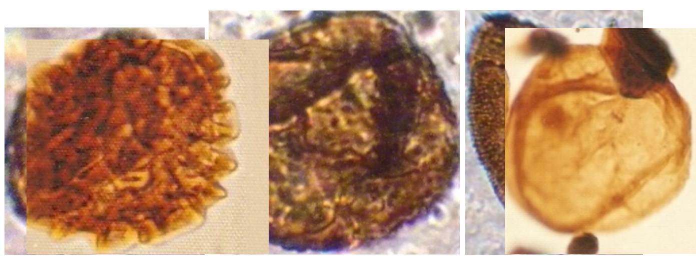


6 7 8 9 10



11 12 13 14 15

Plate 4.7. Palynomorph assemblage of interval 1844-2216 m

1 *Trichotomosulcites* sp. 1
2 *Trichotomosulcites* sp. 2
3 *Retidiporites magdalenensis*
4 *Monocolpites marginatus*
5 *Monocolpopollenites sphaeroidites*
6 *Milfordia jardinei*
7 *Ulmoideipites krempii*
8 *Zlivisporites blanensis*
9 *Foveolatus margaritae*
10 *Longapertites marginatus*
11 *Periretisyncolpites* sp.
12 *Retidiporites* sp.
13 *Inaperturopollenites* sp.
14 *Araucariacites australis*
15 *Longapertites microfoveolatus*

Signifanctly, the two forms which characterise this zone are restricted in the interval. The base of the intervalcoincides with the top of Zone 2 in this well. The upper part of the interval indicates final appearance of *Trichotomosulcites* sp. 1, increase in *Monocolpitesmarginatus*, and assemblage of other forms such as *Cingulatisporitesornatus*, *Retidiporitesmagdalenensis*, *Longapertitesmarginatus*, *Periretisyncolpites* sp. (Plate4.7, no. 11) and *Leiotriletes* sp; noted was occurrence of Stephanocolporate pollen, *Zlivisporitesblanensis*, *Proxapertitescursus* and *Tricolporopollenites* sp.

Dinoflagellate assemblage include *Isabelidinium* sp.6, *Deflandrea* sp. and *Cyclonephediumbelonienae* (Schrank, 1984); similar to those in the underlying Zone 2. Stratigraphically diagnostic Maastrichtian grains with strong appearance include*Monocolpites marginatus* (Plate 4.7, no. 4), *Syncolporites subtilis* (Plate 4.8, no. 9), *Foveotriletes margaritae* (Plate 4.9, nos. 4), *Monosulcites* sp. 1(Plate 4.9, no. 3)*, Longapertites marginatus,*and *Inaperturopollenites* sp. (Plate 4.10, no. 9).

An Early Maastrichtian age was given to the Zone 3 based on the continuous occurrence *Foveotriletesmargaritae,Trichotomosulcites* sp. 1, *Monocolpopollenites sphaeroidites, Cingulatisporites ornatus;* reduced frequencies of *Monocolpites marginatus, Periretisyncolpites giganteus, Longapertites marginatus, Monosulcites* sp.and *Cyathidites*sp.(Plate 4.9, nos. 2). Other important miospore retrieved from the interval were presented in Plates 4.3-5.10.

Chiaghanam *et al*. (2013) assigned Middle Maastrichtian age while Umeji (2005) attributed Late Maastrichtian to Danian age to the Mamu Formation. The interval is stratigraphically equivalent to lower part of Mamu Formation, dated Lower Maastrichtian age.

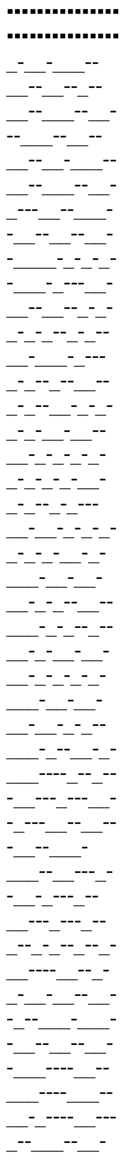
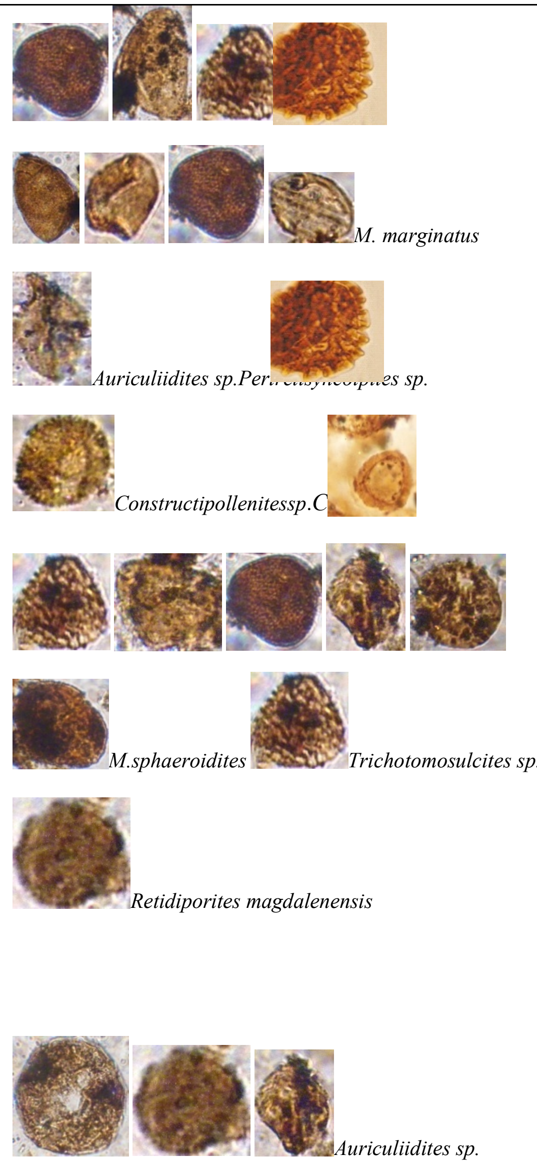
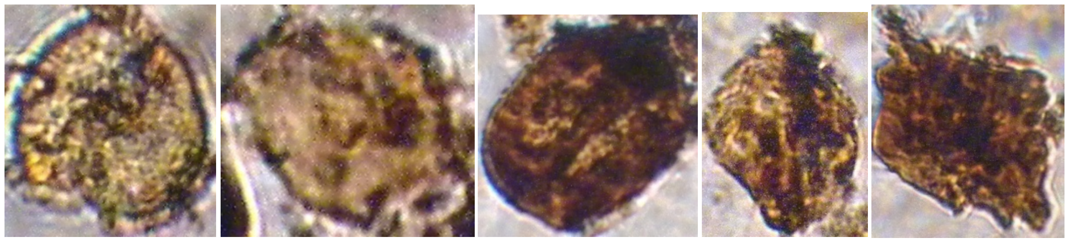
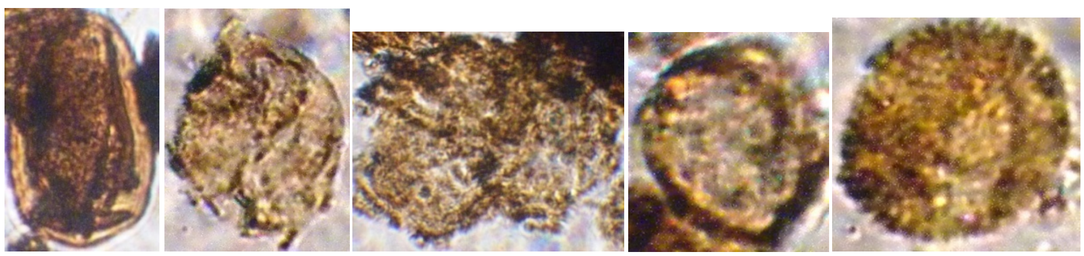
Depth (m)	**Lithology**	**Formation**	**Marker fossils**	**Age**
1920 1981 2085 2112 2140 2164 2188 2216		Mamu		Early Maastrichtian

Figure 4.11. Marker fossil appearances with depth in interval 1920-2216 m

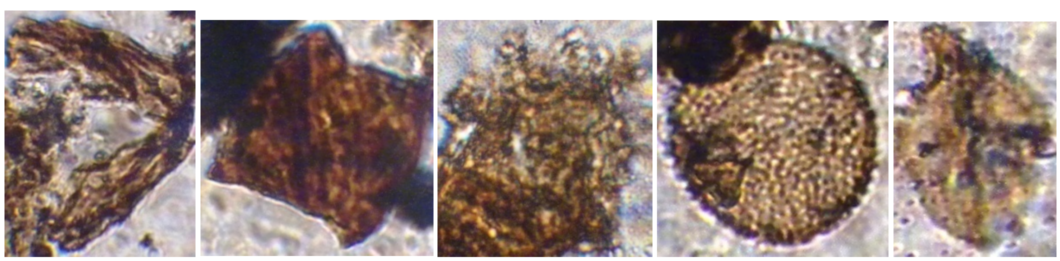
Magnification ×800



1 2 3 4 5



67 8 9 10

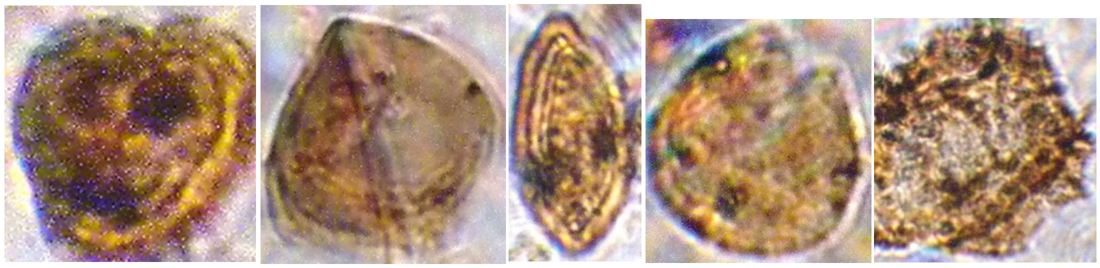


11 12 13 14 15

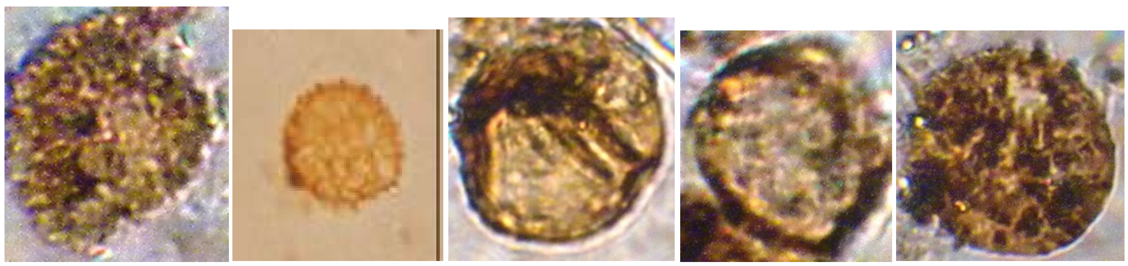
Plate 4.8. Palynomorph assemblage of interval 1844-2216 m

1	*Proxapertites cursus*
2	*Retidiporites magdalenensis*
3	*Tricolpites* sp.
4,5	*Auriculiidites* sp.
6	*Psilatricolpites* sp.
7	*Cribroperidium* sp.
8	*Senagalinium* sp.
9	*Syncolporites subtilis*
10	*Constructipollenites ineffectus*
11	*Ephedripites* sp.
12	*Senegalinium bicavatum*
13	*Oligosphaeridium* sp.
14	*Proxapertites cursus*
15	*Auriculiidites* sp.

Magnification ×800



1 2 3 4 5



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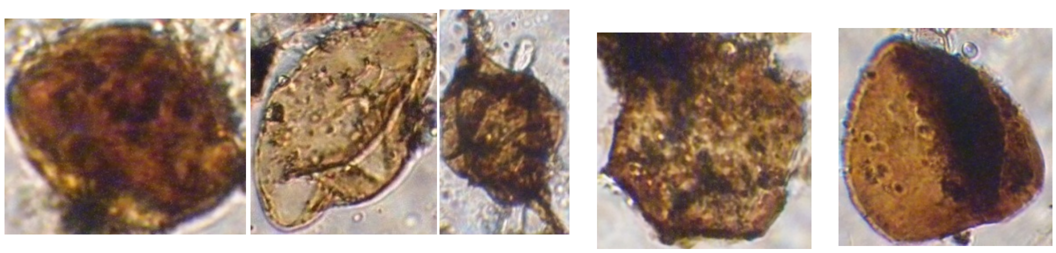


11 12 13 14 15

Plate 4.9. Palynomorph assemblage of interval 1844-2216 m

1 *Cingulatisporites ornatus*
2 *Cyathidites* sp.
3 *Monosulcites* sp.
4 *Foveotriletes margaritae*
5 Peridinoid form
6, 7 *Constructipollenites ineffectus*
8 *Tricoporopollenites* sp.
9 *Syncolporites subtilis*
10 *Spinizonocolpites baculatus*
11 *Longapertites* sp.
12 ? Monocolpites sp
13 Senegalinium sp
14 *Andalusiella polymorpha***Malloy (1972).**
15 *Foveotriletes margaritae***Germeraad *et al.*(1968).**

Magnification ×800

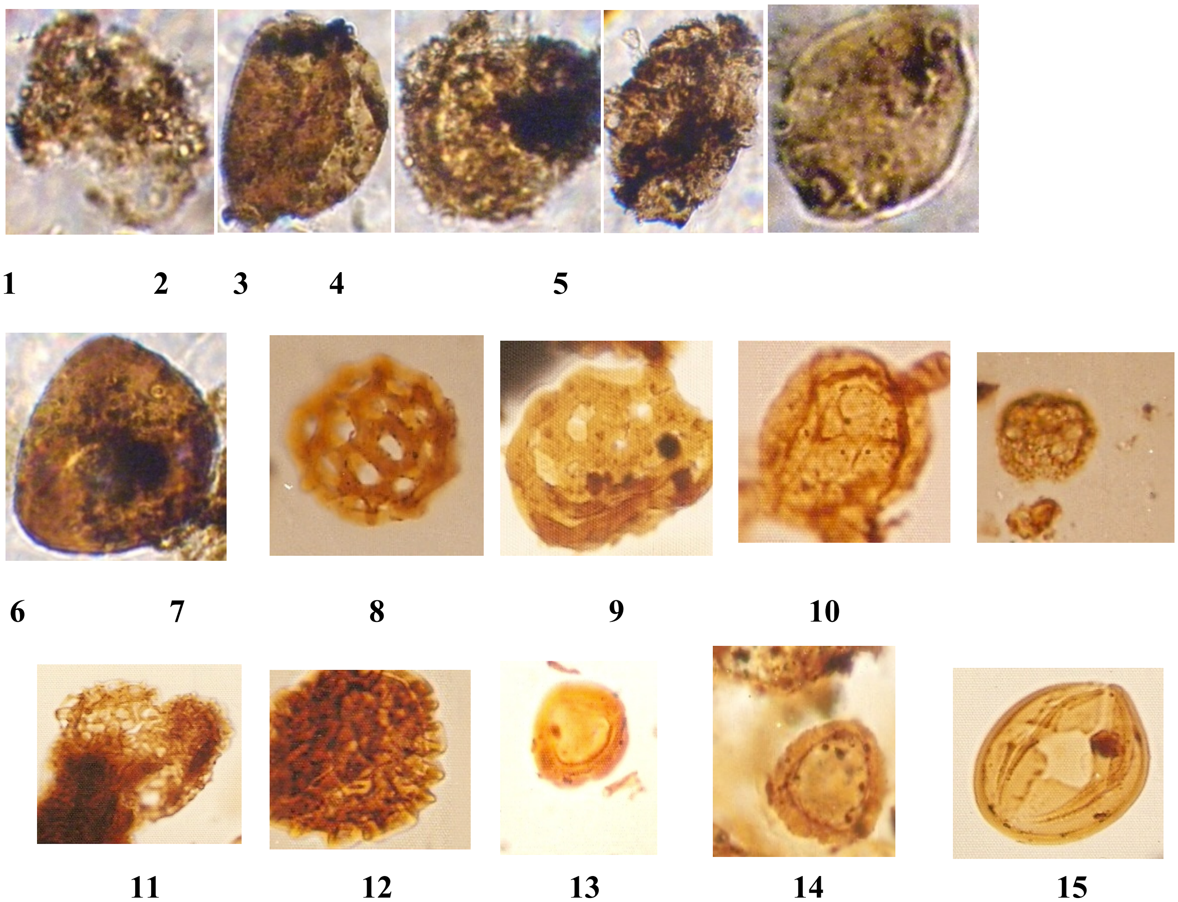


Plate 4.10. Palynomorph assemblage of interval 1844-2216 m

1 *Phelodiniun* sp.
2 *Monosulcites* sp.
3 *Trichodinium* cf. *castanum*
4 *Retidiporites magdalenensis***.**
5 *Retitricolpites* sp.
6 *Foveotriletes margaritae*
7,8 *Buttinia andreevi***Boltenhagen(1967)**.
9, 10 *Zlivisporites blanensis*
11, 12 *Periretisyncolpites* sp.
13-14 *Cingulatisporites ornatus*
15 *Tricolporopollenites* sp.

ZONE 4:*Longapertites marginatus* Acme Zone

The zone is within interval 1372-1844 m, dated Middle Maastrichtian. The base of the interval is characterised by increase in recovery of *Longapertitesmarginatus* (Plate 4.11, no. 7), *Monocolpites marginatus*(Plate 4.11, no. 8), and *Periretisyncolpites* sp. *Longapertites margintus* has about 22 %abundance compared wth *Periretisyncolpites giganteus* (Plate 4.11, nos. 2)11%, *Monocolpites* sp. (Plate 4.11, no. 1) 5%, *Monosulcites* sp.(Plate 4.11, no. 4) 4%, and *Cyathidites* sp.(Plate 4.11, no. 3) at depth 1817 m.Taxapercentage relationshipsareshownin pie and bar charts having*Longapertites marginatus* 52%, P*eriretisyncolpites* sp. 20%. *Monocolpites* sp. 12% and *Monosulcites* sp. 10% (Figures 4.12-4.15). Thedepth is further marked by maximum development of *Constructipolentes ineffectus*(Plate 4.11, no. 5) and first uphole appearance of*Echitriporites trianguliformis*(Plate 4.11, no. 6).

Maastrichtian pollen present in Zone 4 continued into Zone 5 of Nzam-1 well; such forms include*Foveotriletes margaritae, Monosulcites* sp., *Monocolpites marginatus, Cingulatisporites ornatus, Retidiporites magdalenensis, Longapertites microfoveolatus*, and *Proteacidites* sp. 5 (Ola-Buraimo, 2012, 2013). The upper part of the interval is defined by decrease in abundance of *Longapertites marginatus*(Tables4.4)*Spinizonocolpites baculatus*(Plate 4.11, nos. 10), *S. echinatus* (Plate 4.11, no. 15) *Leiotriletes* sp,*Monosulcites* sp.,*Periretisyncolpites giganteus* (Plate 4.11, no. 2),*Monocolpites marginatus*and *Constructipollenites ineffectus*(Plate 4.11, no. 5).

The flora assemblages of Zone 4are similar to those retrievedfrom Coal Seam Measures in Mamu Formation(Ogala *et al.,* (2009); similar to Zone 4 pollen and spores from Tuma-1 and Murshe- 1 wells in Bornu Basin, Nigeria (Ola-Buraimo, 2012, 2013). The Zone 4 is characterised by the occurrence of *Oligosphaeridium* sp.(Plate 4.11, no. 9)*, Oligosphaeridium simplex, Florentinia* sp.(Plate 4.11, no. 11)*, Trichodinium delicathum* (Plate 4.11, no. 12), *Andalusiella polymorpha*, *A. laevigata* (Plate 4.11, no. 13),and microforaminiferal wall linings (Plate 4.11,no.14). The occurrence of these dinoflagellates suggests shallow marine environment of deposition.

Magnification ×800

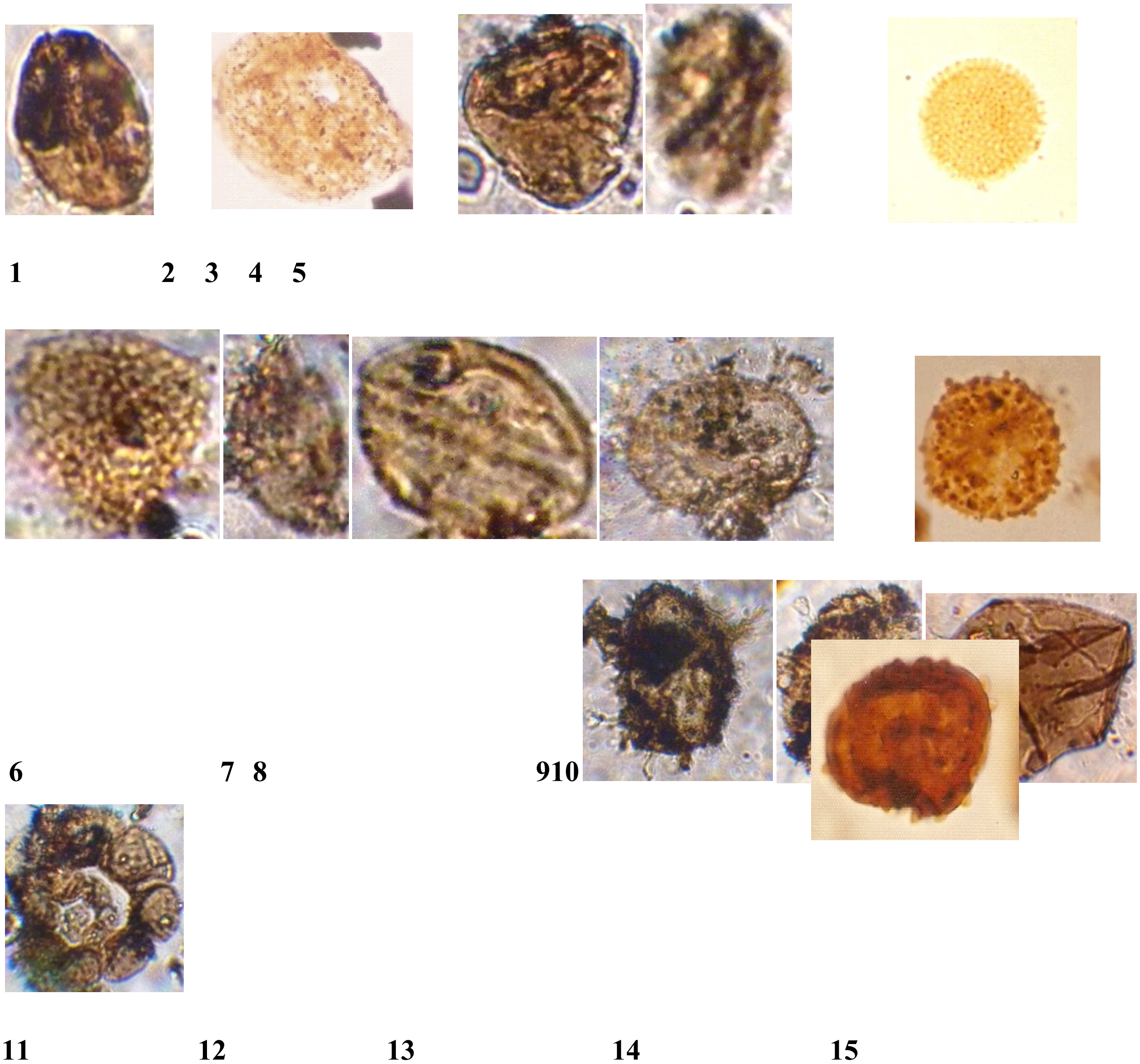


Plate 4.11. Palynomorph assemblage of interval 1372-1844

1 *Monocolpites* sp.
2 *Periretisyncolpites giganteus*
3 *Cyathidites* sp.
4 *Monosulcites* sp.
5 *Constructipollenites ineffectus*
6 *Echitriporites trianguliformis*
7 *Longapertites marginatus*
8 *Monocolpites marginatus*
9 *Oligosphaeridium* sp.
10 *Spinizonocolpites baculatus*

11 *Florentinia* sp.**Lawal(1982).**
12 *Trichodinium* sp.
13 *Andalusiella laevigata***Malloy (1972).**
14 Microforaminifera wall lining
15 *Spinizonocolpites echinatus*

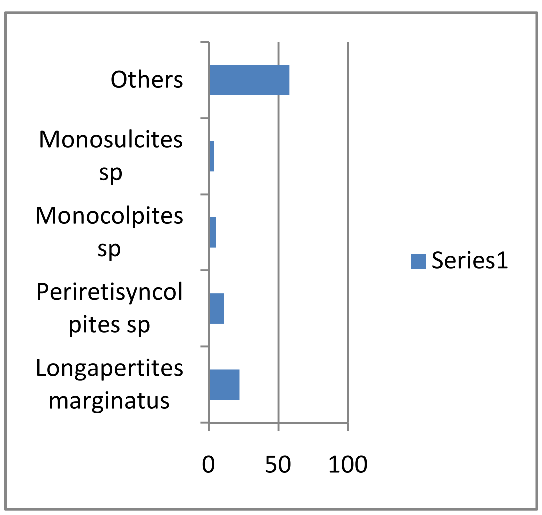


Figure 4.12. Abundance of Longapertites marginatus with other forms present at interval 1372-1844 m

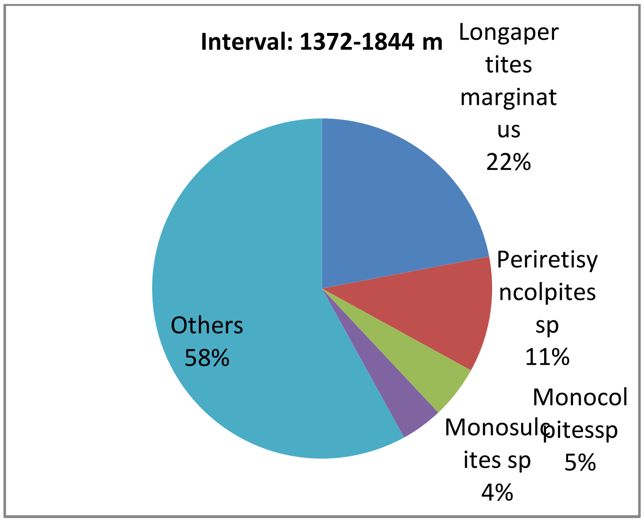


Figure 4.13. Abundance of Longapertites marginatus with other forms in percentages at interval 1372-1844 m

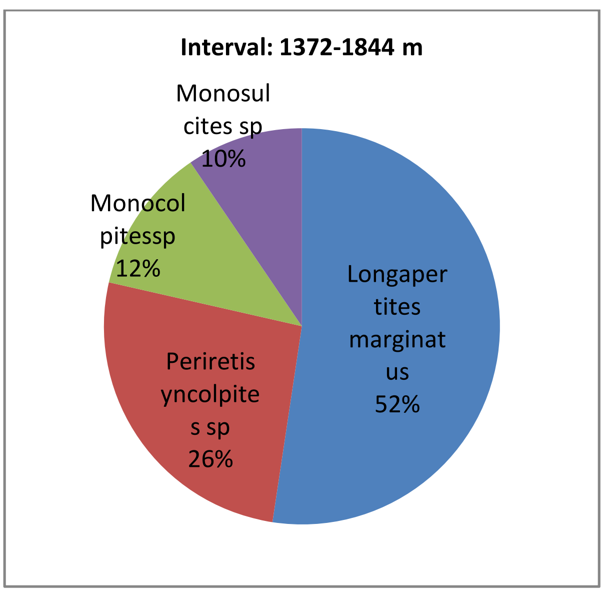


Figure 4.14. Abundance of Longapertites marginatus with other forms in percentages at interval 1372-1844 m

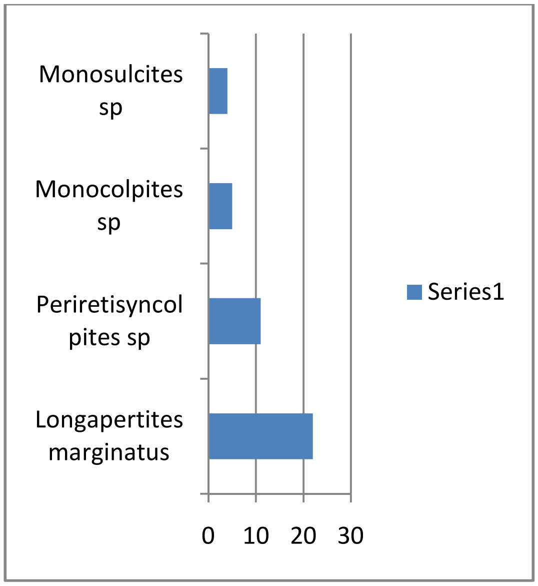


Figure 4.15. Histogram plot of abundance of Longapertites marginatus with otherforms present at interval 1372-1844 m

A shallow marine paleoenvironment with tidal influence was suggested by Chiaghanam *et al.* (2013). Here the Middle Maastrichtian age assigned to this interval is stratigraphically equivalent to upper Mamu Formation and correlate to the same age given for Mamu Formation by Chiaghanam *et al.* (2013).

ZONE 5:*Spinizonocolpites baculatus* Assemblage Zone

The zone is located within interval 847-1372 m, dated Late Maastrichtian. The lower part of the interval is marked by the occurrence of *Spinizonocolpites baculatus*(Figure 4.16; Plate 4.19,nos. 4, 9)*S. echinatus,Constructipollenites ineffectus*(Plate 4.18, no. 2),*Periretisyncolpites* sp.(Plate 4.18, no. 4, 6),*Periretisyncolpites giganteus, Monocolpites* sp.1,low recovery of *Longapertites marginatus* (Plate 4.13, no. 8), *proxapertites cursus* (Plate 4.20, no. 11), and *Verrucatosporites* sp. (Plate 4. 12, no. 3).

The upper part of the interval is defined by the occurrence of *Anacolosidites luidonisi*and*Mauritiidites crassibaculatus* (Plate 4.12, no. 1). *Periretisyncolpites* spp. shows break in appearance at 847 m. The upper boundary of the interval shows increase in angiosperm pollen, *Retimonocolpites* sp. (Plate 4.12, no. 5), stephanoporate pollen, and *Monosulcites* sp. (Plate 4.12, no. 4). The upper boundary of the zone was placed at the depth containing high abundance and diversity of miospores (Figures 4.17 and 4.18).This observation is in tandem with boundary between Late Maastrichtian and Paleocene age in Upper Benue Trough (Lawal and Moullade, 1986).

Factors such as increase in angiosperms and decrease in gymnosperms characterize the interval.The lower part of the interval is characterised by low abundance of miospores (1372-924 m; Figure 4.1) while the upper part showed more abundance and diversity in miospores. The upper section of the interval was marked by the occurrence of*Retistephanocolpites williamsi* (Plate 4.12, no. 6), *Proteacidites deehani*, *Echitriporites trianguliformis* (Plate .12, no. 9), *Constructipollenites ineffectus* (Plate 4.12, no. 10), *Longapertites marginatus* (Plate 4.15, no.

15), *Proxapertites cursus* (Plate .12, no. 13), *Retidiporites magdalenensis*(Plate 4.12, no. 8), *Spinizonocolpites baculatus, Anacolosidites*sp.and *Retitricolpites gigeonetii.*

The interval 924–1372 m is less fossiliferous; pollen present are*Tetradites* sp. (Plate 4.13, no. 4), *Mauritiidites crasibaculatus* (Plate 4.12, no. 12), *Syncolporites marginatus* (Plate 4.12, nos. 15),*Lycopodium* spand *Longapertites microfoveolatus* (Plate 4.12, no. 11), *Proxapertites cursus, Longapertites* sp.*, Echitriporites trianguliformis* and *Foveotriletes margaritae* (Figure 4.1).

However, other important pollen recovered that characterise this zone are presented in Plates 5.43 to Plate 5.59. Late Maastrichtian age was assigned to the interval.Miospores assemblages in Zone 7 are similar to forms described in Upper Maastrichtian age sediments of other places (Jardine and Magloire, 1965; Muller, 1968; Germaraad *et al.,* 1968; Jan du Chene, 1977; Kiesse and Jn du Chene, 1979; Salard Cheboldaeff, 1979, 1981, 1990; Lawal and Moullade, 1986; Ola-Buraimo, 2012, 2013).

Decrease in gymnosperms that characterise Zone 5 is similar to palynological character that defined the top of Gombe Formation. Sulcate, triporate, tricolpates forms that mark the analysed interval are also contained in northeastern Nigeria sediments (Ayinla *et al.,* 2014). The zone 5 is comparable with*Proteacidites dehaani* zone of Pan Tropical regions (Germaraad *et al.* (1968). Some of the floralassemblages' assigned Paleocene age in this interval was also reported in other sedimentary basins in Nigeria including Kerrikerri Formation in Bornu Basin, Ewekoro Formation in Dahomey Embayment, Mamu Coal Seam Measure in Anambra Basin (Ogala*et al*., 2009).

Therefore, the zone 5 is equivalent probably to ?Ajali and Nsukka Formations. Nsukka Formation was dated Danian age (Umeji, 2008). This is in sharp contrast to the date obtained in this study but correlate to the work of Bankole and Ola-Buraimo (2017). It is clear that there was no deposition of Ajali Sandstone in this well because it could not be delineated lithologically and on distinctive palynological characterisation.

Magnification ×800

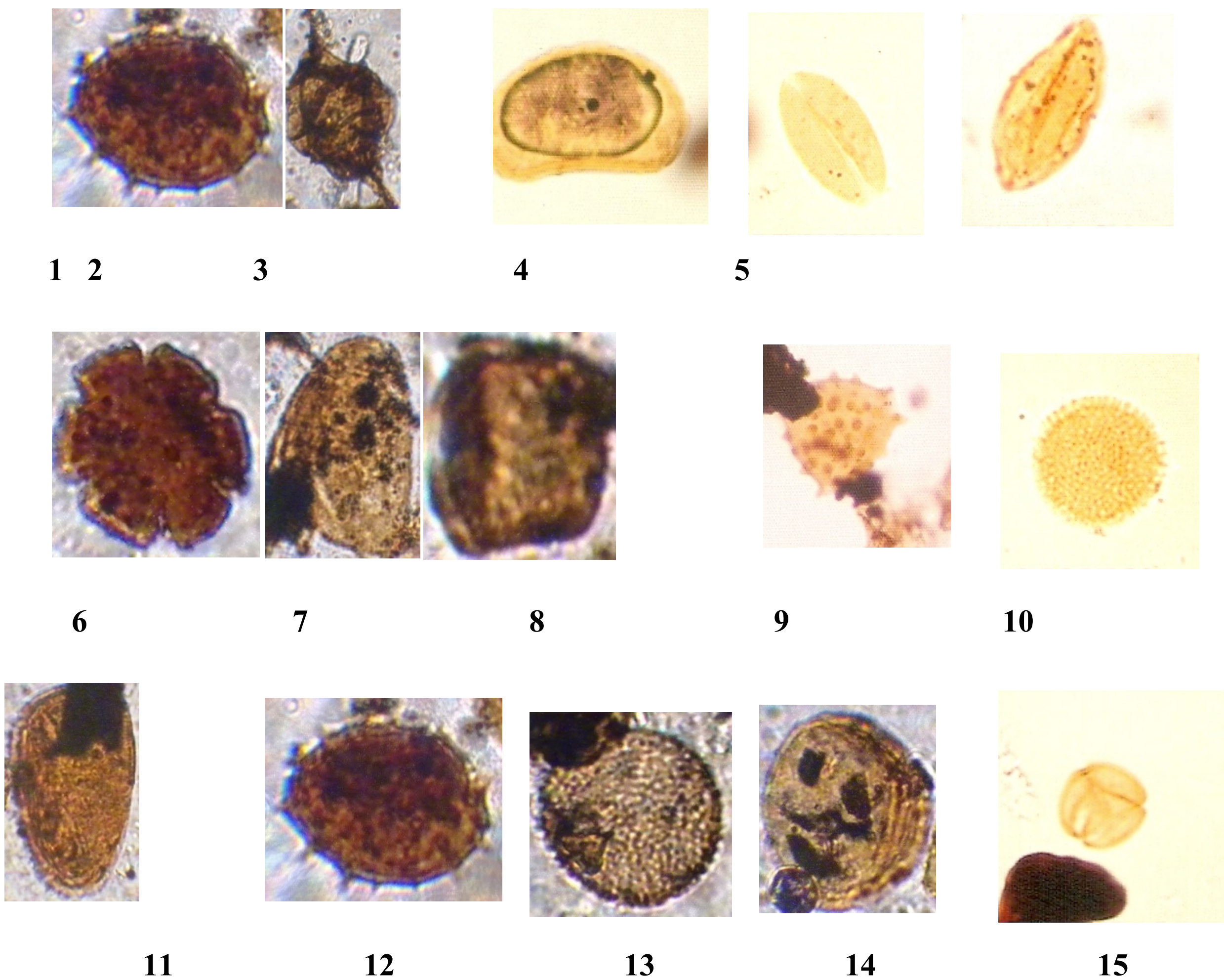


Plate 4.12. Palynomorph assemblage of interval 847-1372 m

1 *Mauritiidites crasibaculatus*
2 *Andalusiella polymorpha*
3 *Verrucatosporites* sp.
4 *Monosulcites* sp.
5 *Retimonocolpites* sp.
6 *Retistephanocolpites williamsi*
7 *Longapertites marginatus*
8 *Retidiporites magdalenensis*
9 *Echitriporites trianguliformis*

10 *Constructipollenites ineffectus*
11 *Longapertites microfoveolatus*.
12 *Mauritiidites crasibaculatus*
13 *Proxapertites cursus*
14 *Proxapertites operculatus*
15 *Syncolporites marginatus*

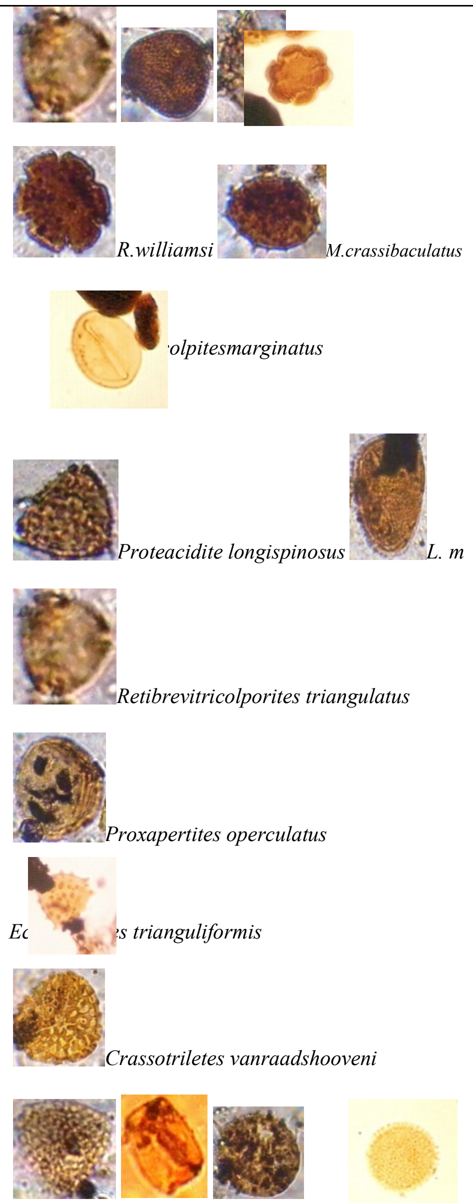
Depth (m)	**Lithology**	**Formation**	**Marker fossils**	**Age**
8258 266 273 282 343 377 390 418		Nsukka		Late Maastrichtian

Figure 4.16. Marker fossil appearances with depth in Zone 5

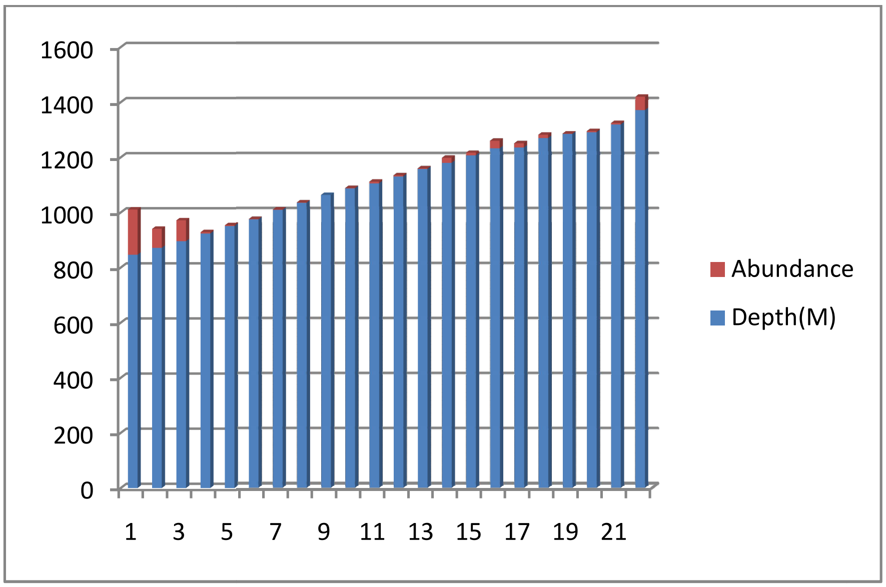


Figure 4.17. Depth-Abundance plot for the upper part of Zone 5

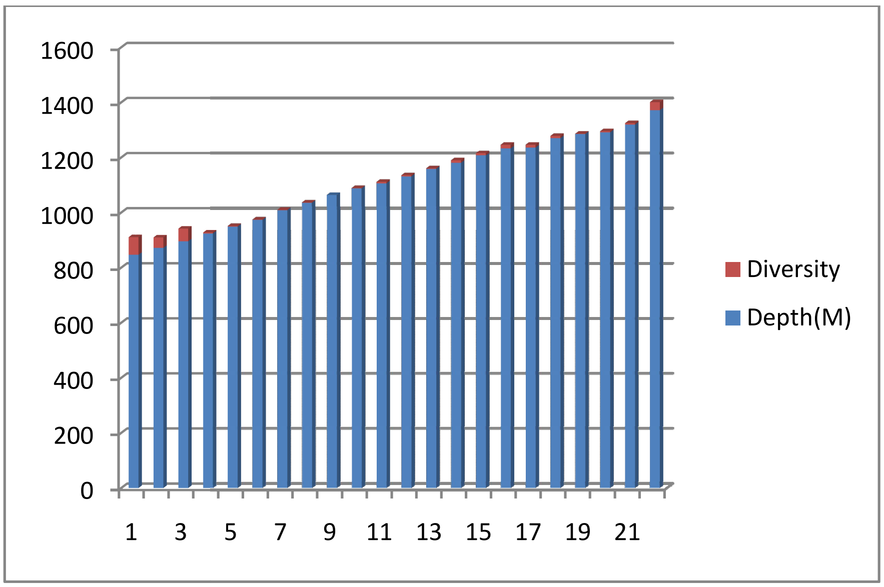


Figure 4.18. Depth-Diversity plot for the upper part of Zone 5

Magnification ×800

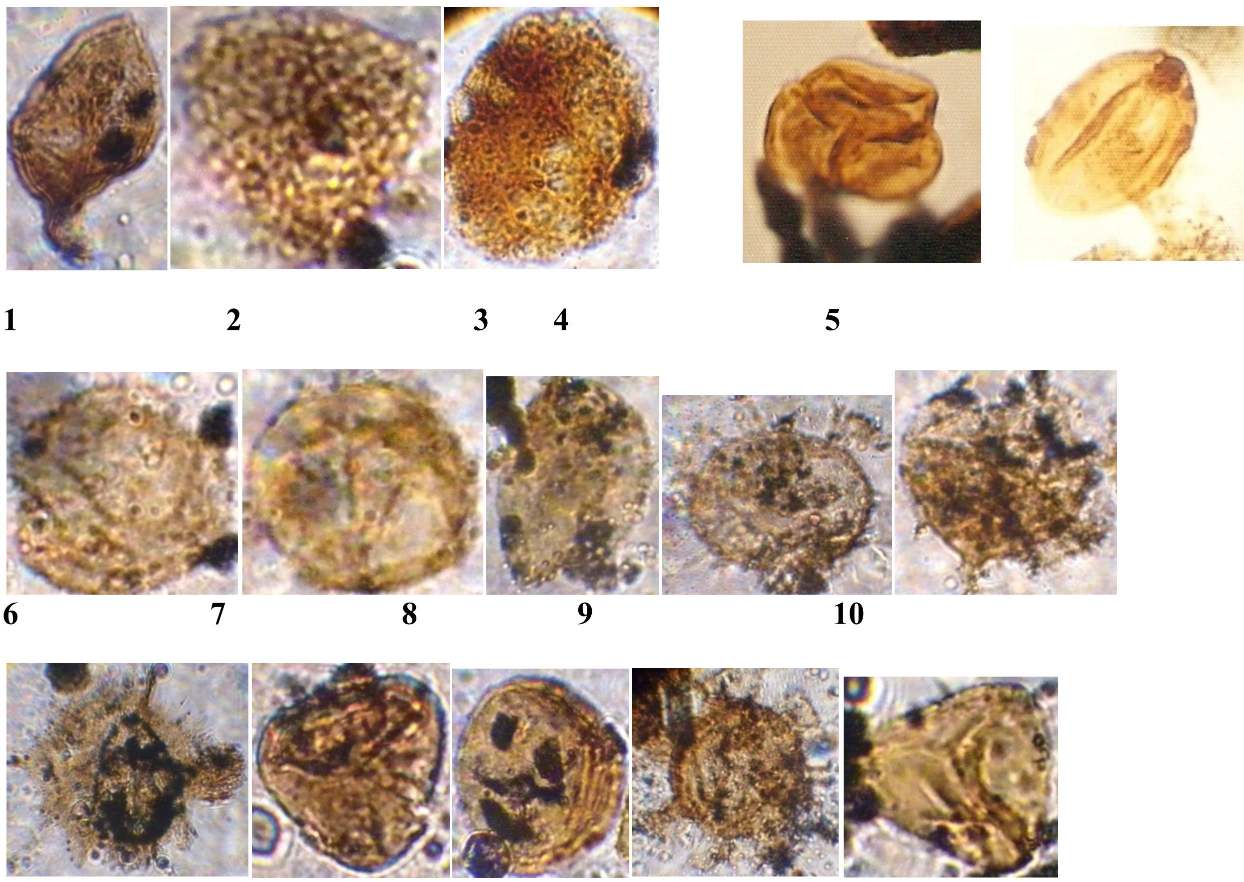


Plate 4.13. Palynomorph assemblage of interval 847-1372 m

1 Indeterminate dinocyst
2 *Echitriporites trianguliformis*
3, *Periretisyncolpites* sp.
4 *Tetradites* sp.**Kotova (1984).**
5 *Tricolpites* sp.
6 *Retidiporites magdalenensis*
7 *Batiacasphaera* sp.
8 *Longapertites marginatus*
9 *Oligosphaeridium* sp.

10 Dinoflagellate cyst
11 *Florentinia* sp.
12 *Cyathidites* sp.
13 *Proxapertites operculatus*
14 *Oligosphaeridium pulcherrimun*
15 *Cyathidites australis*

Magnification ×800

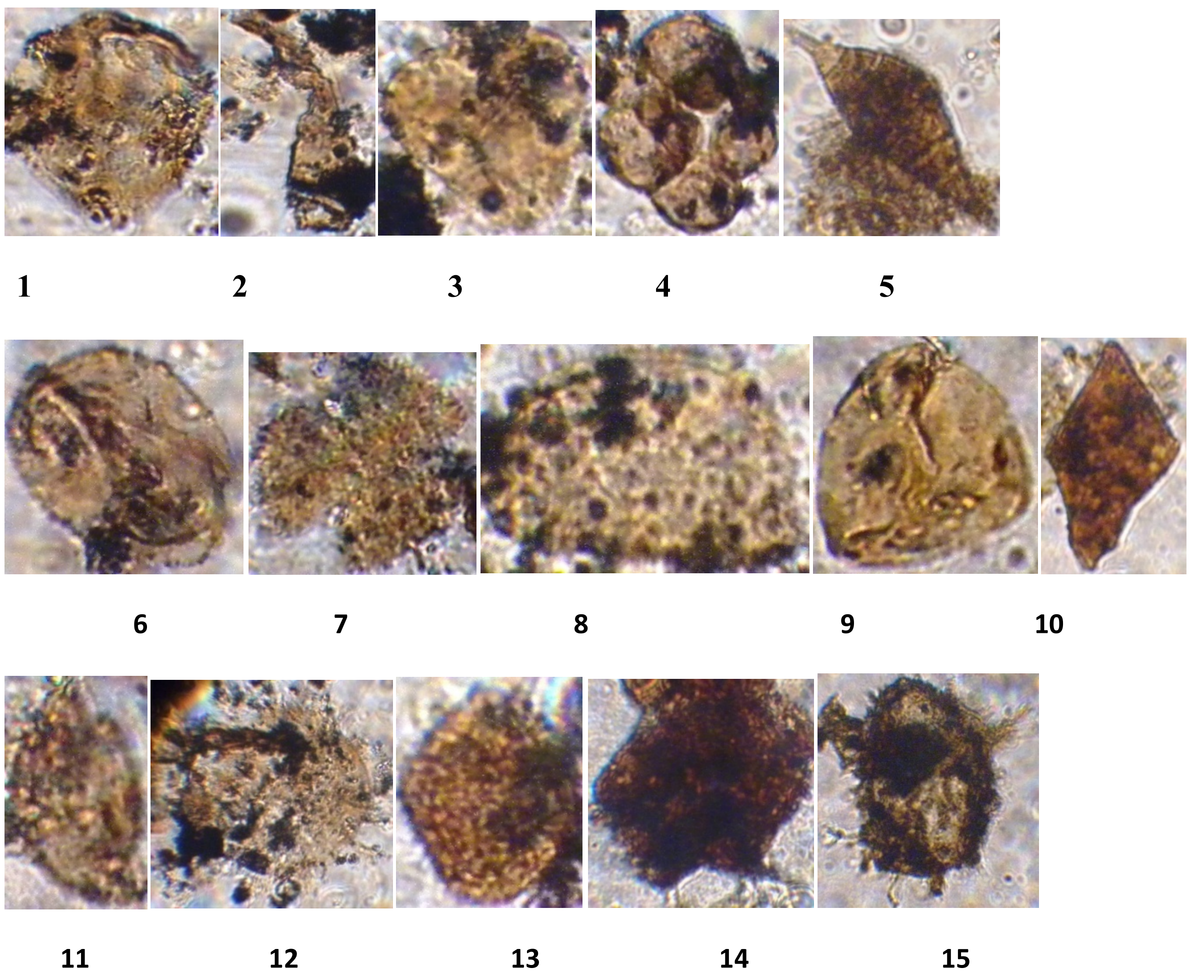


Plate 4.14. Palynomorph assemblage of interval 847-1372 m
1 *Triporites* sp.
2 *Odontochitina* sp.
3 *Cyathidites* sp.
4 Microforaminiferal wall lining
5 Fungal spore
6 *Cyathidites australis*
7 *Tricolpites gigantoreticulatus*
8 *Longapertites marginatus*

9 *Cupanieidites reticularis*
10 *Andalusiella polymorpha*
11 *Auriculiidites* sp.
12 *Oligosphaeridium* sp.
13 *Phelodinium* sp.
14 *Senegalinium bicavatum*
15 *Florentinia* sp.

Magnification ×800

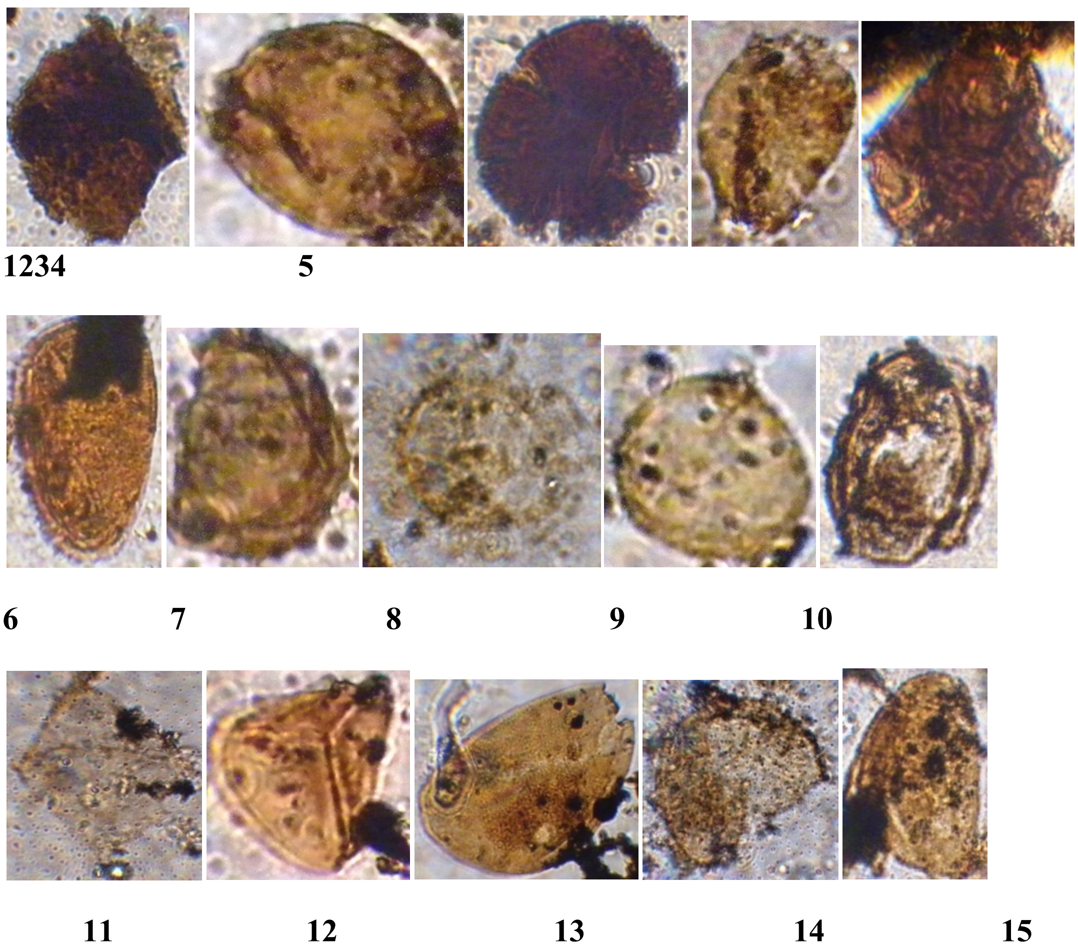
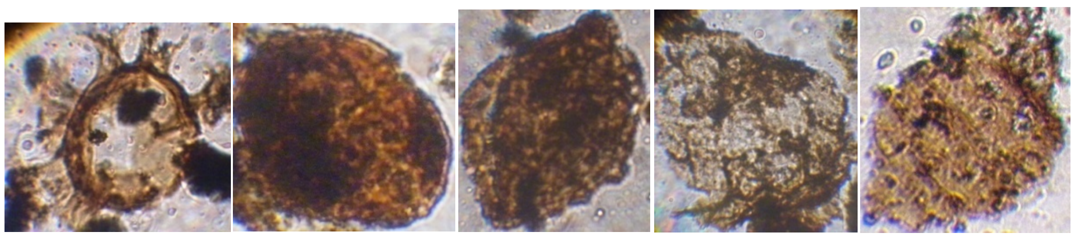


Plate 4.15. Palynomorph assemblage of interval 847-1372 m

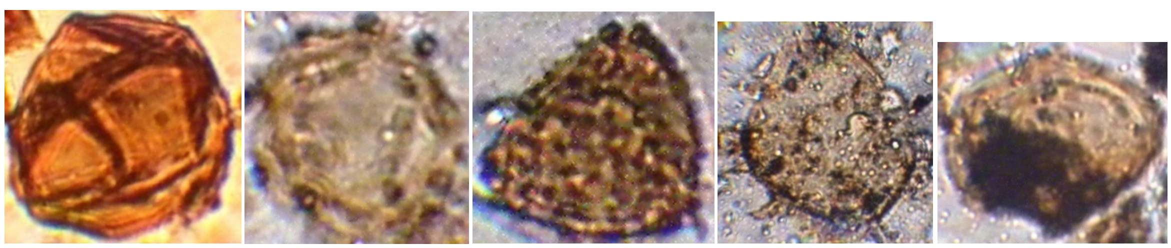
1 *Subtilisphaera* sp.
2 Triporate pollen
3 *Stephanocolpites*sp.
4 *Retidiporites magdalenensis*
5 *Subtilisphaera* sp.
6 *Longapertites microfoveolatus*
7 *Longapertites verneendenburgi*
8 *Oligosphaeridium* sp.

9 *Retitriporites* sp.
10 Indeterminate pollen
11 *Subtilisphaera* sp.
12 *Cyathidites* sp.
13,15 *Longapertites marginatus*
14 *Caningia* sp.

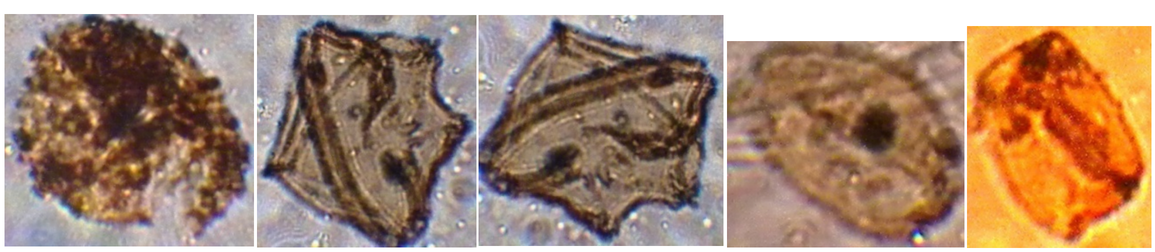
Magnification ×800



1234 5



678 9 10



11 12 13 14 15

Plate 4.16. Palynomorph assemblage of interval 847-1372 m
1 *Oligosphaeridium pulcherrimun*
2 *Monocolpopollenites sphaeroidites*
3 *Cf Subtilisphaera* sp.
4 Forma
5 *Botryococcus brunii*
6-7 *Batiacasphaera* sp.
8 *Proteacidites longispinosus*

9 *Oligosphaeridium* sp.
10 *Inaperturopollenites* sp
11 Cf. *Distaverrusporites* sp.
12-13 *Peridinacae* sp. (Forma T1)
14 *Monocolpites* sp.
15 *Retidiporites magdalenensis*

Magnification ×800

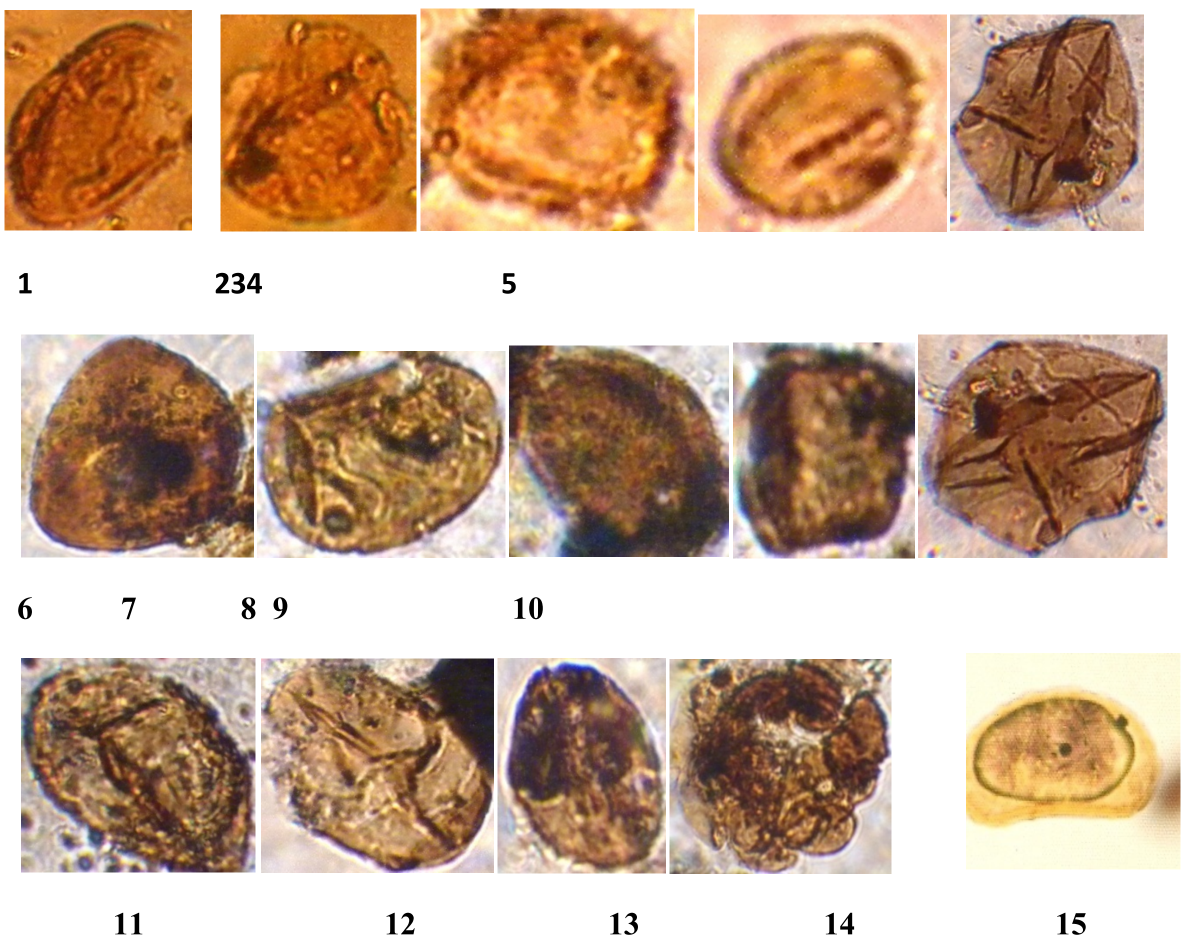


Plate 4.17. Palynomorph assemblage of interval 847-1372 m

1 *Longapertites marginatus*

2 *Monosulcites* sp.

3 ?*Monocolpites* sp.

4 *Tricolpites* sp.

5,10 *Andalusiella laevigata*

6 *Foveolatus margaritae*

7 *Laevigatosporites* sp.

8 *Longapertites marginatus*

9 *Retidiporites magdalenensis*

11-13 *Monocolpites* sp.

14 Microforaminiferal wall lining

15 *Verrucatosporites* sp.

Magnification ×800

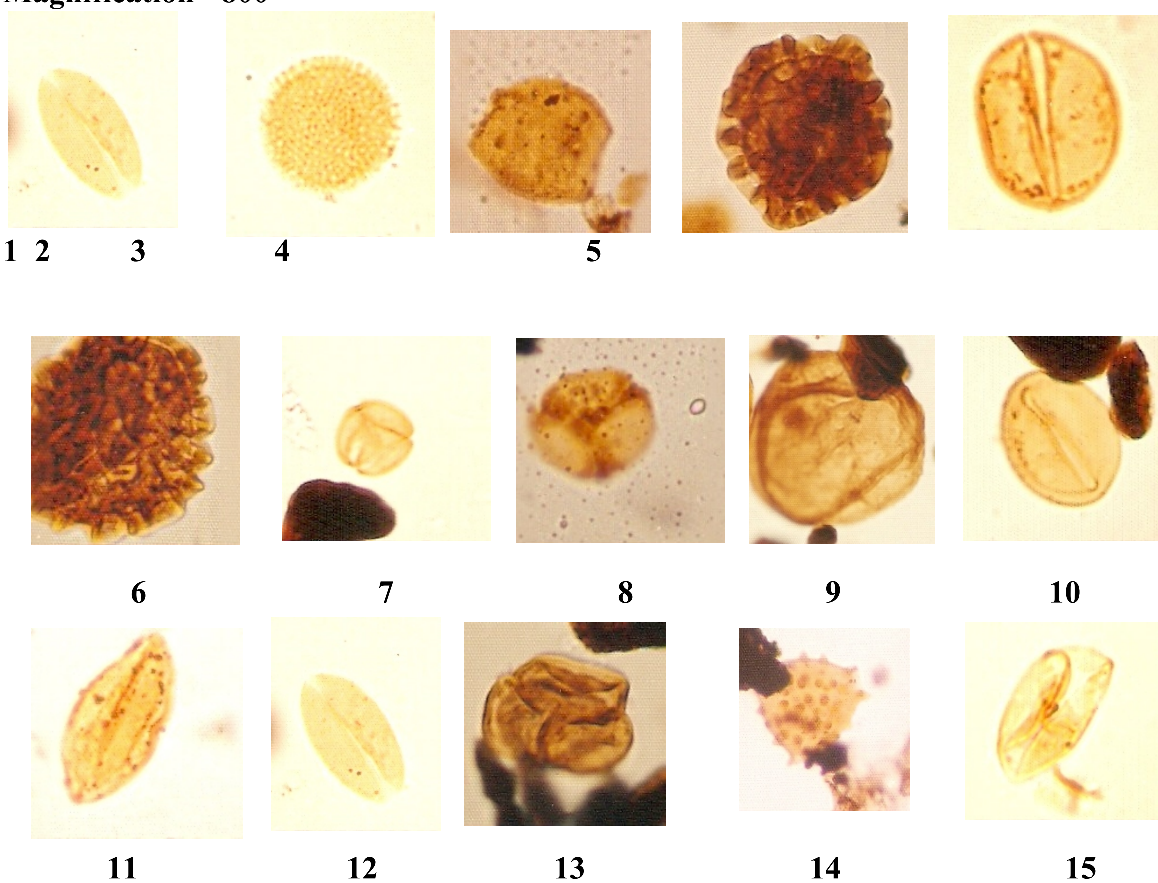


Plate 4.18. Palynomorph assemblage of interval 847-1372 m

1 *Monosulcites* sp.

2 *Constructipollenites ineffectus*

3 *Retidiporites magdalenensis*

4,6 *Periretisyncolpites* sp.

5,10 *Monocolpites marginatus*

7-8 *Syncolporites marginatus*

9 *Inaperturopollenites* sp.

11 *Retimonocolpites* sp.

12,15 *Monosulcites* sp.

13 *Tetradites* sp.

14 *Echitriporites trianguliformis*

Magnification ×800

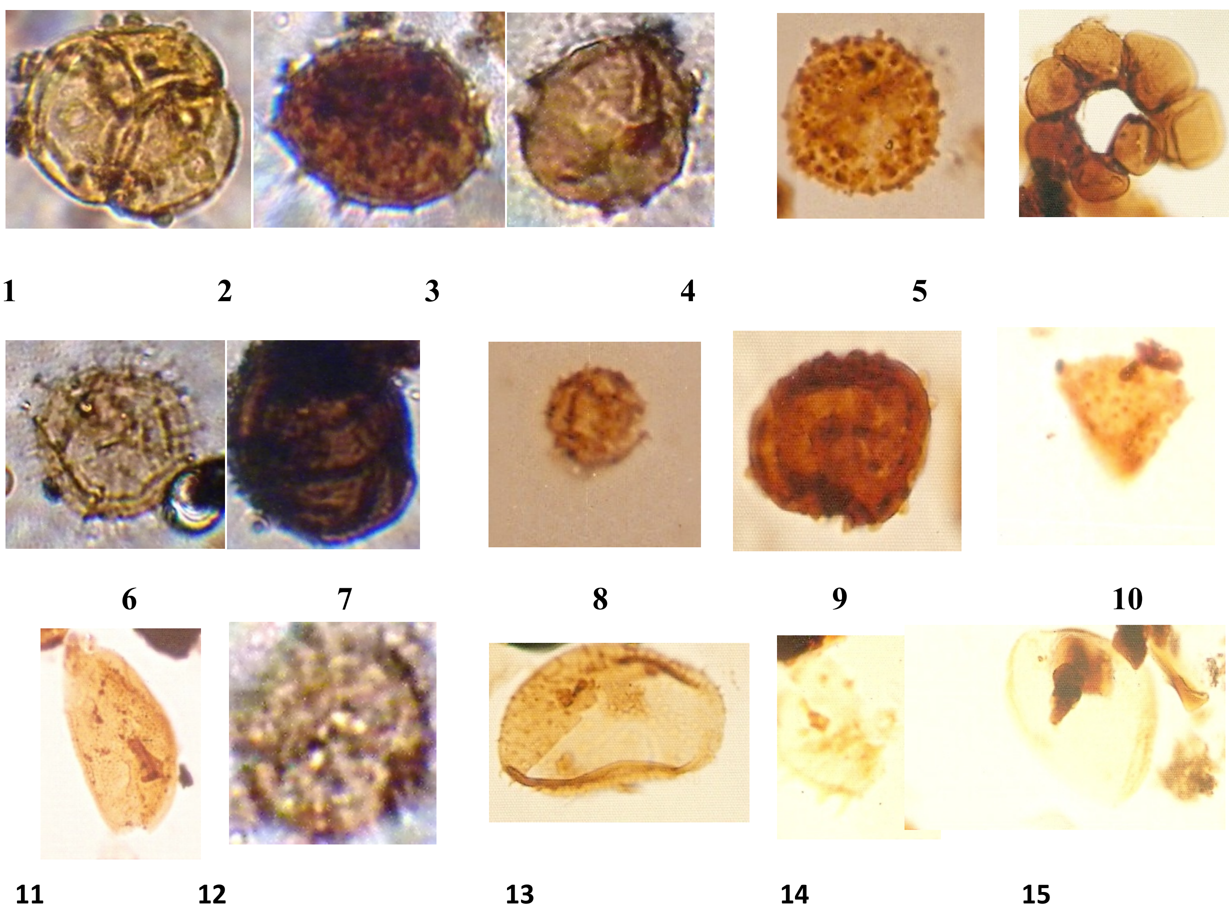


Plate 4.19. Palynomorph assemblage of interval 847-1372 m

1 *Gemmatetradites* sp.

2 *Mauritiidites crasibaculatus*

3 *Proteacidites longispinosus* **Jardine & Magloire (1965)**

4,9 *Spinizonocolpites baculatus***Muller (1968)**

5 Microforaminiferal wall lining

6 *Spiniferites mirabilis*

7 *Batiacasphaera* sp.

8 *Spinizonocolpites echimatus*
10 *Proteacidites* sp.
11,15 *Longapertites verneendenburgi* **Germeraad *et al.* (1968)**
12 *Tricolpites* sp. (Cf. *T. giganteus*)
13-14 *Spinizonocolpites echinatus* **Muller (1968)**

Magnification ×800

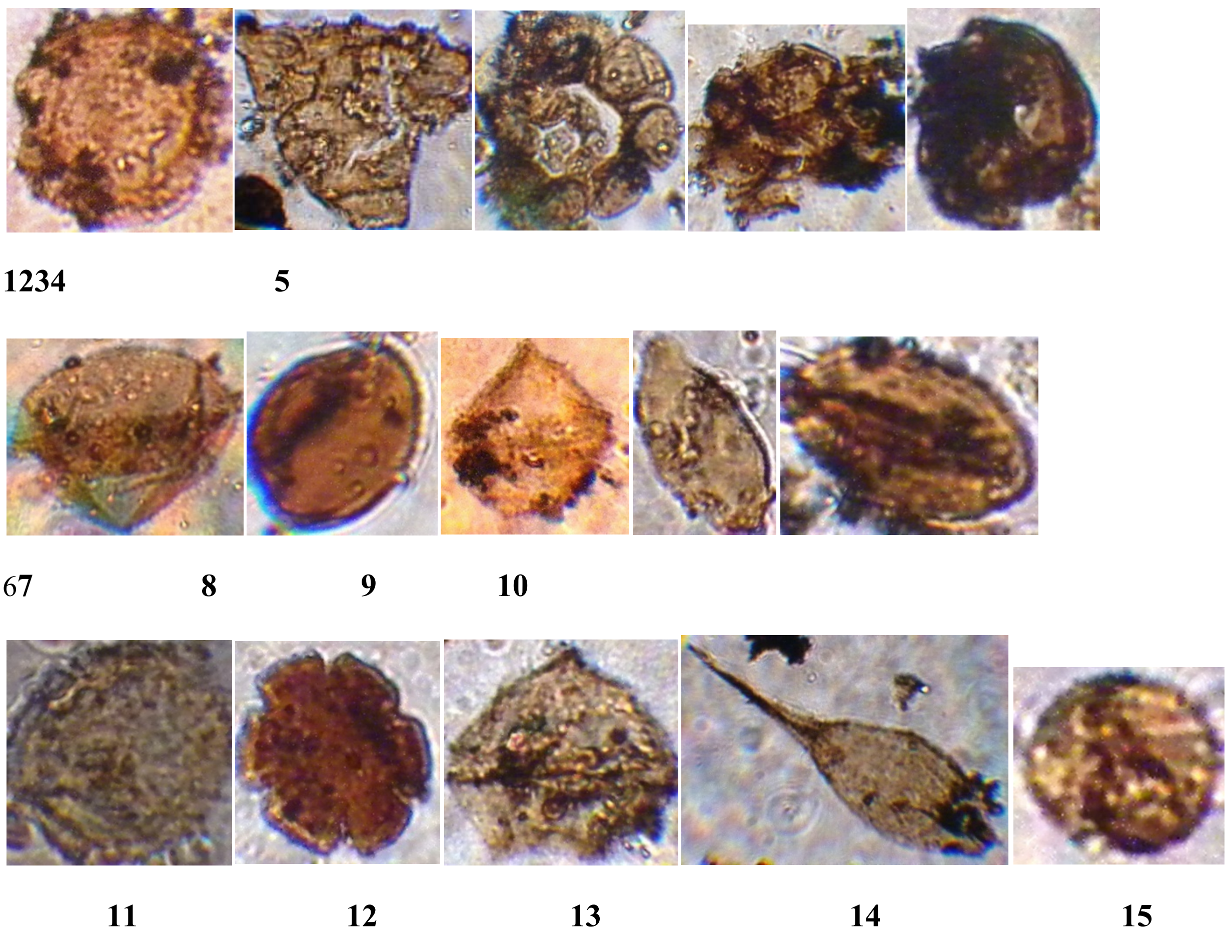


Plate 4.20. Palynomorph assemblage of interval 847-1372 m
1 ?*Gonyaulacysta* sp.
2 *Subtilisphaera* sp. 1 (Forma J)
3 Microforaminiferal wall lining (Spiral type)
4 *Callaiosphaeridinium asymmetrinun*
5 *Spinidinium* sp.
6 *Araucariacites* sp.
7 *Monocolpites marginatus*

8 *Criroperidinium edwardsii*
9 *Longapertites microfoveolatus*
10 *Monosulcites* sp.
11 *Proxapertites cursus*
12 *Retistephanocolpites williamsi* in
13 *Cribroperidinium* sp.1
14 *Palaeocystodinium* sp.
15 *Tricolpites* sp. 2

ZONE 6:*Mauritiidites crassibaculatus* Assemblage Zone

The Zone 6 is located in interval 518-847 m, dated Early Paleocene. The lower part of this zone coincides with the top of Zone 5 characterised by the last downhole occurrence of *Mauritiiditescrassibaculatus* (Plate 4.21,no. 1), *Longapertitesverneendenburgi*(Plate 4.21, no. 5), *Retistephanocolpites williamsi* (Plate 4.21, no. 2), *Uimoideipites krempii* (Plate 4.21, no. 4),and *Psilatricolpites irregularis* (Plate 4.21, no. 6).Other forms appearing at this level include *Graminidites* sp.(Plate 4.21, no. 7), *Ctenolophoniditescostatus* (Plate 4.21, no. 10), *Lycopodium fasgioides* (Plate. 4.21, no. 8), *Proteacidites sigali*(Plate 4.21, no. 11), *Brevitriporites guineitii and Anacolosidites luidonisis.*The base is further defined by high recovery and diversity of sporomorphs that usually characterize the top of Maastrichtian (Lawal and Moullade, 1986) (See Figure 4.1). The basal part of the zone is also marked by the continuous appearance of *Periretisyncolpitesgiganteus*, *Periretisyncolpites*sp.,*Foveotriletesmargaritae* and *Monocolpitesmarginatus*. Forms with new appearances at near bottom of the interval are *Proxapertitesoperculatus* and *Retibrevitricolporitestriangulatus*.

Periretisyncolpitesgiganteus and *Retidiporitesmagdalenensis* showfirst downholeoccurrencein the upper part of the interval. Microflorals that show extinction within the zone are *Mauritiiditescrassibaculatus*, *Constructipollenitesineffectus*, *Foveotriletesmargaritae*, *Retistephanocolpiteswilliamsi*, and *Zlivisporitesblanensis*. The upper part of Zone 6 is characterisedby the new appearance of *Monoporitesannulatus* (Plate 4.21, nos. 3), *Pachydermitesdiederixi* (Plate 4.21, no. 9) and *Psilatricolporitescrassus* (Plate 4.21, no. 15) (See Fig. 4.19). Other stratigraphically important forms recovered were presented in Plates 4.21-4.25.

Germeraad *et al*. (1968) described the occurrence of *Monoporitesannulatus*, *Pachydermitesdiederixi*, and *Psilaticolporitescrassus* in Pan Tropical region sediments to indicate Eocene deposit. The zone is similar in-part to *Proteaciditesdehaani* Zone established by Germeraad *et al*. (1968).

Magnification ×800

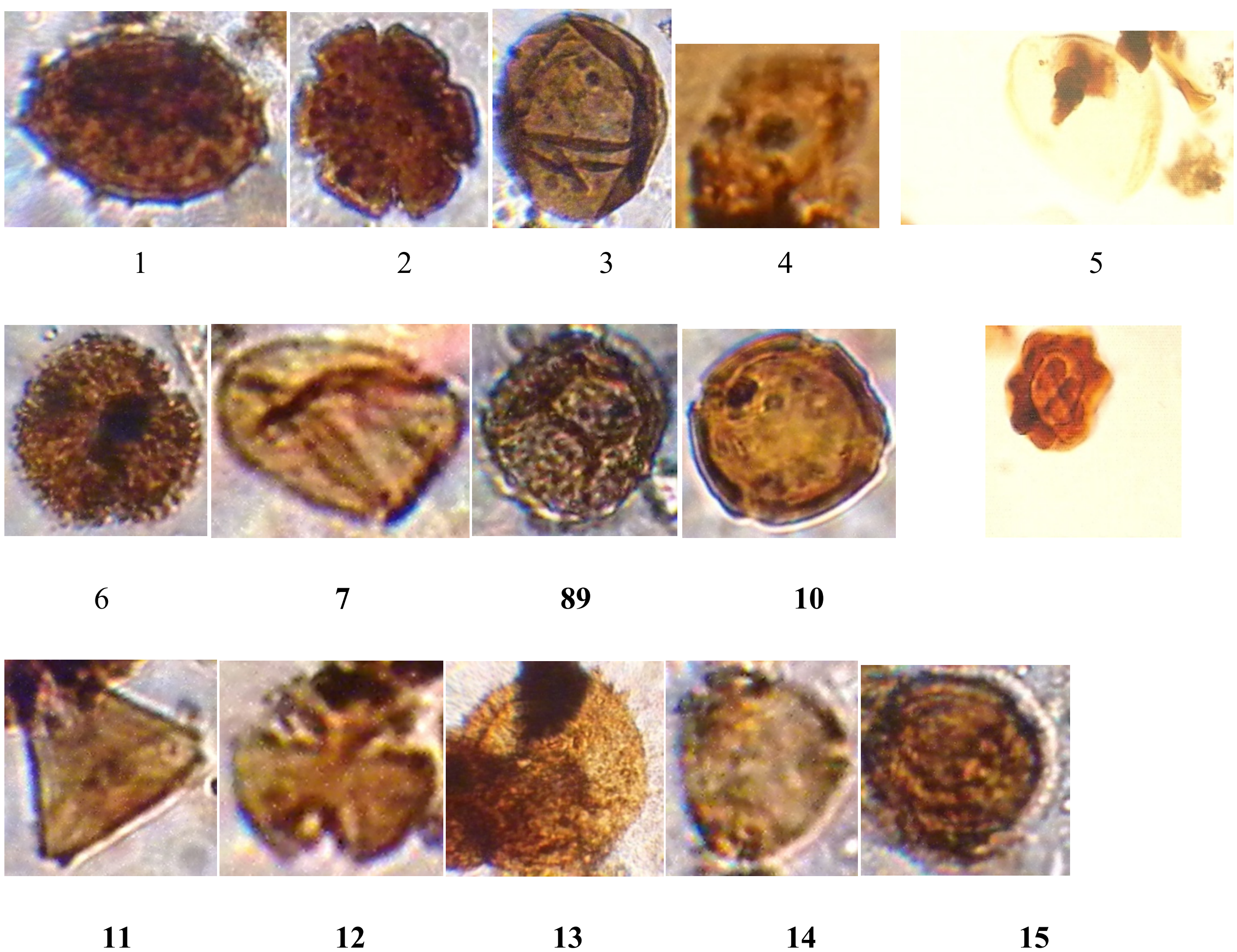


Plate 4.21. Palynomorph assemblage of interval 518-847 m

1 *Mauritiidites crassibaculatus*

2 *Retistephanocolpites williamsi*

3 *Monoporites annulatus*

4 *Ulmoideipites* sp.
5 *Longapertites verneendenburgi*
6 Psilatricolpites irregularis
7 *Graminidite* sp.**Jardine and Magloire(1965).**
8 *Lycopodiumsporites fastigioides***Boltenhagen (1967)**
9 *Pachydermites diederixi*
10 *Ctenolophonidites costatus*
11 *Proteasidites sigali***Boltenhagen(1978)**
12 *Tricolpites* sp. (Cf. 396 of Shell)**Jardine & Magloire(1965).**
13 *Mauritiidites* sp.
14 *Retibrevitricolporites triangulatus*
15 *Psilatricolporites crassus*

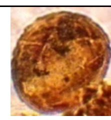
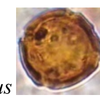
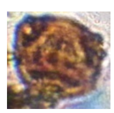
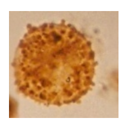
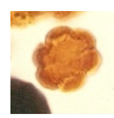
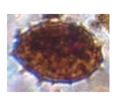
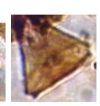
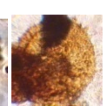
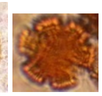
Depth (m)	**Lithology**	**Formation**	**Marker fossils**	**Age**
518 817 847		Imo	 *Psilatricolporitescrassus*  *P. diederixi*  *Monoporites annulatus* *Ctenolophonidites costata*    *P. triangulatusMauritiidites sp.*    	Early Paleocene

Figure 4.19. Marker fossils appearances with depth in interval 518-847 m

Magnification ×800

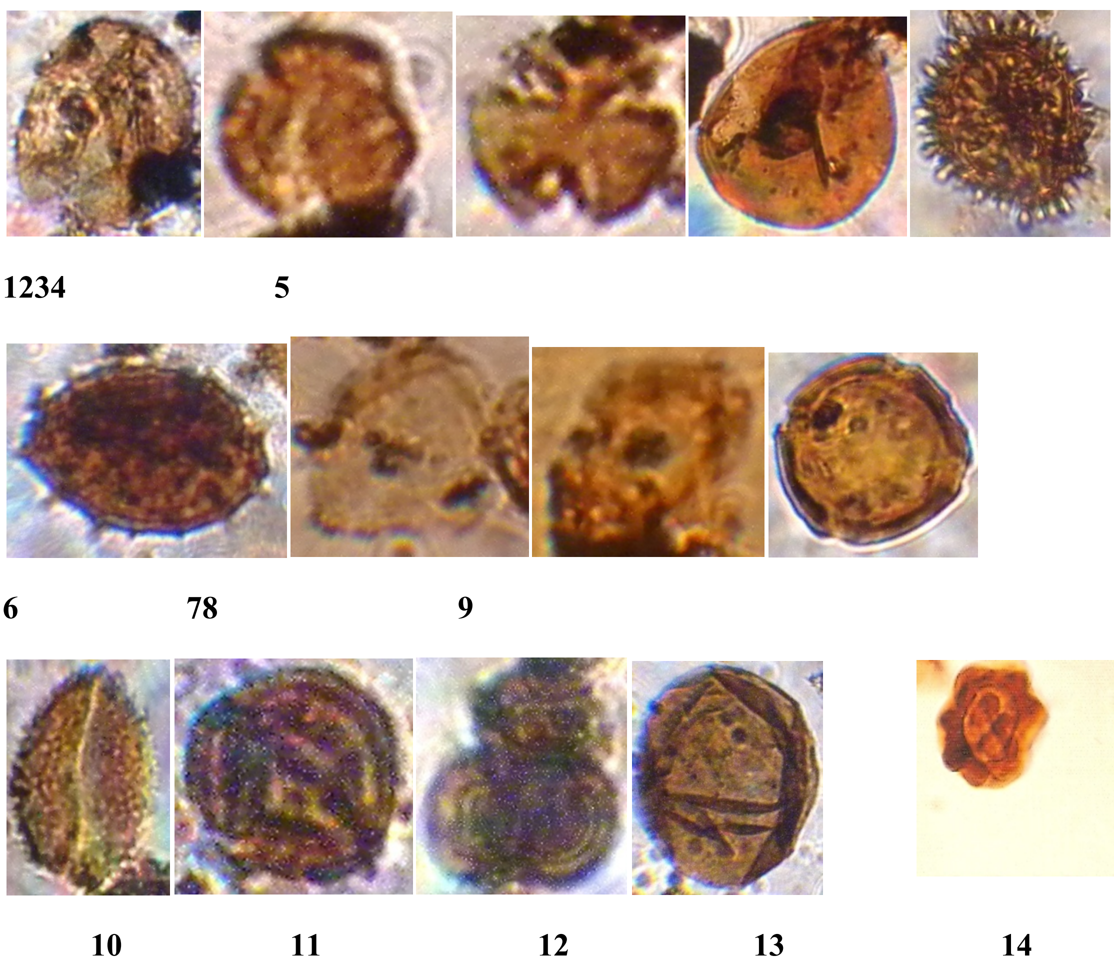


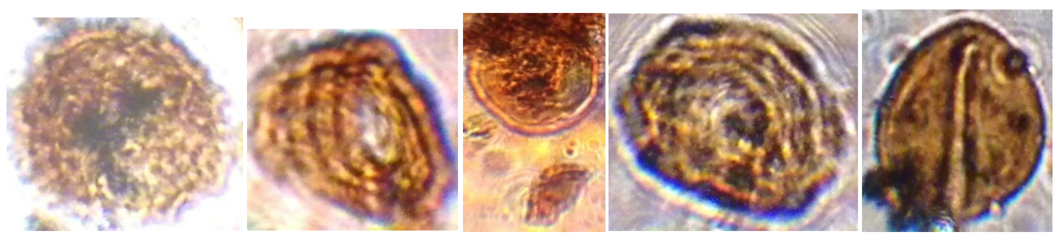
Plate 4.22. Palynomorph assemblage of interval 518-847 m

1 *Inaperturopollenites* sp.

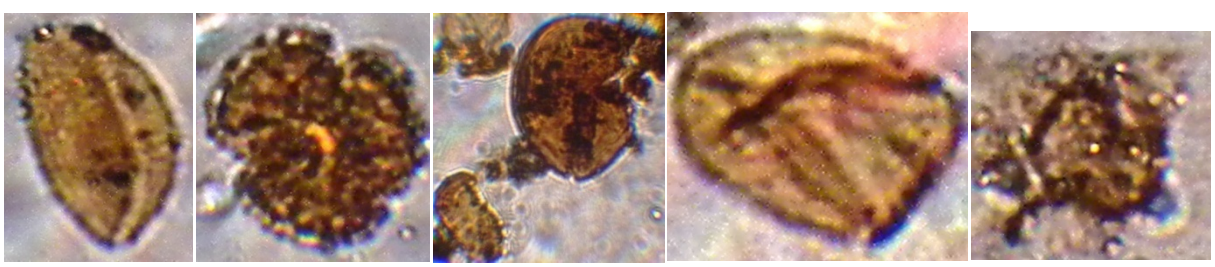
2-3.1 *Tricolpites* sp. (Cf. 396 of Shell) **Jardine & Magloire (1965).**

4 Leiotriletessp.
5 *Spinizonocolpites echinatus*
6 *Mauritiidites crassibaculatus* **Van Hoeken-Klinkenberg (1964).**
7 Indeterminate dinocyst
8 *Ulmoideipites* sp.
9 *Pachydermites diederixi*
10 *Retimonocolpites* sp.
11 *Retitricolporites* sp.
12 *Tetradites* sp.
13 *Monoporites annulatus*
14 *Ctenolophonidites costatus*

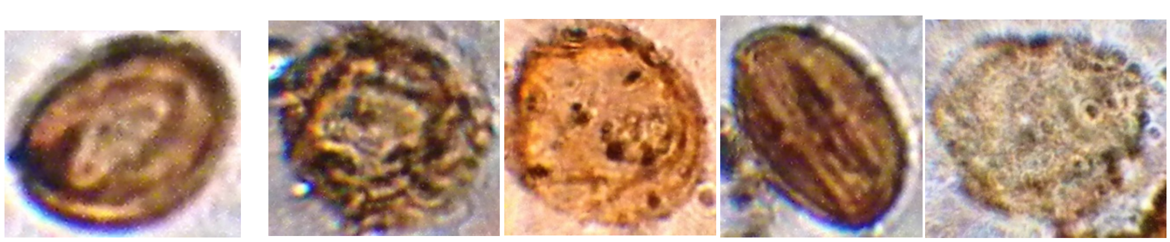
Magnification ×800



1234 5



6 7 8 9 10

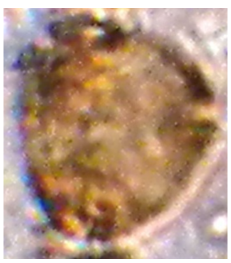
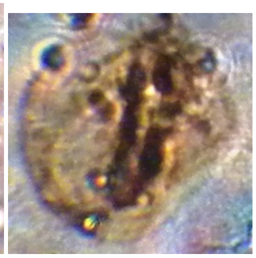
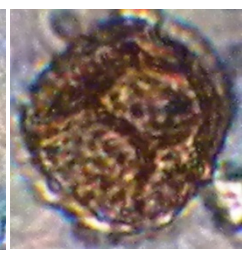
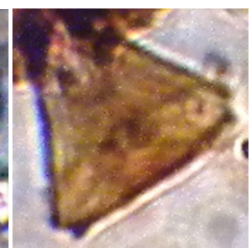
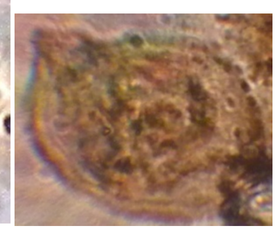


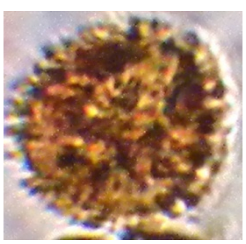
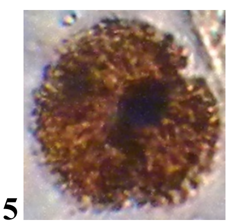
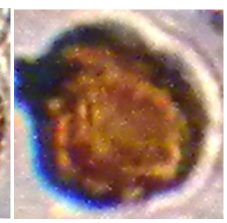
11 12 13 14 15

Plate 4.23. Palynomorph assemblage of interval 518-847 m
1 *Ulmoideipites krempii* **Anderson (1960); Elsik(1968).**

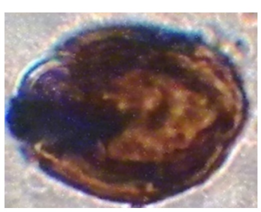
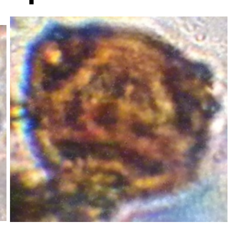
2,4 Indeterminate (Forma T2)
3 Upper pix: *Leiotriletes* sp.
Lower pix: *Longapertites* sp.
5 *Monocolpites marginatus*
6 *Longapertites marginatus*
7 *Retitricolpites* sp. (Cf. 501 of Shell)
8 Upper pix: *Leiotriletes* sp.
Lower pix: *Mauritiidites crassibaculatus*
9 *Graminidite* sp.
10 *Thalassiphora* sp.**Lawal (1982).**
11 *Monocolpites* sp. 2
12 *Triporites* sp.(cf. Retibrevitricolporites triangulatus)
13 *Triporites* sp. (cf 459 of Shell)
14 *Tricolporopollenites* sp.
15 *Triporites* sp. (cf. 459 of Shell)

Magnification ×800

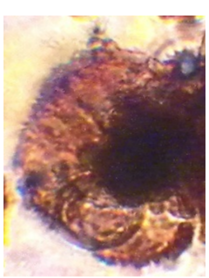
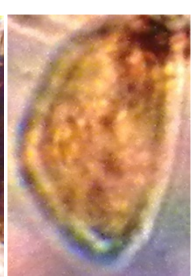
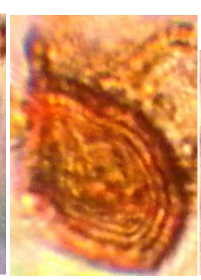
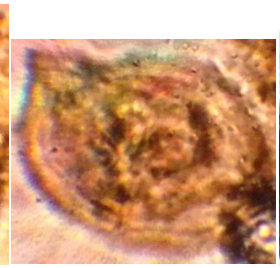
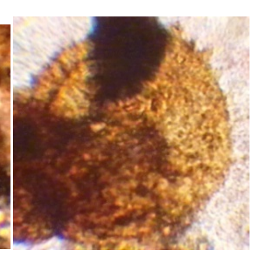






123 **4** **5**

678 **9** **10**

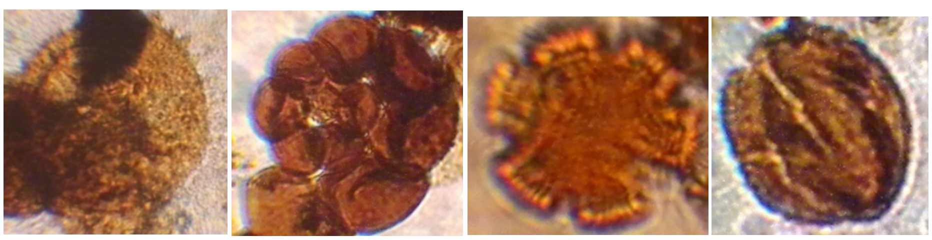






11 12 13 14 15

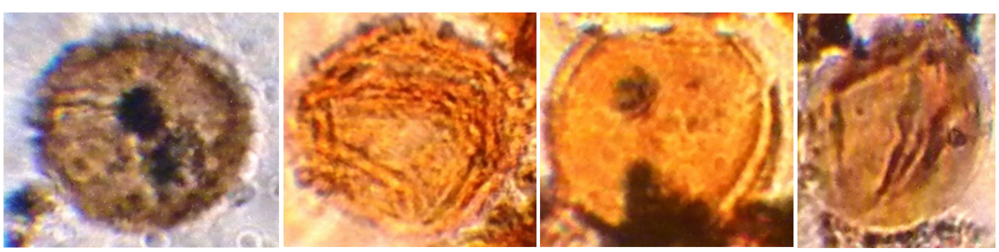
Plate 4.24. Palynomorph assemblage of interval 518-847 m

1 *Retibrevitricolporites triangulatus* **Germeraad *et al*. (1968)**
2 Indeterminate dinocyst
3 *Lycopodiumsporites fastigioides* **Boltenhagen (1967)**
4 *Proteasidites sigali* **Boltenhagen (1978)**
5, 14 Indeterminate dinocyst (Forma T4)
6-7 *Retitricolporites* sp.
8 *Triporites* cf. *Iverseni*
9 *Monoporite* sp.
10 *Psilatriporites triangularis*
11 *Trichodinium delicatum*
12 *Longapertites marginatus*
13 *Diconodinium* sp.
15 *Mauritiidites* sp.

Magnification ×800



1 234



5 6 7 8

Plate 4.25. Palynomorph assemblage of interval 518-847 m

1 *Mauritiidites* sp.

2 Microforaminiferal wall lining

3 *Retistephanocolpites williamsi*

4 *Tricolpites* sp.

5 *Polysphaeridium* sp. 2

6 *Batiacasphaera* sp.

7 Cf. *Proxapertites* sp.

8 *Tricolporopollenites* sp.

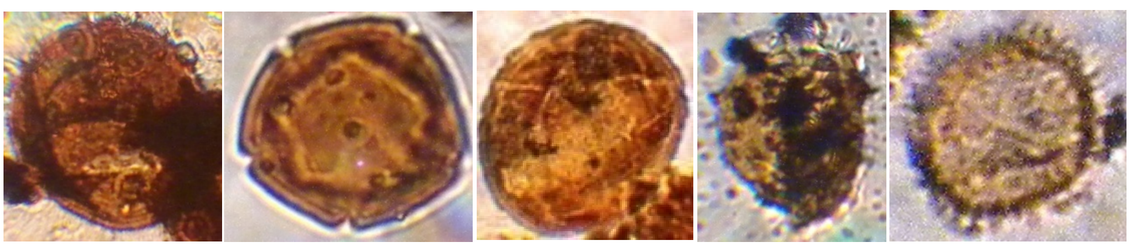
There is little or no sharp difference in the assemblages of microfloral observed in Zones 7 and 8 of Nzam-1 well, Anambra Basin, Nigeria. The only striking feature is the reduced abundance and diversity in sporomorphs recovered. The established Zone 8 for this well is equivalent to Zone P200 of Evamy *et al.* (1978) characterised by basal occurrence of *Mauritiidescrassibaculatus* and quantitative recovery of *Leiotriletes*sp. (See Figure 4.1). The microfloral of this zone is as well similar to miospore assemblages of Kerrikerri Formation, dated Paleocene age (Adegoke *et al*., 1978). It is also similar to floral fossils described by Jan Muller *et al.* (1987) in the palynological zonal scheme of sediments in Venezuela.

The uppermost sediment of Paleocene age is suggested to have been eroded in the Anambra Basin before the deposition of the Eocene sediments. Therefore, an unconformity is suggested to exist between the Paleocene deposits and Eocene sediments in the basin due to non-presence of overlying zone that precedes the Eocene deposits.The *Mauritiiditescrassibaculatus*assemblage zone 8 is here dated Early Paleocene age and stratigraphically belong to Imo Formation. This assigned age is in contrary to Selondian-Aquitanian age erected by Umeji (2005). Palynological evidences that could suggest such younger age do not exist in the analysed section.

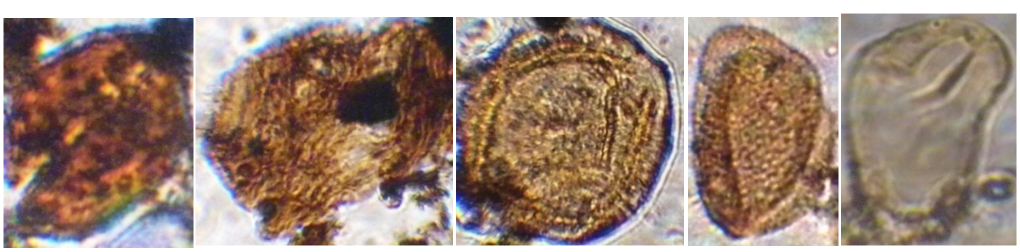
ZONE 7:*Monoporites annulatus* Assemblage Zone

The zone is restricted within interval 390-518 m, dated Middle Eocene. The lower part of the zone was defined based on the last down-hole appearance of *Monoporitesannulatus* (Plate 4.28, no. 5),*Pachydermitesdiederixi* (Plate 4.28, no. 2),*Psilatricolporitescrassus*(Plate 4.28, no. 3)and near base appearance of *Grimsdalae magnaclavata* (Plate 4.28, no. 4). The zone is also characterised by the disappearance of Maastrichtian forms that continued into Paleocene found in the underlying zone 8, comprising of *Periretisyncolpitesgiganteus*,*Retidiporitesmagdalenensis*,*Foveotriletesmargaritae*,*Mauriitiditesc rassibaculatus* (Plate 4.26, no. 6),*Constructipollenitesineffectus*,*Zlivisporitesblanensis*, and *Retistephanocolpteswilliamsi*.

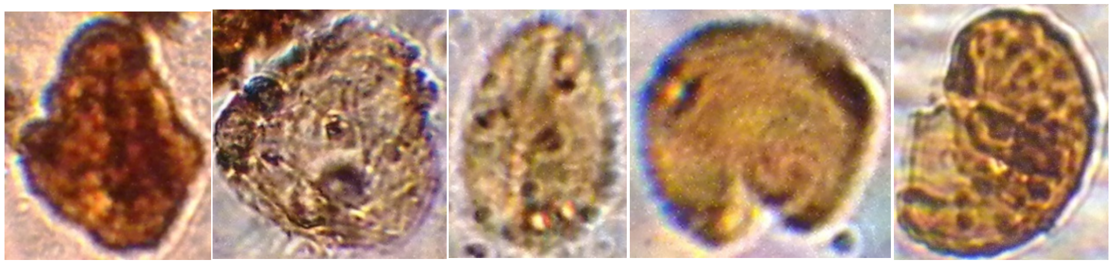
Magnification ×800



1 2 3 4 5



6 7 8 9 10



11 **12** **13** **14** **15**

Plate 4.26. Palynomorph assemblage of interval 390-518 m
1 *Monoporites annulatus*
2 *Pachydermites diederixi*
3 *Psilatricolporutes crassus*
4 *Grimsdalae magnaclavata*
5 *Polysphaeridium* sp. 1
6 *Mauritiidites crassibaculatus*
7 *Striatricolpites catatumbus*
8 *Perfotricolpites digitatus*
9 *Arecipites crassimuratus*
10 Laevigatosporites sp.
11 *Doualaidites laevigatus***Germeraad *et al.*, 1968.**
12, 13 *Retibrevitricolporites triangulatus*
14 *Monosulcites* sp.
15 *Verrucatosporites usmensis*

The near top of the zone 7 is characterised by new appearances of *Crototricolpites crotonoisculptus, ?Cicatricosisporites dorongensis, Striatricolpites catatumbus* (Plate 4 26, no. 7), *Perfotricolpites digitatus* (Plate 4.26, no. 8), *Arecipites crassimuratus*(Plate 4.26, no. 9) and *Doualaidites laevigatus*(Plate 4.26, no. 11). Germeraad *et al*. (1968)described them to have evolved and characterise Eocene age sediments in Nigeria (Fig. 4.20). The upper part of the interval is characterised by the occurrence of *Grimsdalae magnaclavata, Monosulcites* sp.(Plate 4.26, no. 14), *Leiotriletes*sp.; dinoflagellate cysts–*Polysphaeridium*sp. (Plate 4.26, no. 5),*Andalusiella*sp. (Plate 4.28, no. 7) and microforaminiferal wall linings (Plate 4.28, no. 4).

The interval is defined by continuous presence of angiosperm pollens, *Psilatricolporitescrassus*, *Verrucatosporites*sp.,*Laevigatosporites*sp (Plate 4.26, no. 10); continuous occurrence of *Grimsdalaemagnaclavata*, *Monoporitesannulatus*, *Proxapertites operculatus* and *Retibrevitricolporitestriagulatus*. New forms include*Cicatricosisporitesdorogensis*, *Crorotricolpitescrotonoiscultus, Crassotriletesvanraadshooveni* and *Perfotricolpitesdigitatus*.

Germeraad *et al.* (1968) described the occurrence of marker forms present in this zone such as *Monoporitesannulatus*, *proxapertitesoperculatus*, *Pachydermitesdiederixi*, *Perfotricolpitesdigitatus* and *Cicatricosisporitesdorogensis* to indicate Middle Eocene age.The assemblages observed in this zone are also similar to P400 Zone and Subzone P420 of Evamy *et al*. (1978); though the uppermost part of subzone P429 was not observed in the analysed interval.

The Early Eocene sediment is not present in the stratigraphic section analysed. These sediments may have been eroded or not deposited along with the underlying Upper Paleocene sediments. Thus, an unconformity exists between the overlying Eocene and the underlying Paleocene sediments.Therefore, the *Monoporites annulatus* Assemblage Zone 7 erected for the Nzam-1 well in Anambra Basin, Nigeria was conveniently assigned Middle Eocene age. An enigmatic form limited to Middle Eocene-*Grimsdalaemagnaclavata* was found (Salard Chaboldaeff, 1990). Hence, the zone can be compared with the Nsukka-1 borehole studies of Jan du Chene and Salami (1978), Coal Seam measure in Enugu studied by Hoeken Klinkenberg(1964), from Tuma-1 and Mushe-1 wells located in Bornu Basin, northeastern Nigeria (Ola-Buraimo, 2012, 2013) dated Eocene age. The Zone 9 interval is stratigraphically equivalent to Ameki Formation in the Anambra Basin.

Depth (m)	Lithology	Formation	Markerfossils	Age

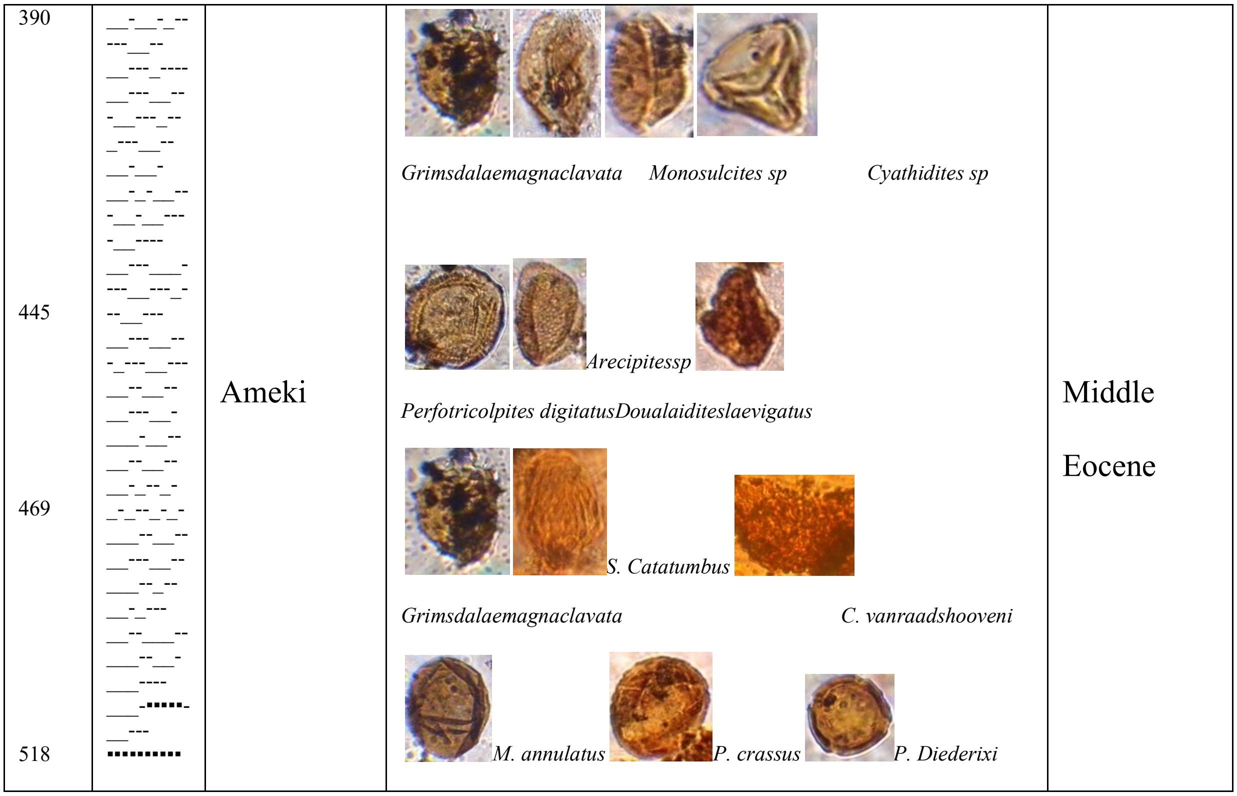
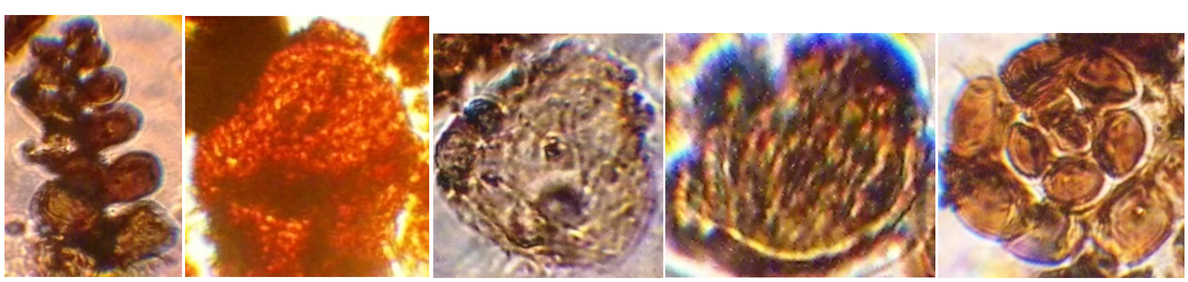
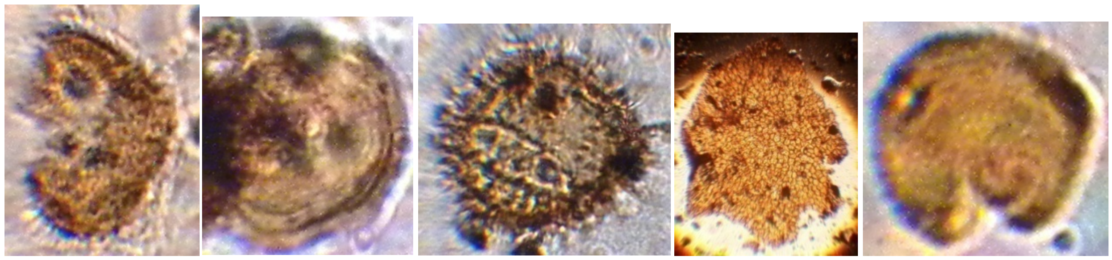


Figure 4.20. Marker fossils appearances with depth in interval 390-518 m

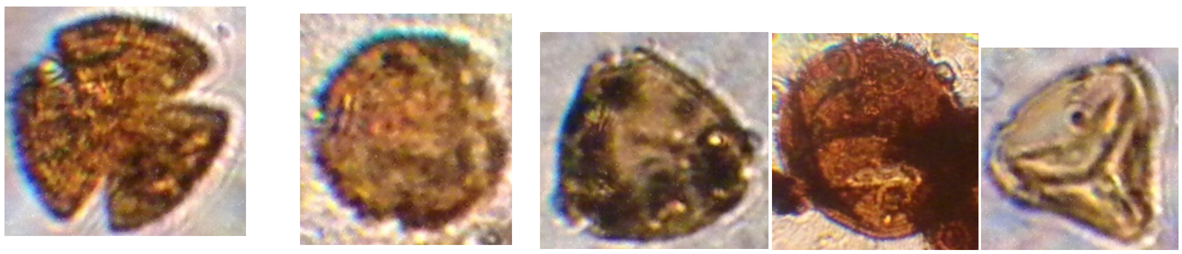
Magnification ×800



1234



6 7 8 9 10



11 12 13 14 15

Plate 4.27. Palynomorph assemblage of interval 390-518 m

1Microforaminiferal wall lining (bi-serial type)

2 *Monoporites* sp. 2

3 *Retibrevitricolporites triangulatus*

4 *Psilastephanocolpites* sp.

5 Microforaminiferal wall lining

6 ?*Cleistophaeridium* sp.

7 *Proxapertites cursus*

8 *Cleistophaeridium* sp.

9 Forma R

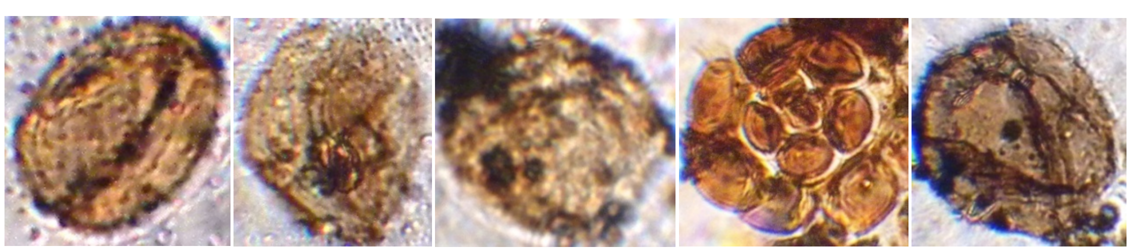
10,13 *Retibrevitricolporites triangulatus*

11,12 *Tricolpites* sp.

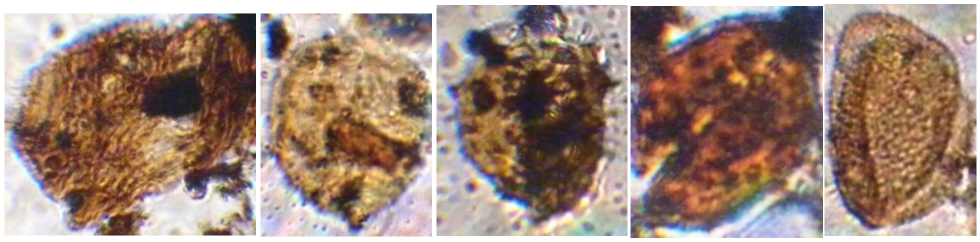
14 *Monoporites annulatus*

15 *Cyathidites* sp

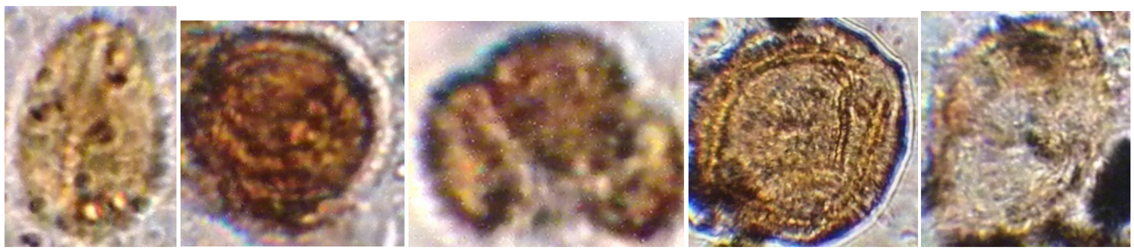
Magnification ×800



1234 5



6 7 8 9 10



11 12 13 14 15

Plate 5.28. Palynomorph assemblage of interval 390-518 m

1 *Monocolpites marginatus*
2 *Monosulcites* sp.
3 *Corsinipollenites jussiaeensis* (456 of shell)
4 Microforaminifral wall lining (spiral)
5 *Monoporites annulatus*
6 *Striatricolpites catatumbus*
7 *Andalusiella polymorpha* sp. 2
8 *Grimsdalae magnaclavata* in
9 *Mauritiidites crassibaculatus*
10 *Arecipites crassimuratus*
11 *Monosulcites* sp.
12 *Psilatricolporites crass*us
13-4 *Perfotricolpites digitatus*
15 Indeterminate

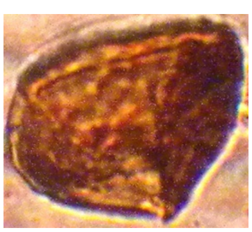
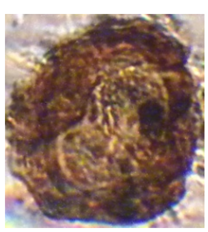
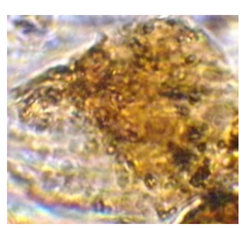
ZONE 8:*Echitricolporites spinosus* Assemblage Zone

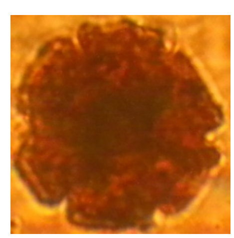
The zone is located in interval 113-390 m, dated Late Miocene to Pliocene age. Thelower part of the interval is characterised by the appearance of new forms such as *Cyperacaepollis* sp.(Plate 4.29, no. 1) and *Nymphae lotus*(Plate 4.29, no.2). At depth 335 mwas appearance of*Podocarpus millanjianus* (Plate 4.29, no. 3) and *Zonocostites ramonae*. Other microflora that are noted to characterise Late Miocene and Pliocene deposits are *Arecipites* sp.(Plate 4.29, no. 4),

Crototricolpites crotonoisculptus, Retistephanocolpites gracilis(Plate 4.29, no. 5)*, Multiareolites formosus*(Plate 4.29, no. 6)*, Echiperiporites estalae*(Plate 4.29, no.7), *Canthium* type(Plate 4.29, no. 8) and *Retitricolporites irregularis* (Plate 4.29, no. 9).
At depth 232 msome of these forms continue to appear while other diagnostic forms that depict Pliocene age such as *Podocarpus millajianus* appeared in association with *Echiperiporites estalae, Elaeis guineensis*(Plate 4.29, no. 11)*, Striamonocolpites rectosriatus* and *Arecipites* sp.The interval is particularly characterised by Neogene dinoflagellate cysts such as *Multispinula quanta*(Plate 4.29, no. 12)*, Impagidinium* sp.(Plate 4.30, no. 5)*, Operculodinium centrocarpum*(Plate 4.30, no. 1)*, Operculodinium* sp., *Selenopemphix nephroides*(Plate 4.30, no. 2)*, Tuberculodinium vancampoae* (Plate 4.30, no. 3) and *Polysphaeridium zoharyi*.

The upper part of the interval where the analysis of the well samples ends is marked by the co-occurrence of *Crassoretitriletes vanraadshooveni*(Plate 4.29, no. 10)*, Laevigatosporites* sp.(Plate 4.29, no. 14)*, Arecipites* sp., *Monoporites annulatus* and *Retibrevitricolporites obodoensis* (Plate 4.29, no. 13). Other stratigraphically important pollen, spores and dinoflagellate cysts recovered in the interval and diagnostic of the zone are presented in Plates 4.29-4.32. The assemblage of fossils recovered in this interval is comparable to Zone P800 (subzone P820-P880) dated Late Miocene to Pliocene. Therefore, the zone 8was assigned Late Miocene to Pliocene age equivalent to Ogwashi-Asaba Formation (Fig. 4.21). However, the result obtained in this well for the Ogwashi-Asaba Formation is in contrary to geologic age (Oligocene) given by Nwajide (1990) and Late Eocene to Early Miocene and Pleistocene age suggested by Umeji (2012) . One of the marker pollen identified in the sample (*Podocarpus millanjianus)* was also reported in the work of Umeji (2012). She noted the co-occurrence of Oligocene and Pliocene forms which were also recovered in the analysed samples.

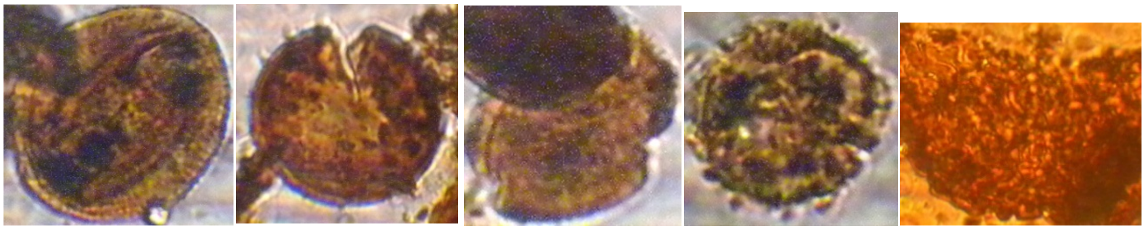
Magnification ×800

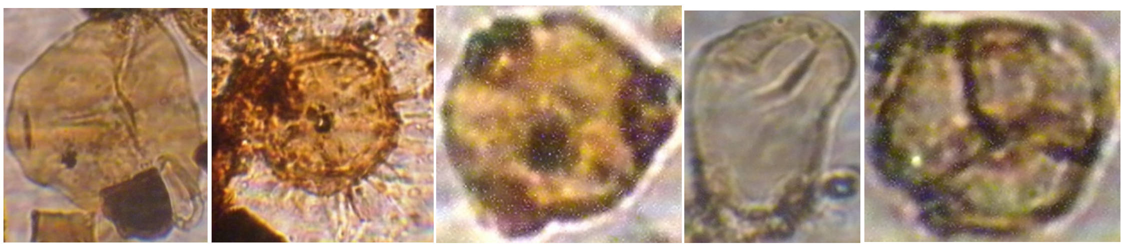


1

2 **3** **4** **5**



6 7 8 9 10

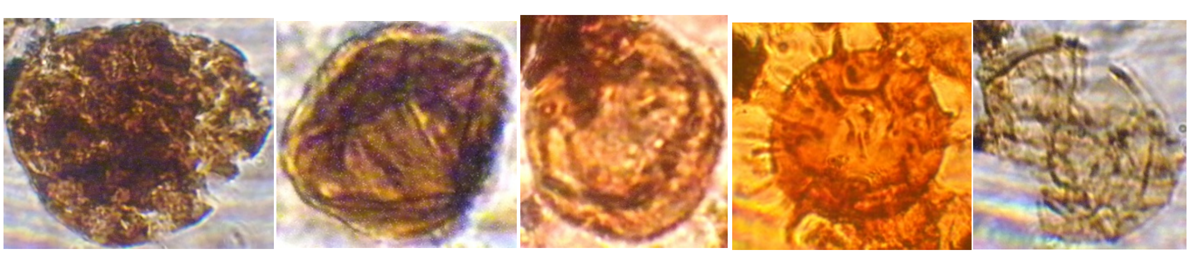


11 12 13 14 15

Plate 4.29. Palynomorph assemblage of interval 113-390 m

1 *Cyperaceaepollis* sp.
2 *Nymphae lotus*
3 *Podocarpus millanjianus*
4 *Arecipites* sp.
5 *Retistephanocolpites gracilis*
6 *Multiareolites formosus*
7 *Echiperiporites estalae*
8 *Canthium* type
9 *Retitricolporites irregularis*
10 *Crassoretitriletes vanraadshooveni*
11 *Elaeis guineensis*
12 *Multispinula quanta*
13 *Retibrevitricolporites obodoensis*
14 *Laevigatosporites* sp.
15 *Anthocerus* sp.

Magnification ×800



12 3 45

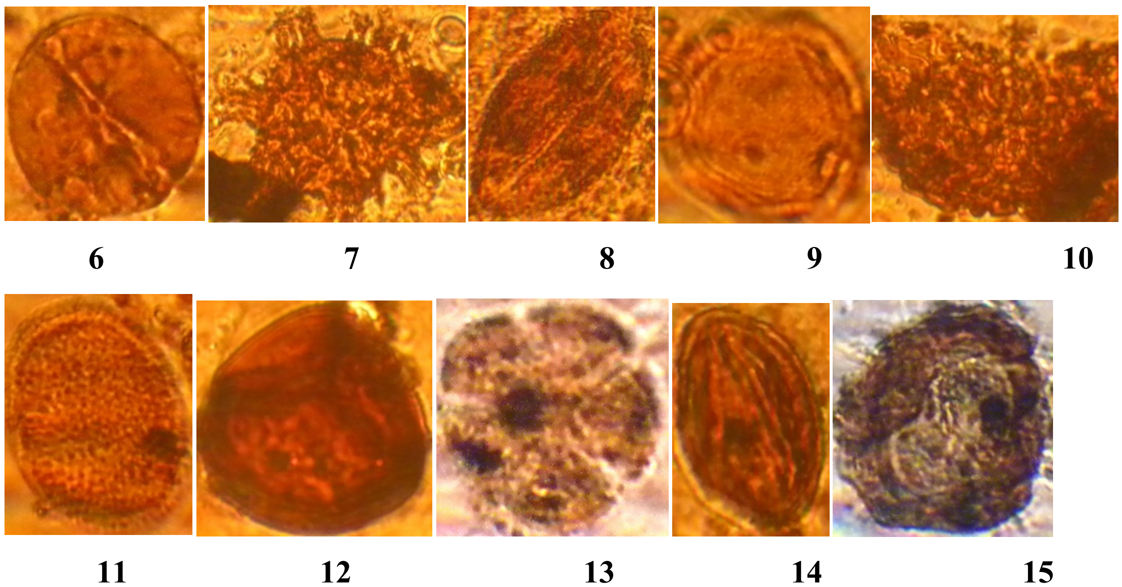


Plate 4.30. Palynomorph assemblage of interval 113-390 m

1 *Operculodinium centrocarpum*
2 *Selenopemphix nephroides*
3 *Tuberculodinium vancampoae*
4 *Spiniferites mirabilis*
5 *Impagidinium* sp.
6 *Monocolpites marginatus*
7 *Histrichokolpoma rigaudae*
8 *Retimonocolpites* sp.
9 *Uapaca* sp.
10 *Crassoretitriletes vanraadshooveni*
11 *Arecipites* sp.
12 *Anthocerus* sp.
13 *Retistephanocolpites* sp.
14 *Tricolporites* sp.
15 *Nymphae lotus*

Depth(m)	Lithology	Formation	Marker fossils	Age

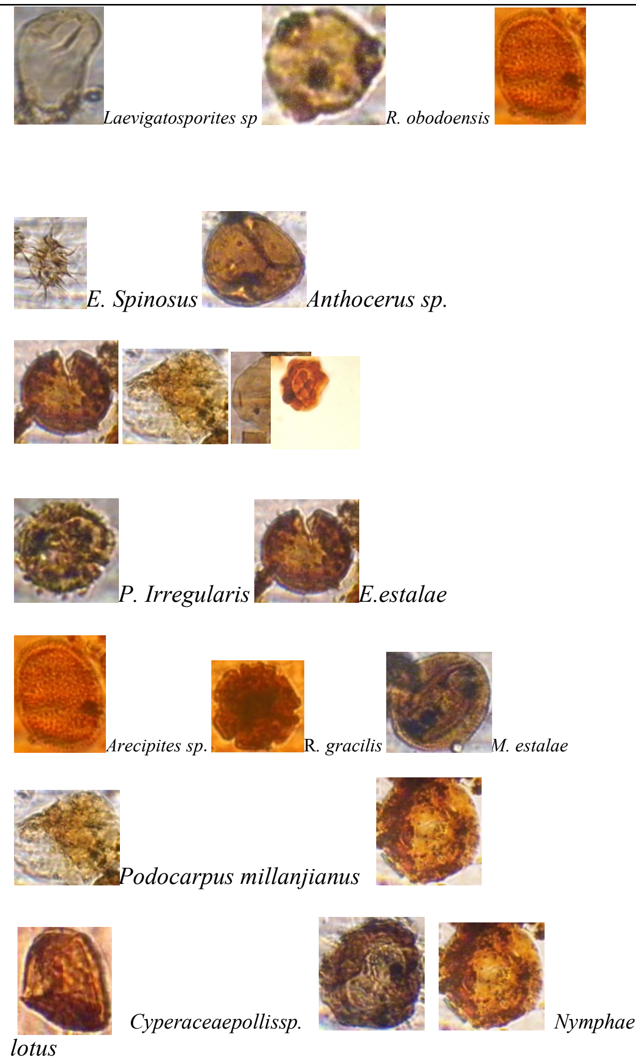
113 151 232 256 335 366		Ogwashi-Asaba		Late Miocene To Pliocene

Figure 4.21. Marker fossils appearances with depth in interval 113-366 m

Magnification ×800

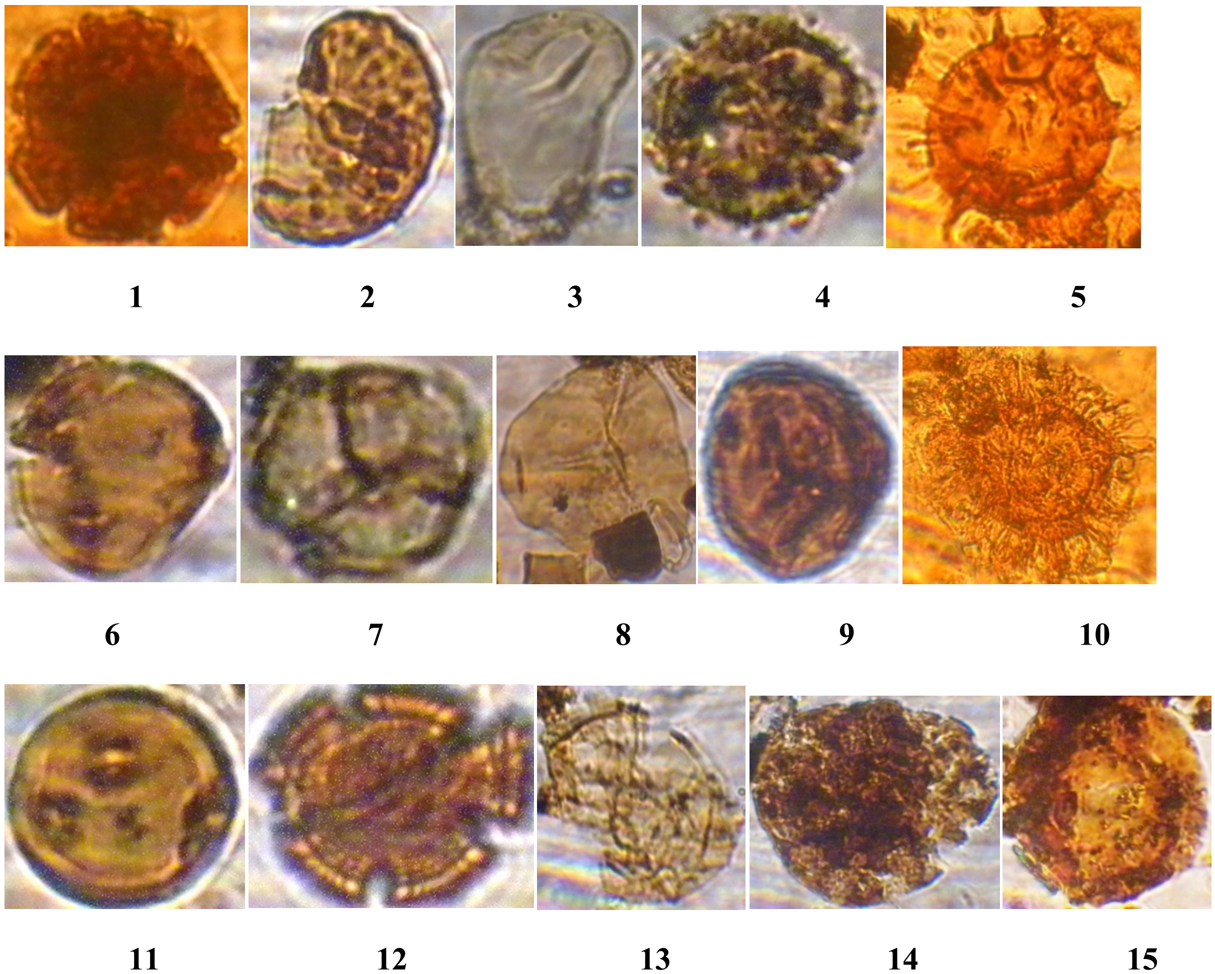
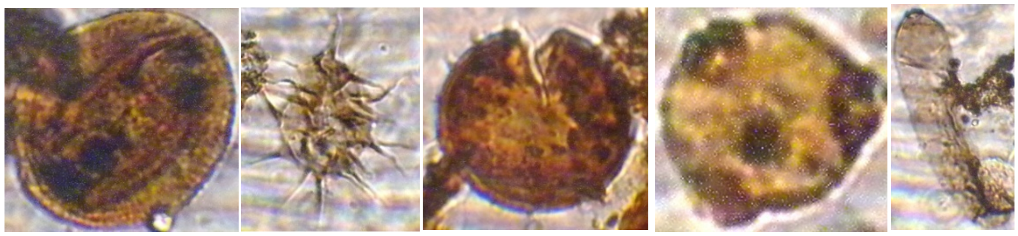


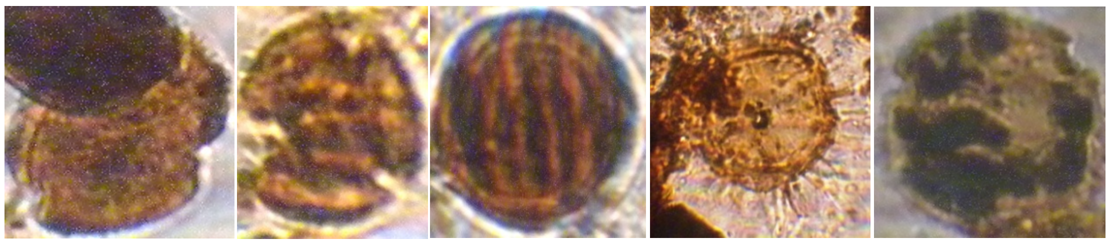
Plate4.31. Palynomorph assemblage of interval 113-390 m

1 *Retistephanocolpites gracilis*
2 *Verrucatosporites usmensis*
3 *Laevigatosporites* sp.
4 *Retitricolporites irregularis*
5 *Spiniferites mirabilis*
6 *Psilatricolporites crassus*
7 *Anthocerus* sp.
8 *Elaeis guineensis*
9 *Zlivisporites neogenicus*
10 *Nematosphaeropsis labyrinthea*
11 *Uapaca* sp.
12 *Stephanocolpites* sp.
13 *Impagidinium* sp.
14 *Operculodinium centrocarpum*
15 *Nymphae lotus*

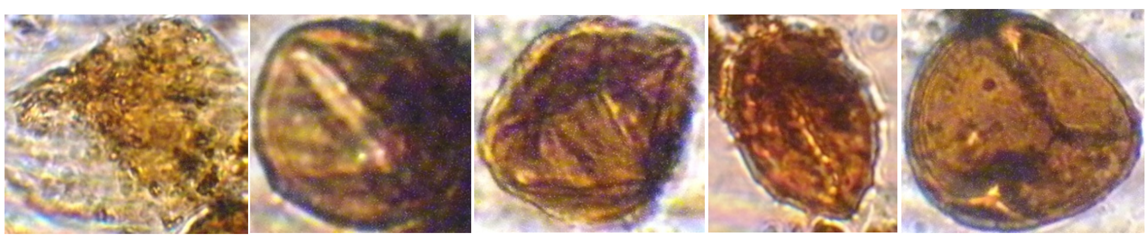
Magnification ×800



1234 5



67 89 10



11 12 13 14 15

Plate4.32. Palynomorph assemblage of interval 113-390 m

1 *Multiareolites formosus*
2 *Echitricolporites spinosus*
3 *Echiperiporites estalae*
4 *Retibrevitricolporites obodoensis*
5 NPP
6 *Canthium* type
7 *Tricolpites* sp.
8 *Psilastephanocolpites* sp.
9 *Multispinula quanta*
10 *Uapaca* type
11 *Podocarpus millanjianus*
12 *Monocolpites marginatus*
13 *Selenopemphix nephroides*
14 *Mauritiidites crassibaculatus*
15 *Anthocerus* sp.

Therefore, it showed that the Oligocene forms present were reworked grains and they are referred to as derived fossils. The derived fossils are not significantly useful for biostratigraphical age dating. Thus, only younger fossilspresent were used for age dating of the sediment whereby Late Miocene to Pliocene age was given to Ogwashi-Asaba Formation. The Ogwashi–Asaba Formation is lying unconformably on the older Ameki Formation. Therefore, the youngest dated sediment in the Anambra Basin from this study is Late Miocene-Pliocene in age (Figs. 4.1 and 4.21). A summary of the established zones, bases of their erection, ages and corresponding formations that depict the chronostratigraphy, palynological zones, paleoenvironment of deposition of respective formations from the oldest Asu River Group at the bottom to the youngest Ogwashi/Asaba Formation at the top of the Nzam-1 well were presented in Table 4.5.

Table 4.5. Chronosratigraphy and palynological zones established for the Nzam-1 well

Event /FM	Depth (Ft)	Palynological Zone	Characteristics	Age	Paleo-Environment
Ogwashi - Asaba	**113**	**Echitricolporites spinosus**	**Characterised by co-occurrence of *Anthocerus* sp, *Cyperacaepollis* sp, *Multiareolitesformosus*, Retistephanocolpites gracilis, and Podocarpus millanjianus**	**Upper Miocene To Pliocene**	**Open marine** **Marginal marine**
POST SANTONIAN SEDIMENT AMEKI	390 518	*Monoporites Annulatus* Assemblage Zone 9	Characterised by co-occurrenceof *Monoporites annulatus, pachydermites diederixi, Psilatricolporites crassus* and *Grimsdalae magnaclavata*	Middle Eocene	**Marginal marine**
IMO	847	*Mauritiidites crassibaculatus* Assemblage Zone 8	*Co-occurrence of Mauritiidites crassibaculatus,* with *Retistephanocolpites williamsi, Ctenolophonidites costatus, Proteacidites sigali* and *Anacolosidites luidonisis*	Early Paleocene	**Open marine**
NSUKKA	1372	*Spinizonocolpites baculatus* Assemblage Zone 7	Co-occurrence of Spinizonocolpate pollens, associated with *Constructipollenites ineffectus, Periretisyncolpites spp.*, and increase in angiosperm pollen	Late Maastrichtian	**Continental** **Marginal marine** **Continental**
MAMU	1844	*Longapertites marginatus* Acme Zone 6	Maximum development of *Longapertites marginatus*	Middle Maastrichtian	**Open marine** **Continental** **Open marine**
	2216	*Foveotriletes margaritae* Assemblage Zone 5	Co-occurrence of *Foveotriletes margaritae, Trichotomosulcites sp. 1,* and reduced frequency of *Longapertites marginatus*	Early Maastrichtian	Marginal marine Continental Open marine
NKPORO	2716	*Milfordia spp* Interval Zone 4	Well development of *Milfordia* pollen in association with *Cupanieidites reticularis* and *Longapertites sp. 3*	Campanian	Marginal marine Open marine Continental Marginal marine
AWGU SHALE	2906	*Zlivisporites blanensis* Assembale Zone 3	Co-occurrence of *Z. blanensis* and abundance of Monosulcate, tricop(or)ate, grains of angiosperms	?Santonian To Coniacian	Marginal marine Continental Open marine

5.2.2 Palynozonation of Umuna-1 well

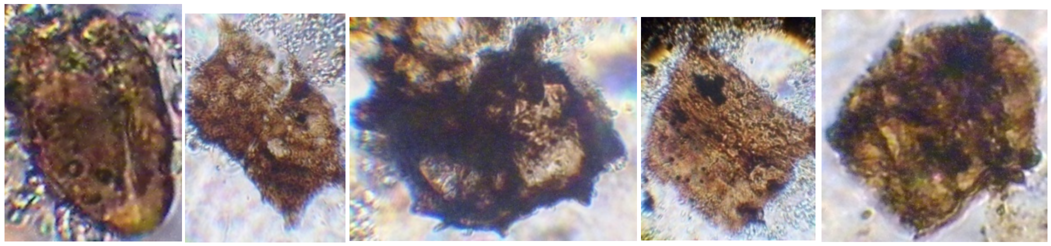
The chronostratigraphy of Umuna-1 well ranges from Albian to Pliocene. Eight palynological zones were erected and compared to the reference well- Nzam- 1 well of this study. Thus, the basis of establishing the palynozones for this well follows that described for the rerefence well Nzam- 1.The detail palynostratigraphy of the Umuna-1 well is presented in Figure 4.2 and also given below.

ZONE 1:*Cretacaeiporites* spp. Acme Zone

The zone is situated between intervals 1180-1689 m, dated Upper Cenomanian to Turonian.The lower part of the intervalcoincides with the uppermost horizon of the underlying zone 1. The near base is barren probablyas a result of intensive oxidation of the organic matter. The top of the zone is characterised by top occurrence of *Cretacaeiporites infrabaculatus*and *Cretacaeiporites mulleri.* At depth 1628m was appearance of *Elaterocolpites* sp., a characteristic marker form that depicts Cenomanian age (Kotova, 1984). At depth 1551m another diagnostic form of *Verrutriletes formgroup* (Plate 4.33, nos. 9, 11)of Herngreen (1973) was recovered, also depictive of Cenomanian deposit. The overlying depth (1524m) is moderately rich, contains *Triorites africaensis* and first appearance of *Peromonolites peroreticulatus* (Plate 4.33, no. 10;see Fig.4.2).The upper part of the zone is unlikely to be present in the analysed interval, it is suggested that it might have been eroded or not deposited. Other stratigraphically important forms are present in Plate 4.33.

The zone is further characterised by relative high abundance of *Cretacaeiporites* spp. Therefore, the interval is conveniently dated Upper Cenomanian to Turonian age.

Magnification ×800



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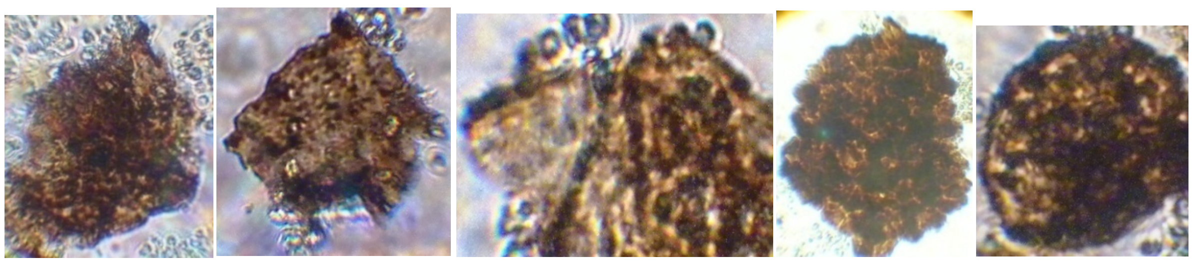

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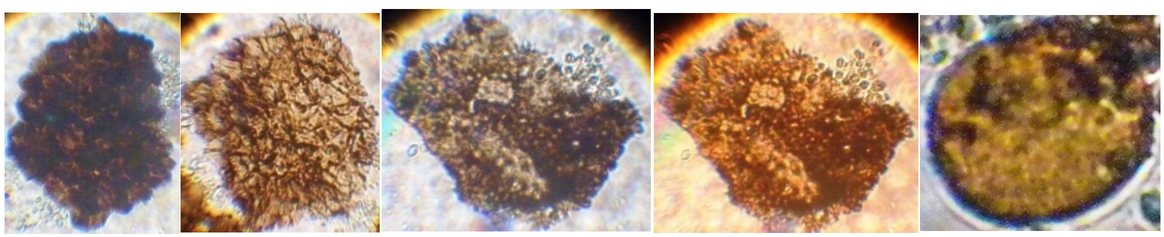


11 12 13 14 15

Plate4.33. Palynomorph assemblage of in terval 1180-1689 m for Umuna- 1 well

1	*Monosulcites* sp.
2	*Subtilisphaera* sp. 6
3	? *Galeacornea* sp.**Kotova (1978).**
4	*Senegalinium* sp. 6**Lawal (1982).**
5	Forma T1
6	*Senegalinium bicavatum***Jain & Millepiad (1975)**
7	*Senegalinium* sp.
8	*Monosulcites* sp.
9,11	*Verrutriletes formgroup* 1**(in Herngreen, 1973)**
10	*Peromonolites peroreticulatus***Brenner (1968)**
12	Peridinoid type
13-14	*Phelodinium bolonienae* **(Riegel, 1974)**
15	*Micrhystridium* sp.**Schrank (1984)**

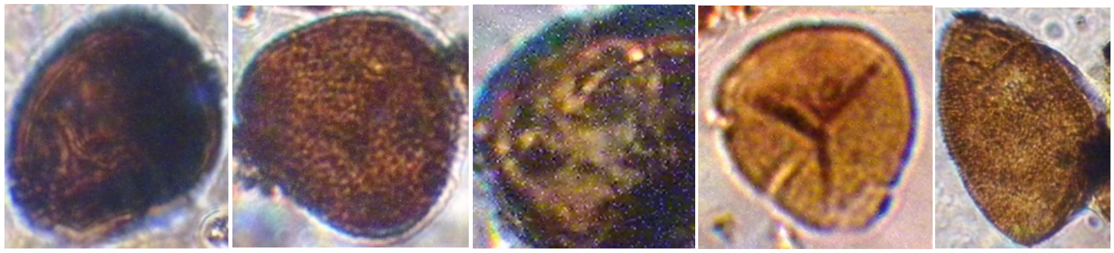
ZONE 2: *Milfordia* spp. Acme Zone

The zone is situated in interval 765-1180 m, dated Campanian.The lower part of the zone is marked by the basal appearance of *Longapertites* sp. 3(Plate 4.34, no. 5) and co-occurrence of other diagnostic forms such as *Auriculiidites reticulatus* (Plate 4.34, no. 11) *Foveotriletes margaritae* (Plate 4.34, no. 1), *Retidiporites magdalenensis* and *Longapertites marginatus*(Plate 4.34, no. 3). At the near base of the section is the appearance of *Longapertitesverneendenburgi* (Plate 4.34, no. 7), *Echitriporites trianguliformis*, *Distaverrusporites* sp., *Monocolpopollenites sphaeroidites* (Plate 4.34 no. 1), *Periretisyncolpites giganteus* and *Zlivisporites blanensis* (Plate 4.34, no. 14);continuous occurrence of *Foveotriletes margaritae and Longapertites verneendenburgi*.

Depth 1125m shows the first uphole appearance of *Milfordia jardinei*. Overlying depth (1109m) shows the first occurrence of *Cingulatisporites ornatus, Ulmoidites krempi* and *Stephanocolpites* sp. All the Maastrichtian forms present also have their offshoot in the same zone in Nzam -1 well. The *Milfordia* spp. acme zone is well represented in Umuna-1 well like in Nzam- 1 well. Some of the forms that were described to have their offshoot in the zone include *Buttinia andreevi*, *Retidiporites magdalenensis, Periretisyncolpites* sp., *P. giganteus, P. magnosagenatus* (Kieser & Jan du Chene, 1979) and *Auriculidites reticulatus*. Other forms present in the zone include *Tricolpites* cf.*iverseni, Tricolpites giganteus, Inaperturopollenites* sp., *Cingulatisporites ornatus* and *Proxapertites cursus.* However, other associated forms that are also stratigraphically important are presented in Plates 4.34-4.40.

The uppermost horizon of the zone is placed at 786 m on the basis of the last appearance of *Milfordia jardinei, Triorites sp,* and *Cupanieidites reticularis.* It is further defined by relatively highly fossiliferous stratigtigraphic horizon. Other pollen and spores present at this level include *Retidiporites magdalenensis, Laevigatosporites* sp., *Retitricolpites gageannetti* (Boltenhagen, 1976), *Tricolporopollenites* sp. (Jardine and Magloire, 1965), *Tricolpites gigantoreticulatus* and *Spinizonocolpitesbaculatus*.

Magnification ×800



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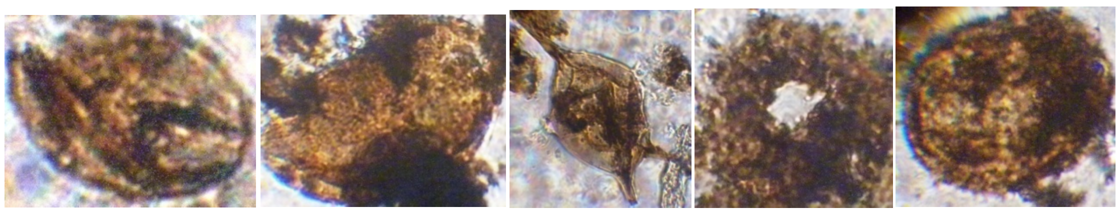

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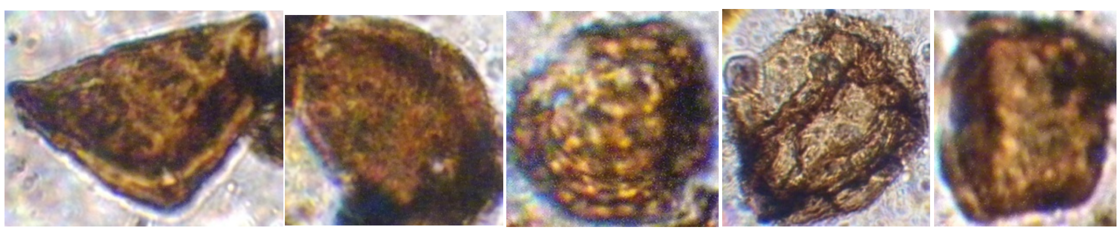

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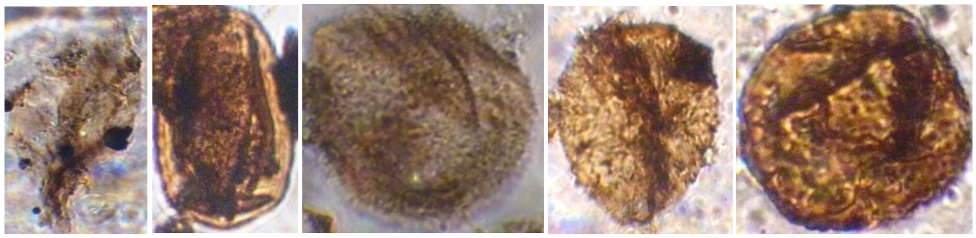
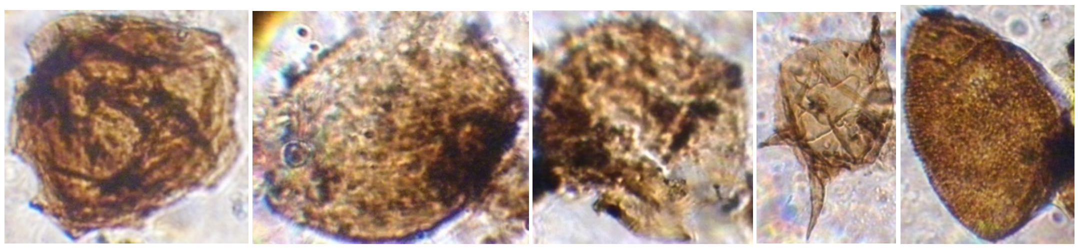
Plate4.34. Palynomorph assemblage of interval 768-1180 m for Umuna- 1 well

1 *Monocolpopollenites sphaeroidites*
2 *Foveotriletes margaritae*
3 *Longapertites marginatus*
4 *Cyathidites* sp.
5 *Longapertites* sp. 3
6 *Tricolporopollenites* sp.
7 *Longapertites vaneendenburgi*
8 *Ceratiopsis diebelii*
9 *Milfordia jardinei*
10 *Caningia* sp
11 *Auriculiidites reticulatus*
12 *Longapertites marginatus*
13 *Rugulatisporites caperatus*
14 *Zlivisporites blanensis*
15 *Retidiporites magdalenensis*

Magnification ×800



12 3 4 5



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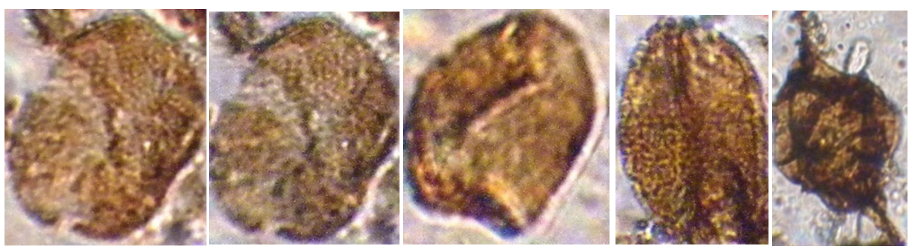


11 12 13 14 15

Plate4.35. Palynomorph assemblage of interval 768-1180 m for Umuna- 1 well

1 *Auriculiidites* sp. 1
2 *Tricolpites* sp.
3 *Cyclonephelium distinctum*
4 Indeterminate dinocyst
5 *Araucariacites australis*
6 *Homotryblium* sp. A
7 *Striapollenites* sp.
8 *Triporites* sp.
9 *Ceratiopsis diabelii*
10 *Longapertites* sp. 3
11,12 *Retimonocolpites* sp.
13 *Retidiporites magdalenensis*
14 *Retimonocolpites* sp. 1
15 *Andalusiella polymorpha*

Magnification ×800

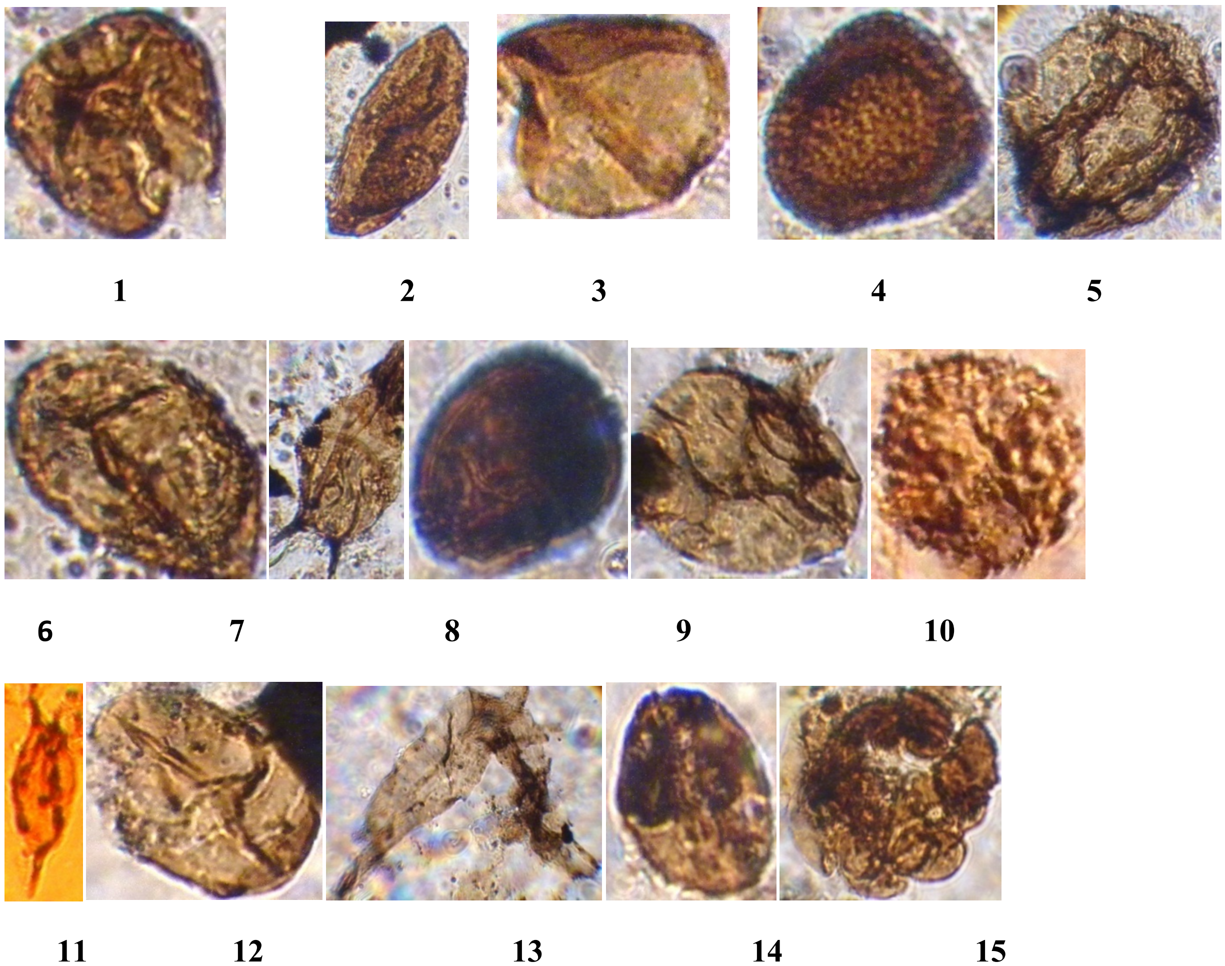


Plate4.36. Palynomorph assemblage of interval 768-1180 for Umuna- 1 well

1,3 *Cyathidites* sp.
2 *Monosulcites* sp.
4 *Foveotriletes margaritae*
5 ? *Zlivisporites blanensis*
6 *Monocolpites* sp.
7 *Ceratiopsis diabelii*
8 *Monocolpopollenites sphaeroidites*
9 *Tricodinium delicatum*
10 Indeterminate pollen
11 *Palaeocystodinium australinum*
12,14 *Monocolpites marginatus*
13 *Odontochitina* sp.
15 Microforaminifera wall lining

Magnification ×800

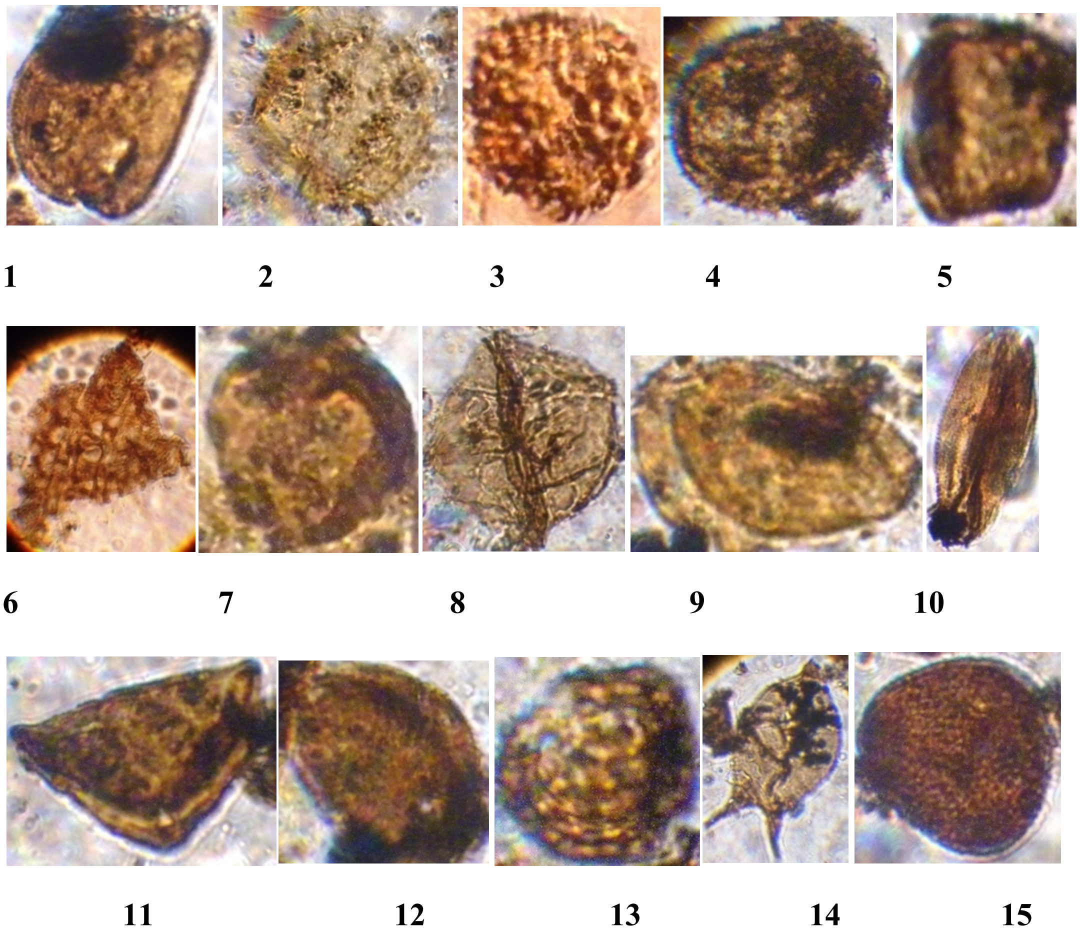
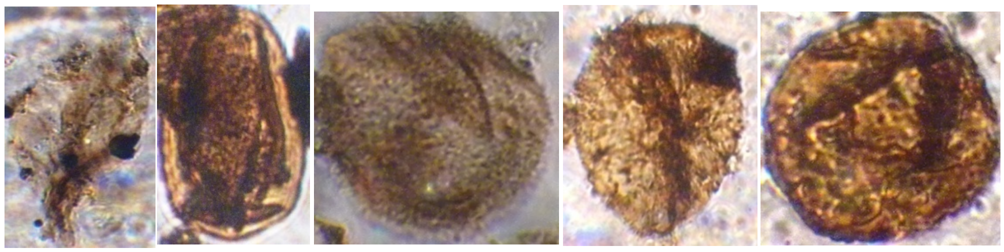


Plate4.37. Palynomorph assemblage of interval 768-1180 m for Umuna- 1 well

1,9 *Longapertites marginatus*
2 *Oligosphaeridium pulcherrimum*
3 Indeterminate pollen
4 *Caningia* sp.
5 *Retidiporites magdalenensis*
6 Calcium oxalate crystal
7 *Monocolpopollenites sphaeroidites*
8 *Phelodinium bolonienae*
10,11 *Auriculiidites reticulatus*
12 *Longapertites marginatus*
13 *Rugulatisporites caperatus*
14 *Ceratiopsis diebelii*
15 *Foveotriletes margaritae*

Magnification ×800



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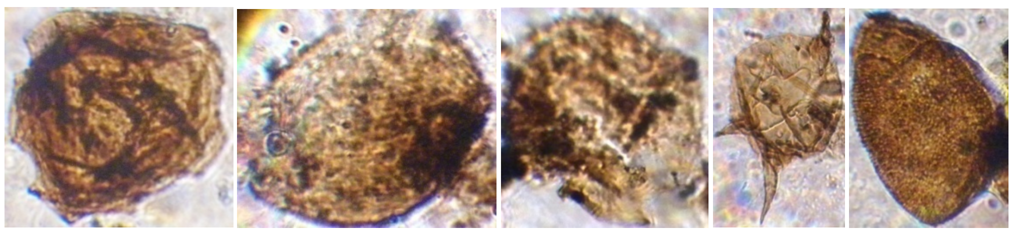

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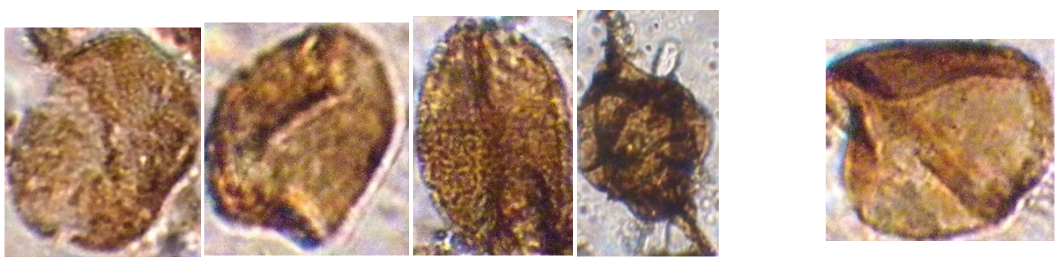


11 12 13 14 15

Plate4.38. Palynomorph assemblage of interval 768-1180 m for Umuna- 1 well

1 *Auriculiidites* sp. 1
2 *Tricolpites* sp.
3 *Cyclonephelium distinctum*
4 Indeterminate dinocyst
5 *Araucariacites australis*
6 *Homotryblium* sp. A
7 *Striapollenites* sp.
8 *Triporites* sp.
9 *Ceratiopsis diabelii*
10 *Longapertites* sp. 3
11 *Retimonocolpites* sp.
12 *Retidiporites magdalenensis*
13 *Retimonocolpites* sp. 1
14 *Andalusiella polymorpha*
15 *Cyathidites* sp.

Magnification ×800

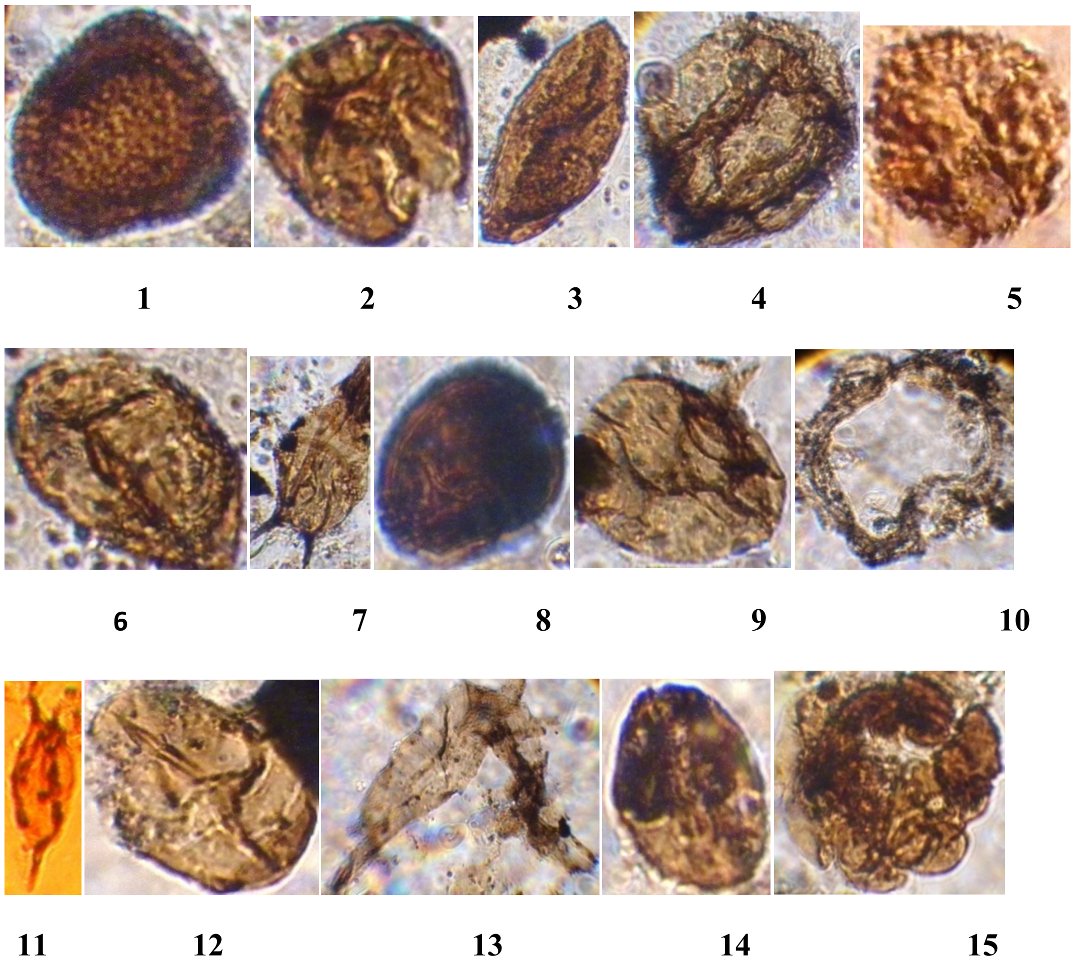
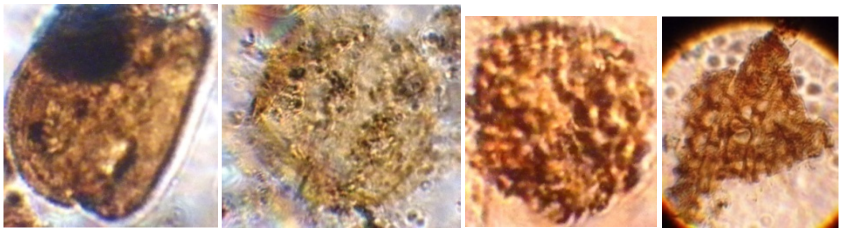


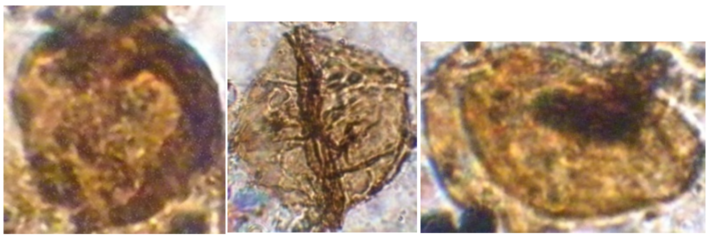
Plate4.39 Palynomorph assemblage of interval 768-1180 m for Umuna- 1 well

1 *Foveotriletes margaritae*
2 *Cyathidites* sp.
3 *Monosulcites* sp.
4 ? *Zlivisporites blanens*
5 Indeterminate pollen
6 *Monocolpites* sp.
7 *Ceratiopsis diabelii*
8 *Monocolpopollenites sphaeroidites*
9 *Tricodinium delicatum*
10 Indeterminate cyst
11 *Palaeocystodinium australinum*
12,14 *Monocolpites marginatus*
13 *Odontochitina* sp.
15 Microforaminifera wall lining

Magnification ×800



1 **2** **3** **4**



5 **6** **7**

Plate4.40. Palynomorph assemblage of interval 768-1180 m for Umuna- 1 well

1,7 *Longapertites marginatus*

2 *Oligosphaeridium pulcherrimum*

3 Indeterminate pollen

4 Calcium oxalate crystal

5 *Monocolpopollenites sphaeroidites*

6 *Phelodinium bolonienae*

Therefore, the association of *Milfordia jardinei, Buttinia andreevi* and *Auriculiiditesreticularis* is in tandem with the observation made in Nzam-1 well of this study. Jardine and Magloire (1965), Petrogrants and Troifimoi (1971), Herngreen (1975a) used some of the floras present in this zone to date sediments of other parts of the world to be Campanian to Lower Maastrichtian age. Thus, the interval (765-1180m) is here dated Campanian because of its limitation to non inclusion of interval that contains *Trichotomosulcites* sp. 1 of Lawal and Moullade (1986) which suggests Early Maastrichtian age. Here, the C/M boundary is placed based on the high fossiliferous horizon and non-appearance of *Trichotomosulcites* sp.(Fig. 4.2). This marker form is not present within the zone 2 interval. Therefore, the C/M (Campanian/Maastrichtian) boundary is placed at 765m. It is worthy to know that there is existence of hiatus (unconformity relation) between this zone and the underlying Zone 1. The supposed *Zlivisporites blanensis* assemblage zone belonging to Awgu Formation is missing and can not be accountable for in this well (Umuna- 1 well). This was suggested to have been due to erosional removal or presence of a fault in the well section. Evidence of missing Awgu Formation in a stratigraphic sequence has been reported by Umeji (2007) where it was cited that Campanian Nkporo Shale oversteps the Turonian Eze-Aku Formation at Leru along the Enugu-PortHarcourt Road. However, the interval studied is here conveniently assigned Campanian age and stratigraphically equivalent to Nkporo Shale.

ZONE3: *Foveotriletes margaritae* Assemblge Zone

The zone was located in interval 524-768 m, dated early Maastrichtian. The lowermost part of the zone coincides with the uppermost part of the underlying zone 2. The lower part of the interval is characterised by continuous occurrence of *Trichotomosulcites* sp. 1of Lawal and Moullade (1986; Plate 4.41, no. 1) and *Retidiporites magdalenensis*. Other pollen that mark the zone include *Syncolporites subtilis* (Plate 4.41, no. 3),*Periretisyncolpites* sp. (Plate 4.41, no. 4), *Proxapertites cursus* (Plate 4.41, no. 11), stephanocolpatepollen (Plate 4.41, no. 7) and *Foveotriletes margaritae* (Plate 4.41, no. 8); another factor is the increase in angiosperm pollen, especially monocolpate forms.

Magnification ×800

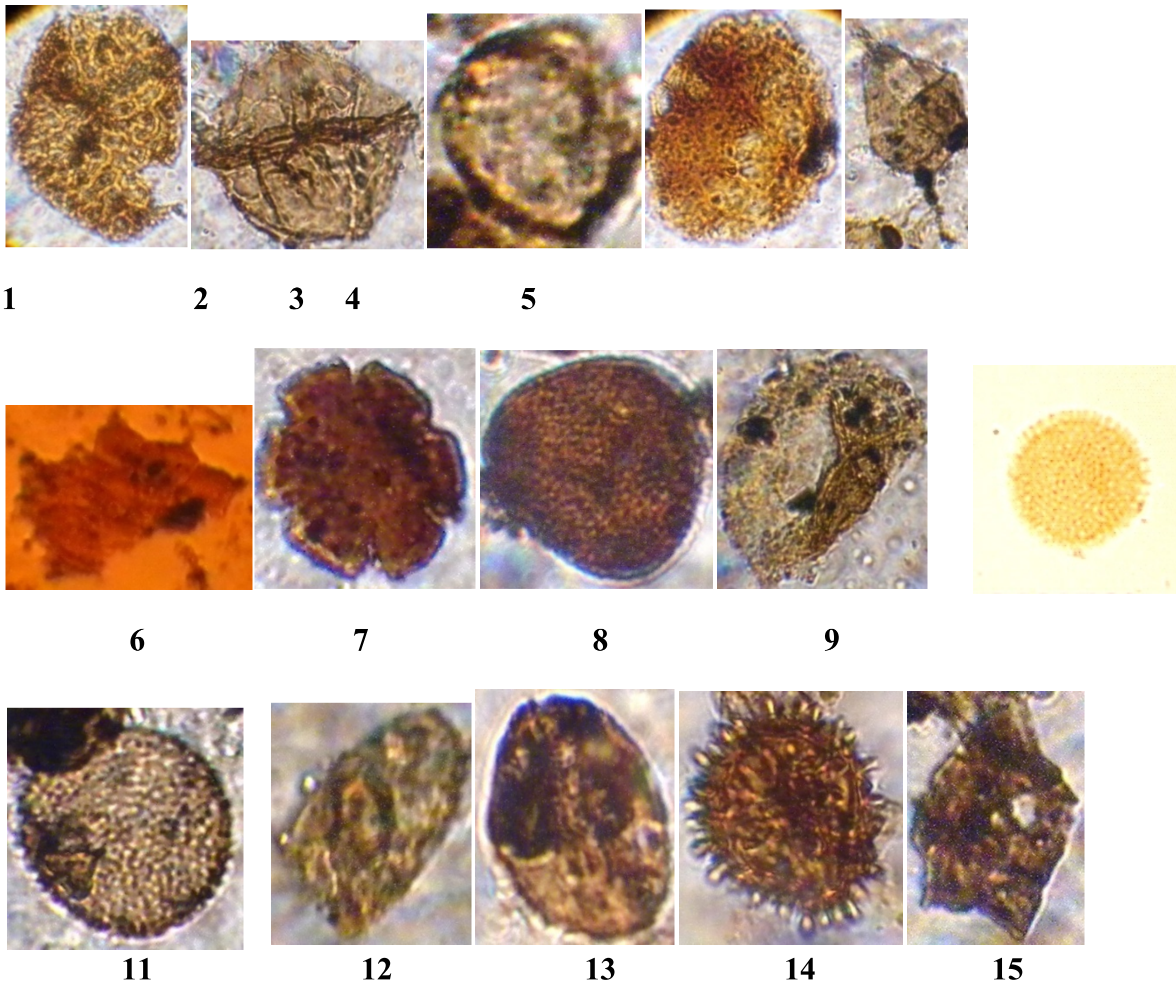


Plate4.41. Palynomorph assemblage of interval 524-768 m for Umuna- 1 well

1 *Trichotomosulcites* sp.
2 *Trichodinium* sp. 1
3 *Syncolpites subtilis*
4 *Periretisyncolpites* sp.
5 *Ceraptiopsis diabeli*
6 *Pediatrum* sp.
7 *Retistephanocolpites williamsi*
8 *Foveotriletes margaritae*
9 *Longapertites verneendenburgi*
10 *Constructipollenites ineffectus*
11 *Proxapertites cursus*
12 *Longapertites* sp.
13 *Monocolpites marginatus*
14 *Spinizonocolpites echinatus*
15 *Senegalinium* sp

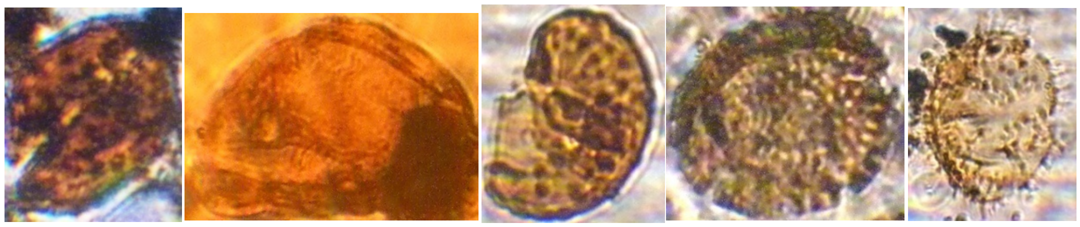
The top of this zone was placed at 524m. It is further characterised by the presence of *Constructipollenites ineffectus, Longapertites* marginatus, *Proxapertites cursus,* (Plate 4.41, no. 11)*, Monocolpitesmarginatus* (Plate 4.41, no. 13)*, Retidiporites magdalenensis, Trichotomosulcites* sp. 1, *Spinizonocolpites echinatus* (Plate 4.41, no. 14)and *Zlivisporites blanensis.* Microfloral with continuous occurrence include *Retidiporites magdalenensis,, Monocolpites marginatus,*and *Ttrichotomosulcites* sp. 1. Other miospores with fair and continuous occurrence are *Zlivisporites blanensis, Longapertites marginatus,* and *Constructipollenites ineffectus.*

The interval is known to be associated with low frequencies of *Retidiporites magdalenensis* when compared with overlying zone as shown in the reference well Nzam- 1. The pollen and spores assemblage in this zone are also similar to those described for Zone 3 in Nzam- 1 well, dated Early Maastrichtian age (See Tables 4.4). Microplanktons that dominate and characterise this interval are *Senegalinium* sp. (Plate 4.41, no. 15), *Andalusiella* sp., *Isabelidium* sp. 6, *Phelodinium bolonienae, Batiacasphaera* sp., *Cyclonephelium distinctum, Gonyaulacysta* sp.,and *Deflandre* sp. Dinoflagellates contained in this interval are also similar to those described for zone 3 in Nzam- 1 well. Therefore, the interval was dated Early Maastrichtian age.

ZONE 4: *Mauritiidites crassibaculatus* Zone

The zone is situated in interval 481-524 m, dated Lower Paleocene. The uppermost horizon of theinterval was placed at 524 m. The interval was marked by paucity of palynomorphs compared to the lower interval. This observation is similar to the remarks of earlier workers including Lawal and Moullade (1986), Ola-Buraimo (2012, 2013), Ayinla *et al.* (2014) on Cretaceous-Tertiary (K/T) boundary; also emphasised in Nzam-1 well of this study. The interval is further characterised by the appearance of *Mauritiidites crassibaculatus*(Plate 4.42, no. 1); associated with *Verrucatosporites*sp. (Plate 4.42, no. 3), *Longapertites marginatus* (Plate 4.42, no. 2)and *Proxapertites cursus*(Plate 4.42, no. 4). Other pollen grains and spores present are *Retimonocolpites* sp. (Plate 4.42, no. 6), *Syncolporites* sp. (Plate 4.42, no. 7), *Echitriporites trianguliformis* (Plate 4.42, no. 8) and *Proteacidites* sp. (Plate 5.42, no. 9).

Magnification ×800



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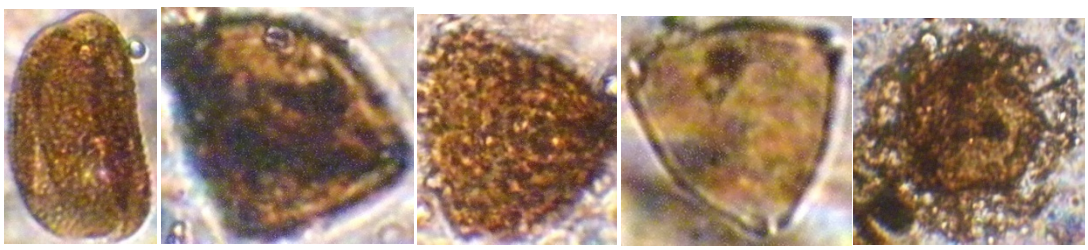
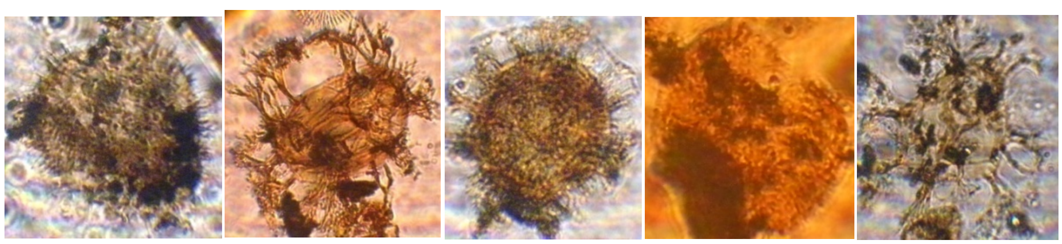


67 8 910



11 12 13 14 15

Plate4.42. Palynomorph assemblage of interval 481-524 m for Umuna- 1 well

1 *Mauritiidites crassibaculatus*
2 *Longapertites marginatus*
3 *Verrucatosporites* sp.
4 *Proxapertites cursus*
5 *Pentodinium laticinctum*
6 *Retimonocolpites* sp.
7 *Syncolporites* sp.
8 *Echitriporites trianguliformis*
9 *Proteacidites* sp.
10 *Histricosphaeridiumturonica*
11 *Cometodinium* sp.
12 *Distatodinium* sp. A
13 *Hystrichosphaeridium turonica*
14 *Phelodinium bolonienae*
15 *Homotriblium plectilum*

Apart from few diagnostic miospores present, the interval is dominated by organic wall microplanktons such as *Hystrichosphaerina turonica* (Plate 4.42, no. 10), *Cometodinium* sp.

(Plate 4.42, no. 11), *Distatodinium* sp. (Plate 4.42, no. 12), *Hystrichosphaeridium* sp.,*Batiacasphaera* sp., *Phelodinium bolonienae*(Plate 4.42, no. 14), *Pentodinium laticinctum* (Plate 4.42, no. 5), *Homotriblium plectilum*, *Histrichosphaeridium turonica* (Plate 5.103, no. 7), *Senegalinium* sp. and microforaminiferal wall lining (Plate 4.43, no. 7). Other important palynomorphs recovered and stratigraphically diagnostic in the interval are presented in Plates 4.42-4.43.

The uppermost part of the interval was defined by first uphole appearance of *Monoporites annulatus*. The interval was dated Lower Paleocene age. The interval is equivalent to Imo Formation lying unconformably on the Mamu Formation. The Nsukka Formation dated upper Maastrichtian in Nzam-1 well is missing in the Umuna-1 well probably due non-deposition, erosional removal or formation thinout in the well section.

Magnification ×800

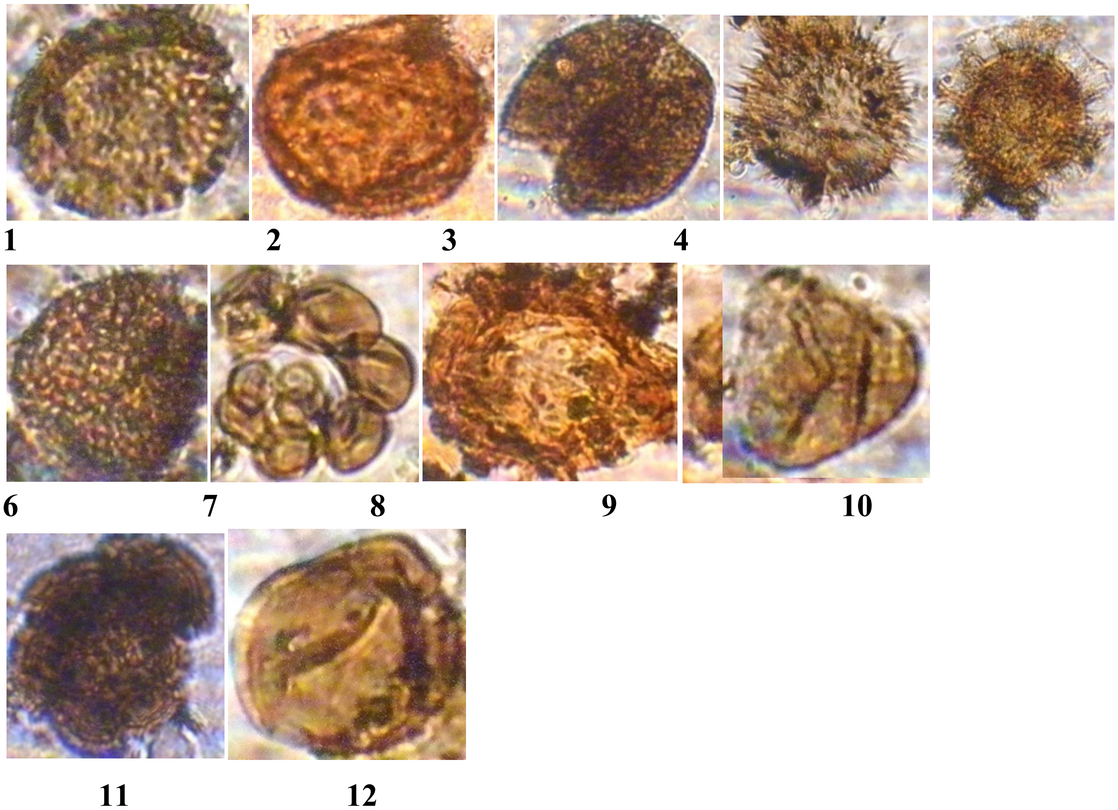


Plate4.43. Palynomorph assemblage of interval 481-524 m for Umuna- 1 well

1	*Proxapertites cursus*
2	*Selenipemphix nephroides*
3	Indeterminate pollen
4	*Polysphaeridium* sp.
5	*Hystrichosphaeridium turonica*
6	*Echitroporites trianguliformis*
7	Microforaminiferal wall lining
8	*Selenopemphix nephroides*
9	*Cyathidites* sp.
10	Cf *Lejeunecysta* sp.
11	Microforaminiferal wall lining
12	Auriculiidites sp.

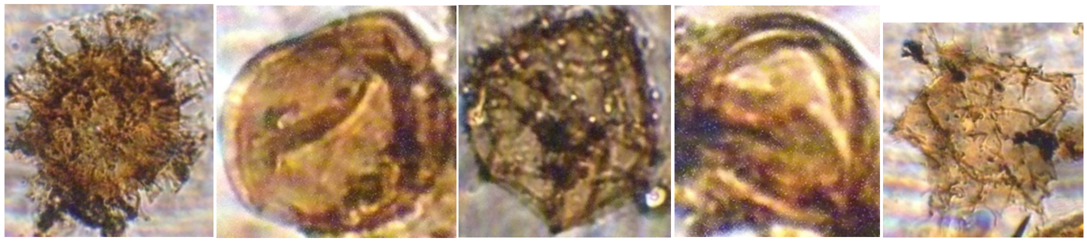
ZONE5:*Monoporites annulatus* Assemblage Zone

The zone was located within interval 329-481 m, dated Middle Eocene (Figure 4.2). The lower part of theinterval coincides with the top of the underlying zone. The lower part of the interval was defined by the first uphole appearance of *Monoporites annulatus*(Plate 4.44, nos. 2 and 4). The interval is characterised by the assemblages of *Monoporites annulatus, Proxapertites cursus, Monosulcites* sp., *Cyathidites* sp., *Laevigatosporites* sp.and *Monocolpites* sp.

The interval is moderately rich in palynomorphs. Dinoflagellate cysts present in the interval are *Batiacasphaera* sp., *Oligosphaera* sp. 3, *Senegalinium* sp.,*Histrichosphaeridium turonica* (Plate 4.44, no. 1), *Lejeunecysta* cf. *L. cinctoria* (Plate 4.44, no. 3), *Paleocystodinium golzowense* (Plate 4.44, no. 6), *Cometodinium* sp. (Plate 4.44, no. 7), *Nematosphaeropsis labyrinthea* (Plate 4.44, nos. 9, 11), *Operculodinium* sp. (Plate 4.44, no. 12), *Oligosphaeridium* sp. (Plate 4.44, nos. 14-15), *Wetzeliella* sp. (Plate 4.44, no. 5), *Distatodinium*sp. (Plate 4.44 no. 10), undifferentiated dinoflagellate cysts; other forms present are *Botryococcus braunii* (algae), non pollen palynomorphs (NPP) and microforaminiferal wall linings.

The upper part of the interval was marked by first uphole appearance of *Nymphae lotus* and *Uapaca* sp. The interval was dated Middle Eocene age based on distinctive assemblages of palynomorphs different from bounding intervals. Stratigraphically, this interval is equivalent to Ameki Formation which lies unconformably on the older Imo Formation.

Magnification ×800



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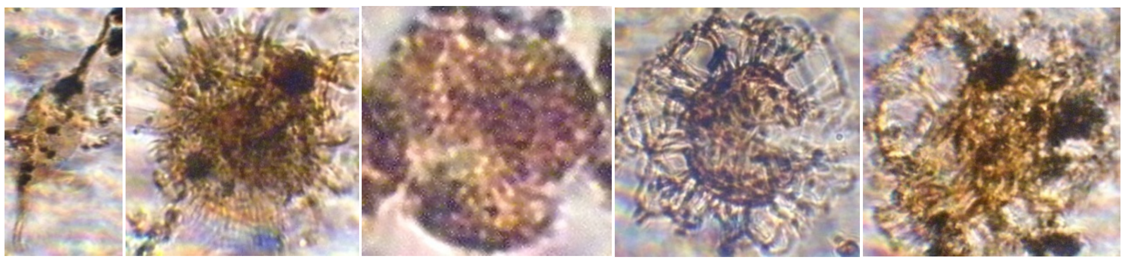
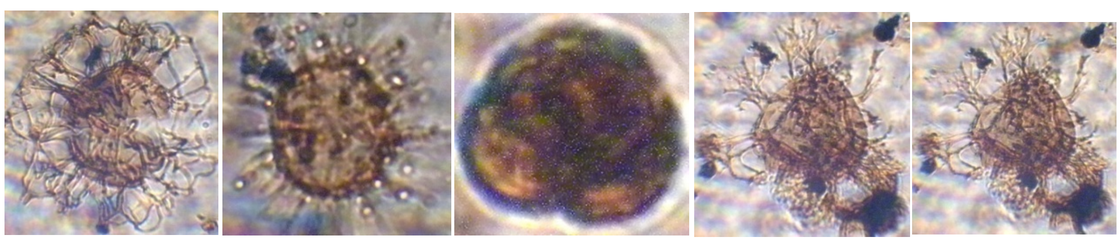


6 7 8 910



11 12 13 14 15

Plate4.44. Palynomorph assemblage of interval 329-481 m for Umuna- 1 well

1 *Hystrichosphaeridium turonica*
2,4 *Monoporites annulatus*
3 *Lejeunecysta* cf. *L. cintoria*
5 *Wetzeliella* sp
6 *Paleocystodinium golzowense*
7 *Cometodinium* sp.
8 *Tricolpites* sp.
9 *Nematosphaeropsis labyrinthea*
10 *Distatodinium* sp.\
11 *Nematosphaeropsis labyrinthea*
12 *Operculodinium* sp.
13 Microforaminiferal wall lining
14,15 *Oligosphaeridium* sp. (widely barbed processes)

ZONE6: *Echitricolporites spinosus* Assemblage Zone

The zone is situated in interval 24-329 m, dated Late Miocene to Pliocene age. The basal part of the intervalwas marked by last downhole and continuous appearance of *Nymphae lotus*; the lower part is further characterised by occurrence of *Echiperiporites estalae*(Plate 4.45, no. 1), *Perfotricolporites digitatus*(Plate 4.45, no. 4), *Uapaca sp, Crassoretitriletes vanraadshooveni, Monoporites annulatus, Monosulcites* sp., *Striatricolpites catatumbus* and *Arecipites* sp.(Plate 4.45, no. 2). At depth 329 m there was sudden increase in frequency of pollen; new miospores that emerged include *Elaeis guineensis, Cypereceaepollis* sp.(Plate 4.45, nos. 4), *Sclerosrema* sp., *Retibrevitricolporites obodoensis*and *Lycopodium phlegmaria*(Figure 4.2).

Noticeably was the increase in the recovery of dinoflagellate cysts such as *Oligosphaeridium* sp.(Figure 4.2; Plate 4.45, no, 6), *Spiniferites mirabilis, Multispinula quanta, Impagidinium* sp.(Plate 4.45, no. 7), *Polysphaeridium zoharyi*(Plate 4.45, no. 8), *Tuberculodinium vancampoae*(Plate 4.45, no. 8), *Selenopemphix nephroides,* and *Cometodinium* sp.(Plate 4.45, no. 11). Other forms with relatively low to high frequencies in recovery include *Distatodinium* sp.(Plate 5.45, no. 12), *Wetzeliella* sp. (Plate 4.45, no. 13), *Lejeunecysta* sp.(Plate 4.45, no. 14), *Paleocystodinium golzowense*(Plate 4.45, no. 10), *Wetzeliella gochtii, Deflandrea* sp.*C, Spiniferites pachyderma* (Plate 4.45, no. 15)and *Thalassiphora* sp.(Plate 4.45, no. 5).

The diverse and abundant dinocysts assemblages from this interval suggest that the motile dinoflagellates both cyst producers and non-producers are common in the Late Cenozoic of the Anambra Basin similar to northeastern Gulf of Mexico deposits (Wrenn and Kokinos, 1986).

There is high abundance of dinoflagellates in the uppermost part of Umuna-1 well; suggested to be strongly influenced by factors such as upwelling currents, low turbidity, high temperature within the photic zone, relatively shallow to moderately deep water body, high nutrient and adequate pH and Eh. At depth 311 m, there was an overwhelming dominance of dinoflagellates over miospores. Pollen and spore with new appearance are *Pteris* sp., *Crototricolporites crotonoisculptus*(Figure4.2); new dinoflagellates forms are *Cyclonephelium* sp. 3(Lawal, 1982), *Subtilisphaera* aff.*deformane* (Stover and Evitt, 1978), *Cometodinium* sp. and microforaminiferal wall lining (Figure 4.2; Plate 4.45, no. 11).

Magnification ×800

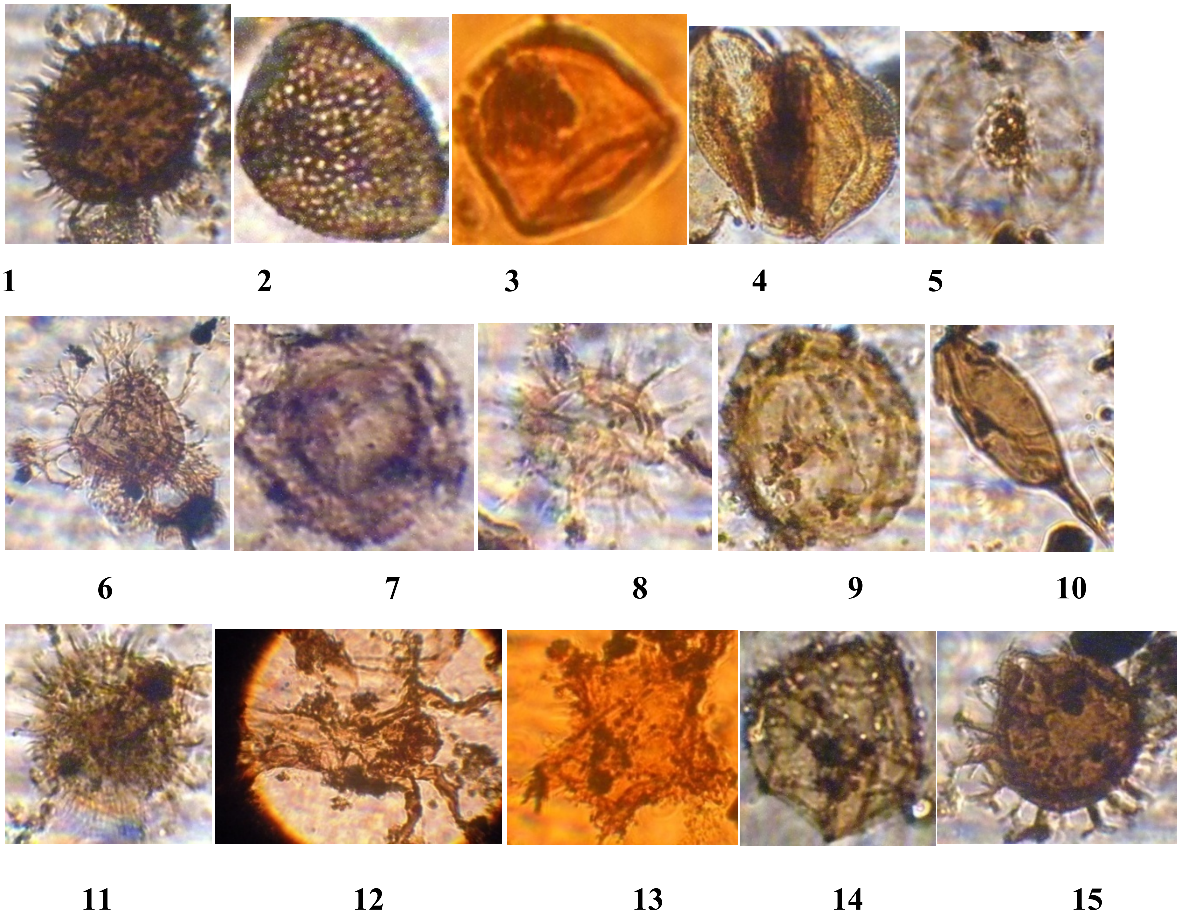


Plate4.45. Palynomorph assemblage of interval 24-329 m for Umuna- 1 well

1*Echiperiporites estalae*

2 *Arecipites* sp.

3 *Cyperaceaepollis* sp.

4 *Perfotricolpites digitatus*

5*Thallasiphora* sp.

6 *Oligosphaeridium* sp. (widely barbed processes)

7 *Impagidinium striata*

8 *Polysphaeridium zoharyi*

9*Tuberculodinium vancampoae*

10*Paleocystodinium golzowense*

11 *Cometodinium* sp.

12*Distatidinium* sp.

13 *Wetzeliella* sp. B

14*Lejeunecysta* cf. *L. cintoria*

15*Spiniferites pachyderma*

At depth 213 m, new emergence of miospores include *Sclerosrema* sp*., Tetradites* sp*., Echitricolporites spinosus*, *Zlivisporites neogenicus, Polyadopollenites* sp.,and *Brevitricolpites guinetii*(Figure 4.2). Dinocysts with new appearance include *Nematosphaeropsis* sp*., Spiniferites parchyderma, Spiniferites membranaceus,* and *Histrichokolpoma* sp. At depth 195 m *Oligosphaeridium* sp. is very abundant and dominates other microplankton (Figure 4.2); *Nymphae lotus* is relatively high in frequency. Dinoflagellates with new appearance are Forma D1 (Plate 4.46, no. 2), Forma D2 (Plate 4.46, no. 3), *Trinovantedinium* sp. and *Lejeunecysta diversiforma*.

Interval 85-171 shows moderate abundance and diversity palynomorphs compared to adjacent beds. There was an abrupt decline in frequency and diversity of dinoflagellate cysts and relative increase in frequency and diversity of miospores (Figure 4.2). Diagnostic miospores continue to appear within the stratigraphic interval, these include *Cyperaceaepollis* sp*., Nymphae lotus* and *Arecipites* sp.(Plate 4.45, no. 2)*;* others are *Retimonocolpites* sp.(Plate 4.46, no. 5)*, Lycopodium phlegmaria*, *Perfotricolpites digitatus*, *Longapertites marginatus*(Plate 4.46, no. 6) and*Retistephanocolpites gracilis*(Plate 4.46, no. 7).

Few dinoflagellates that appeared within the interval include *Selenopemphix nephroides, Wetzeliella* sp. B,*Oligosphaeridium* sp., *Spiniferites* sp.(Plate 4.46, nos. 8, 11)*, Thalassiphora* sp*., Inverticysta tabulate* (Plate 4.46, no. 10), *Paleocystodinium* sp., *Impagidinium* sp., *Summatradinium* sp., *Tuberculodinium vancampoae, Deflandea* sp. C (Powel, 1986)*,* Forma T2and *Multispinula quanta.* Other forms are presented in Plates 4.45-4.48. Interval 24-67 m is chracterised by low abundance and diversity of palynomorphs. Relationship of Abundance and diversity of dinoflagellates is low compared to the miospores (Figure 4.2).

The uppermost part of the interval is at 25 m where the analysis commenced is characterised by low abundance of palynomorphs, first downhole occurrence of *Nymphae lotus, Cyperaceaepollis* sp.and *Arecipites* sp. At 67 m depth was occurrence of *Borteria* sp. and other miospores. Therefore, Zone 6 was dated Late Miocene-Pliocene age based on the appearance of marker microplankton forms, *Cyperaceaepollis* sp., *Nymphae lotus, Echitricolporites spinosus, Pteris* sp.and *Retistephanocolpites gracilis* (Evamy *et al*., 1978). The interval is stratigraphically equivalent to Ogwashi-Asaba Formation (Table 4.6).

Magnification ×800

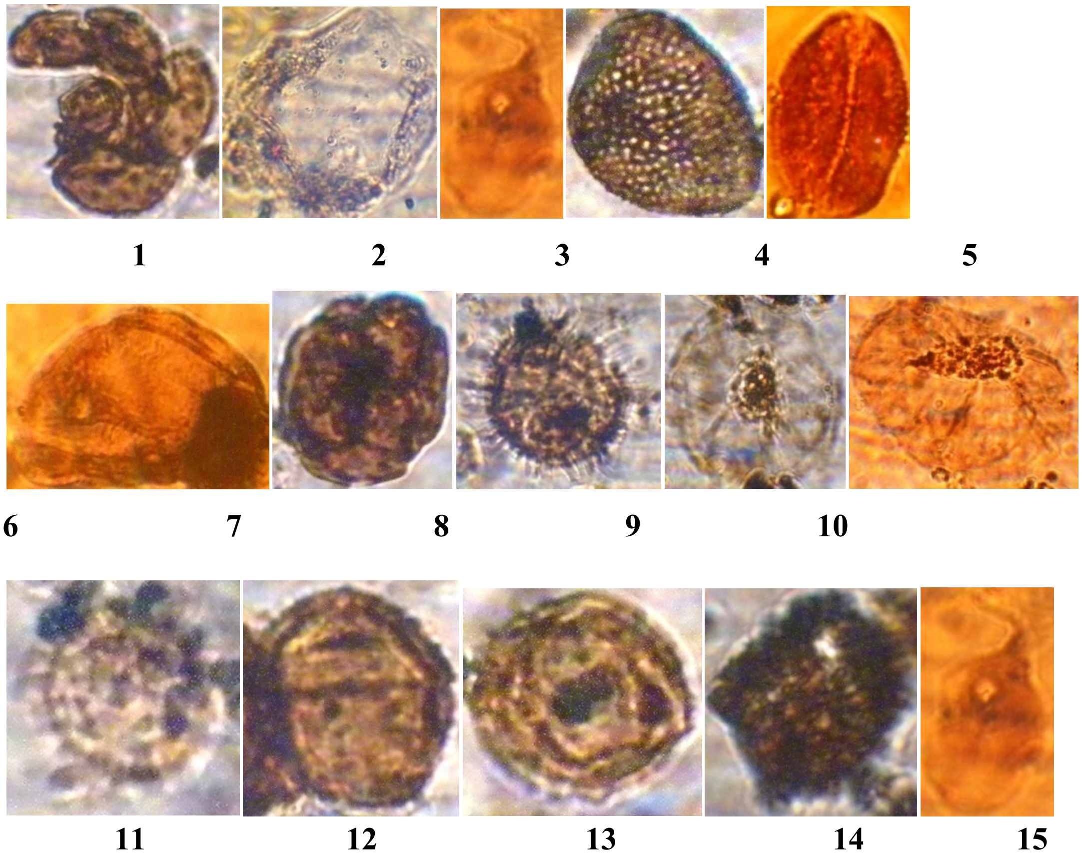
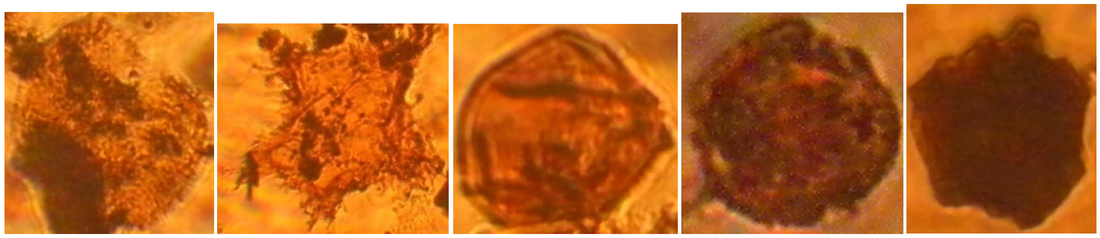


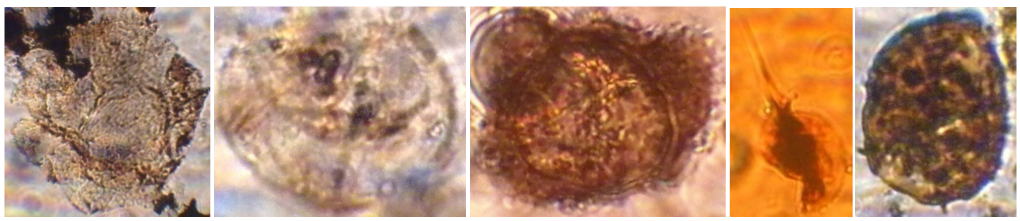
Plate4.46. Palynomorph assemblage of 24-329 m for Umuna- 1 well

1 Microforaminiferal wall lining
2 Forma D1
3 Forma D2
4 *Arecipites* sp.
5 *Retimonocolpites* sp.
6 *Longapertitesmarginatus*
7 *Retistephanocolpitesgracilis*
8*Spiniferites* sp.
9*Thallasiphora* sp.
10*Invertocysta tabulate*
11 *Spiniferites* sp.
12 *Canningia* sp.
13 *Nymphae lotus*
14 Indeterminate
15 Indeterminate dinoflagellate

Magnification ×800



1 **2** **3** **4** 5



6 **7** **8 9** **10**

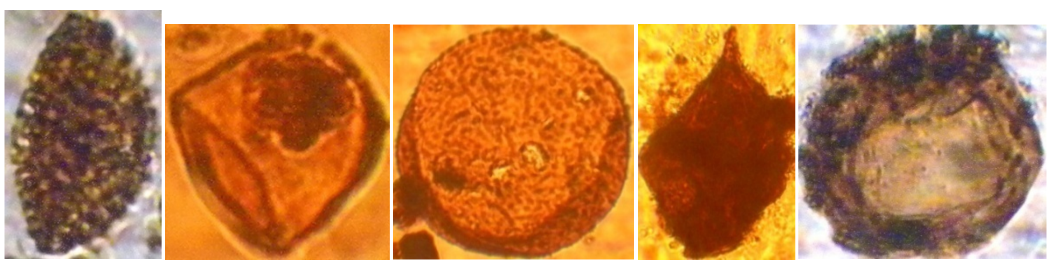


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Plate4.47. Palynomorph assemblage of interval 24-329 m for Umuna- 1 well

1 Indeterminate dinocyst
2 *Wetzeliella* sp. B
3 *Phelodinium* sp.
4 *Psilatriporites* sp
5 Forma R
6 Cf Calcium oxalate crystal
7 *Invertocyster tabulate*
8 Indeterminate
9 Indeterminate cyst
10 *Echiperiporites estalae*
11 *Arecipites* sp.
12 *Nymphae lotus*
13 Indeterminate
14 *Cribroperidinium* sp.
15 Forma B2

Magnification ×800

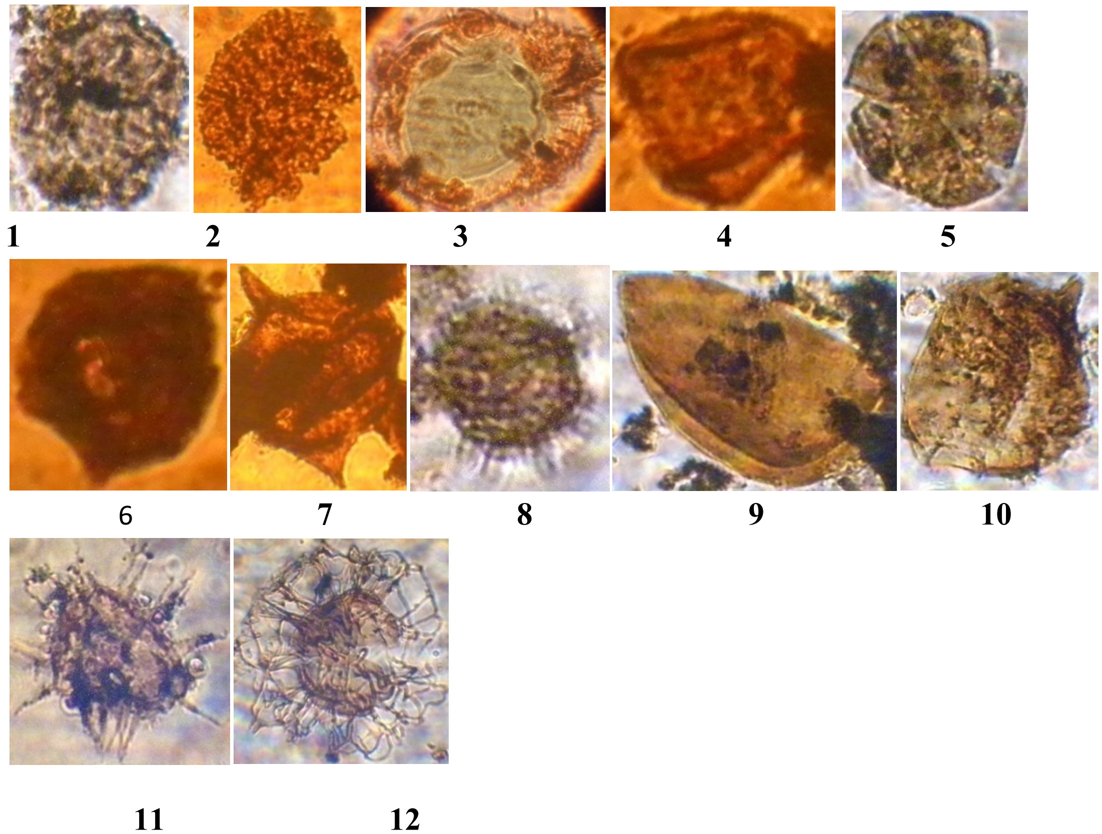


Plate4.48. Palynomorph assemblage of interval 24-329 m for Umuna- 1 well

1 Forma P

2 Indeterminate cyst

3 Indeterminate Forma T4

4 *Cyperaceaepollis* sp.

5*Retistephanocolpites gracili*

6 Forma T3

7 *Deflandrea* sp.

8 *Operculodinium* sp.

9 *Longapertites microfoveolatus*

10 Forma T2

11*Echitricolporites spinosus*

12 *Nematosphaeropsis* sp.

Table 4.6. Chronosratigraphy and palynological zones established for the Umuna-1 well

Depth (m)	Formation	Palynological Zones	Age
24	Ogwashi/Asaba	*Echitricolporites spinosus* zone 7	Late Miocene To Pliocene
329	Ameki	*Monoporites annulatus* Zone 6	Middle Eocene
481	Imo	*Mauritiidites crassibaculatus* Zone 5	Lower Paleocene
524 765	Mamu	*Foveotriletes margaritae* Assemblage Zone 4	Early Maastrichtian
1180	Nkporo	*Milfordia spp* Assemblage Zone 3	Campanian
2310	Eze Aku	*Cretacaeiporites spp* Assemblage Zone 2	Turonian to Upper Cenomanian

4.2.3 Palynozonation of Akukwa-2 well

The palynostratigraphy of Akukwa-2 well was carried out on forty samples. The palynomorphs recovered are poorly preserved, but contained some index fossils which permitted establishment of chronostratigraphy, palynozones and interpretation of paleoenvironment of deposition. Six palynozones were erected; the bases of establishing the zones are similar to that of the reference well- Nzam -1 well. To a large extent, there is a strong correlation in terms of pollen and spores taxa recovered in this well compared to those of the reference well; while new pollen and spore grains that are stratigraphically important show appearances.

The bases of establishing the zones in Akukwa-2 well are presented in Table 14 and also given below:

ZONE 1:*Cretacaeiporites* spp. Acme Zone

The zone is situated in interval 3261-3200 m, dated Upper Cenomanian to Turonian age. The lower part of this interval is marked by preponderance of *Cretacaeiporites infrabaculatus*. The top is also defined by top occurrence of *Liliacidites* sp.; new appearance of *Eucomiidites* sp. and *Leptolepidites verrucatus.* Pollen grains with continuous occurrence in the zone include Cretacaeiporate forms, *Classopollis* sp.and *Triorites africaensis*.
The interval is defined by maximum development of *Cretaeiporate* pollenand *Punctioratipollis krutzsci*(Figure 4.3 and Table 4.7). New taxon that evolved in the interval is *Proxapertites* sp.The *Proxapertites* sp. was described by Kotova (1984) to have appeared in the South Atlantic sediments dated Cenomanian. *Classopollis* sp. showed disappearance in this interval, while other forms present in the interval include *Monosulcites* sp., *Graminidites* sp., *Cyathidites* sp., *Phelodinium bolonienae, Botryococcus braunii* (algae); *Tricolpites* sp., *Monosulcites* sp. and fungal spore.

The uppermost part of the interval is marked by top occurrence of *Cretacaeiporites* spp., *Triorites africaensis, Eucomiidites* sp.and *Proxapertites* sp. Some of the forms found in this interval are similar to Zone 1 of Umuna- 1 well. The interval was dated Upper Cenomanian to Turonian based on the maximum development of *Cretacaeiporites* spp.; occurrence of *Triorites africaensis*, *Eucomiidites* sp., *Leptolepidites verrucatus* and *Proxapertites* sp.(Figure 4.3).

ZONE 2:*Zlivisporites blanensis* Assembalge Zone

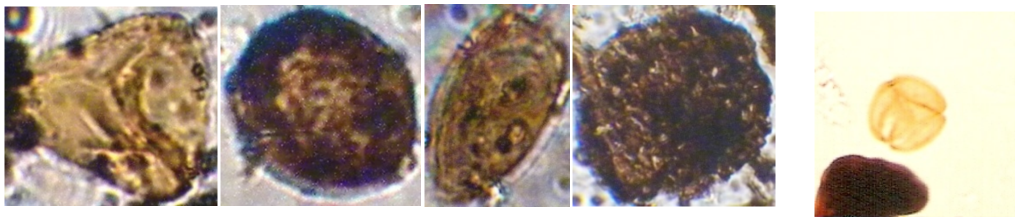
The zone was delineated in interval 3200-3075 m, dated Coniacian to ? santonian. The lower part of the interval coincides with the uppermost horizon of older underlying zone 2; characterised by top occurrence of *Cretacaeiporites* spp., *Triorites africaensis, Eucomidites* sp.and *Proxapertites* sp. The interval is characterised by paucity in palynomorphs, continuous occurrence of *Zlivisporites blanensis* and relative percentage increase in angiosperm grains. Other forms present in the interval include *Cyathidites* sp.*Verrutriletes* sp,*Monosulcites* sp.,*Triporites* sp.,*Senegalinium* sp., fungal spore, *Odontochitina* sp. (Forma E), *Dinogymnium* sp., *Phelodinium bolonienae*, Calcium crystal, and Trochome (non-pollen palynomorphs, Ruta *et al.,* 2007)

The upper part of the interval is marked by the first appearance of *Longapertites* sp. 3 and *Milfordia jardinei*; other forms present are *Monocolpopollenites sphaeroidites, Tricolpites* sp.and *Milfordia* sp. *Longapertites* sp. 3 was used by Lawal and Moullade (1986) to indicate the commencement of Campanian sediments in Kumo-6 well, Lower Benue Trough, Nigeria. It was also used along with *Milfordia* spp. to mark the Santonian/Campanian boumdary in Nzam – well. Thus, the interval is here dated Coniacian–?Santonian age.

ZONE 3:*Milfordia spp.* Acme Zone

The interval is confined within interval 3075-2758 m, dated Campanian. The lower part of the zone coincides with the uppermost horizon of underlying zone 3 characterised by basal occurrence of *Longapertites* sp. 3 and *Milfordia jardinei*. The interval is sparce of sporomorphs, other forms present in the interval are *Cyathidites* sp.(Plate 5.114, no. 1), continuous occurrence of *Zlivisporites blanensis* and *Triporites* sp. Pollen and spores having new appearance within the interval include *Longapertites verneendenburgi* (Plate 5.114, no. 3; 2902 m), *Syncolporites marginatus (*Plate 5.114, no. 5; 2874 m)*, Longapertites marginatus*(Plate 5.114, no. 10)*, Monocolpites* sp.(Plate 5.114, no. 7)*, Constructipollenites ineffectus* (Plate 5.114, no. 8) and *Monocolpites marginatus*(Plate 5.114, no. 9).

Magnification ×800



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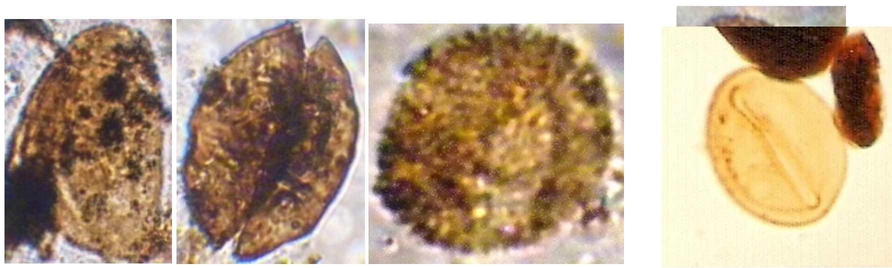
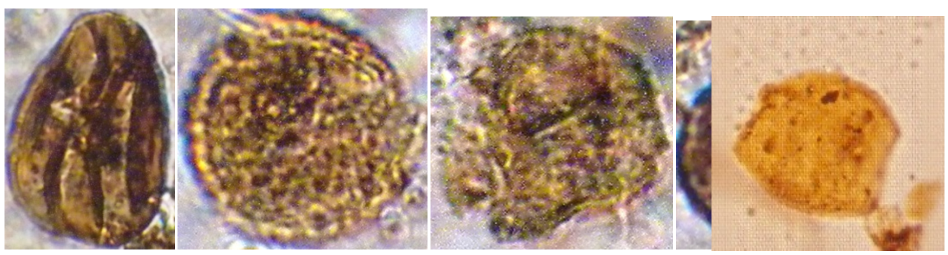


6 7 8 9 10

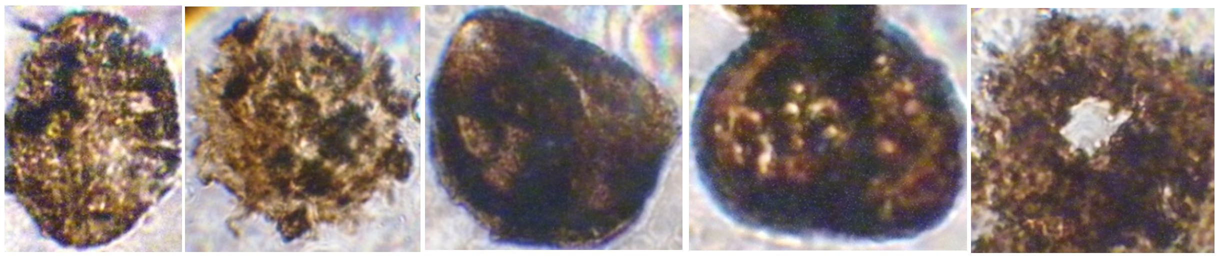


11 12 13 14 15

Plate4.49. Palynomorph assemblage of interval 2758-3075 m for Akukwa- 2 well

1 *Cyathidites* sp.
2 *Milfordia* sp. 2A
3 *Longapertites vaneendenburgi*
4 *Tricolpites* sp.
5 *Syncolporites marginatus*
6 *Longapertites* sp. 3
7 *Monocolpites* sp.
8 *Constructipollenites ineffectus*
9 *Monocolpites marginatus*
10 *Longapertites marginatus*
11 *Tricolpites* sp.
12 *Cicatricosisporites* sp.
13 *Tricolpites* sp.
14 *Retidiporites magdalenensis*
15 *Milfordia* sp. 2A

Magnification ×800



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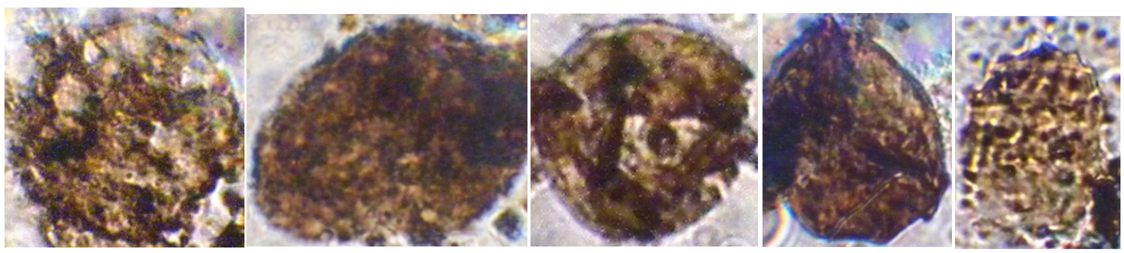
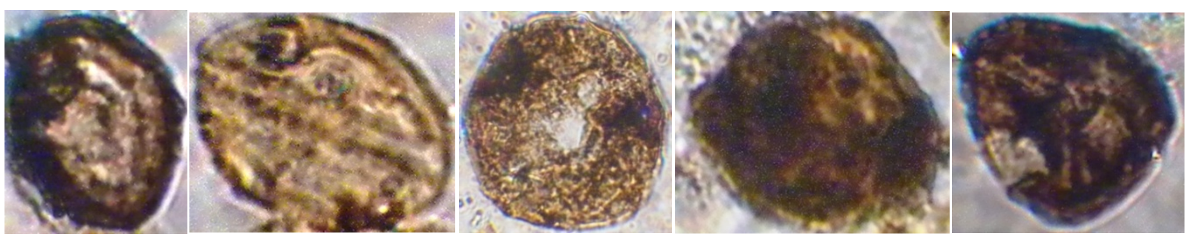


6 7 8 9 10



11 12 13 14 15

Plate4.50. Palynomorph assemblage for interval 2758-3075 m for akukwa- 2 well

1 *Retimonocolpites* sp.

2 *Homotryblium* sp. A

3 *Phelodinium belonienae*

4 *Milfordia* sp. 2B

5-7 *Milfordia jardinei*

8 *Araucariacites australis*

9 *Monocolpites* sp

10 *Dinogymnium* sp.

11 Milfordia sp.

12 *Monocolpites marginatus*

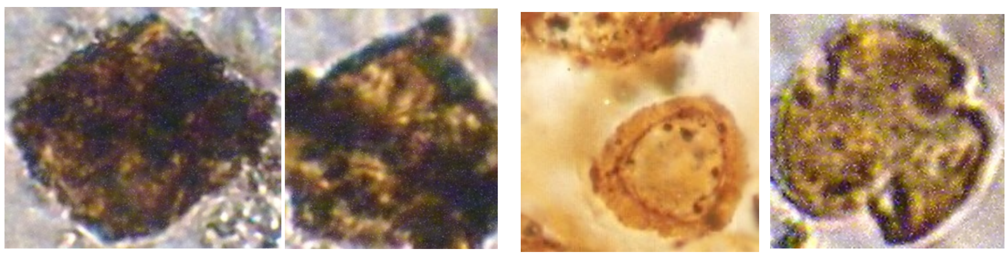
13 *Milfordia jardinei*

14 *Phelodinium belonienae*

15 *Cupanieidites reticularis*

Magnification ×80

1 2 3 4 5



6 7 8 9

Plate4.51. Palynomorph assemblage of interval 2758-3075 m for Akukwa- 2 well

1 *Milfordia* sp.

2 *Milfordia* sp. 4

3 *Milfordia* sp. 2

4 *Cupanieidites reticularis*

5 Milfordia sp. 2A

6 *Phelodinium* sp.

7 *Cribroperidinium edwardsii*

8 *Cingulatisporites ornatus*

9 *Tricolpites* sp.

Some of the pollen grains that evolved in this zone are characteristic forms of Maastrichtian sediments; however, *Milfordia* spp. and *Longapertites* sp. 3 disappeared in the interval (Figure 4.3). The upper part of the interval placed at 2758 m is defined by the first occurrence of *Buttinia andreevi*. Other palynomorphs present are presented in Plates 4.49-4.51. The interval was dated Campanian on the basis of appearance of *Longapertites* sp. 3and *Milfordia* spp. The zone is also equivalent to zone 2 of reference well Nzam– 1 of this study.

ZONE 4:*Foveotriletes margaritae* Assemblage Zone

Zone 4 is situated within interval 2758-2475 m, dated Early Maastrichtian age. The lowermost part of the interval was placed at 2758 m on the basis of last downhole appearance of *Buttinia andreevi.* The interval is moderately rich in palynomorphs and characterised by continuous occurrence of angiosperm pollen (*Tricolporopollenites* sp.; Plate 4.52, no. 3),*Monocolpites marginatus*(Plate 4.52, no. 5), *Aquilapollenites alveolatus*, *Inaperturopollenites* sp.(Plate 4.52, no. 5), *Proxapertites cursus*(Plate 4.52, no. 1), *Longapertites marginatus*(Plate 4.52, no. 2), *Monocolpopollenites sphaeroidites*(Plate 4.52, no. 6), *Cyathidites* sp. (Plate 4.52, nos. 7), *Cupaneidites reticularis, Ephedripites* aff. *regularis, Laevigatosporites* sp.(Plate 4.52, no. 8), *Araucariacites* sp.(Plate 4.52, no. 10) and *Proteacidites* sp. Most of these forms have been reported by Lawal and Moullade (1986) to indicate Early Maastrichtian age.

The interval is composed of dinoflagellate cysts such as *Phelodinium bolonienae, Andalusiella polymorpha, Trichodinium* sp., *Subtilisphaera* sp. 2, *Batiacasphaera* sp., *Senegalinium* sp.,and *Odontochitina* sp.The interval is here dated Early Maastrichtian age. The summary of the palynozones, chronostratigraphy, characteristics of zones, their respective formation and paleoenvironment of deposition is presented in Table 4.7.

Magnification ×800

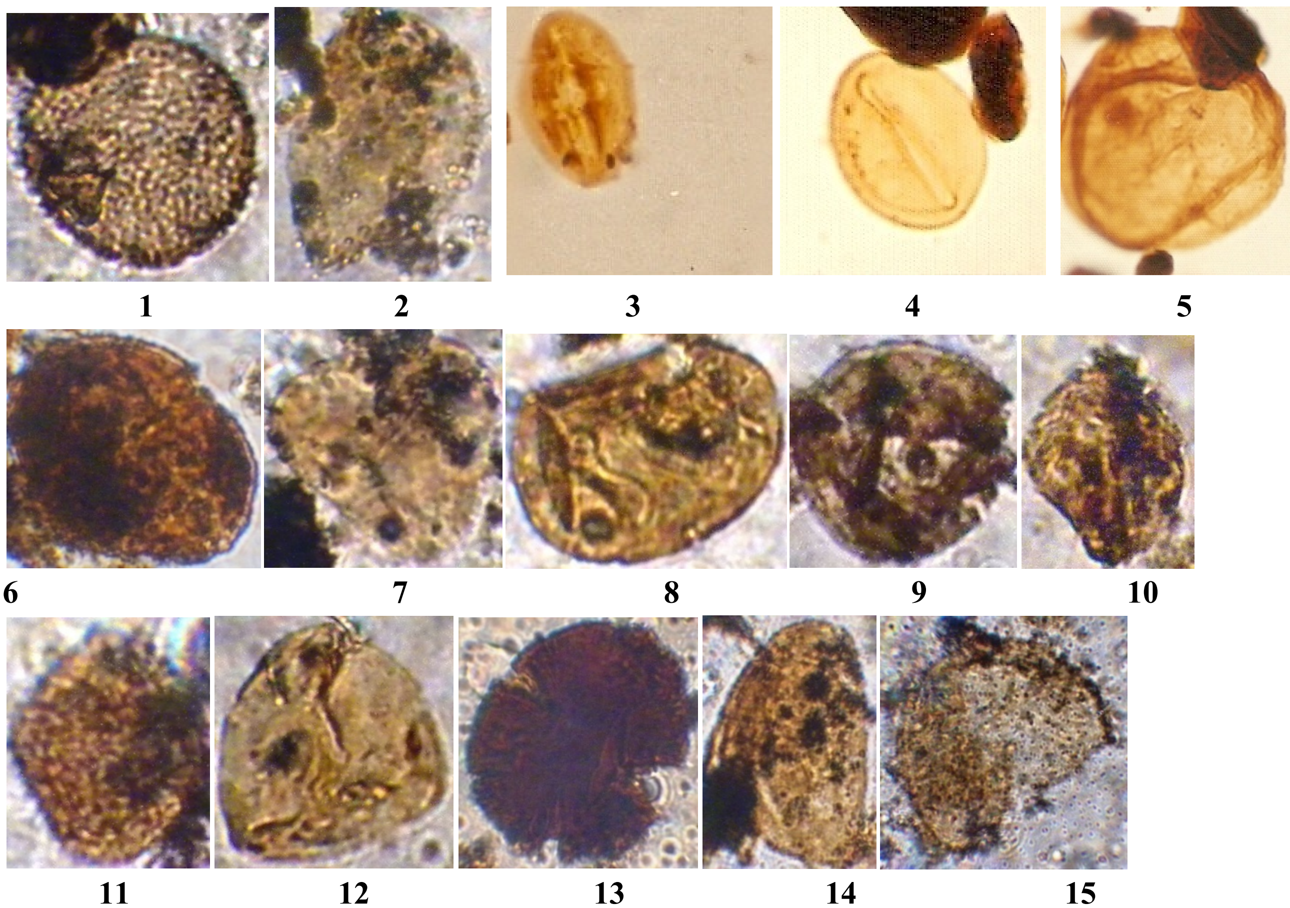
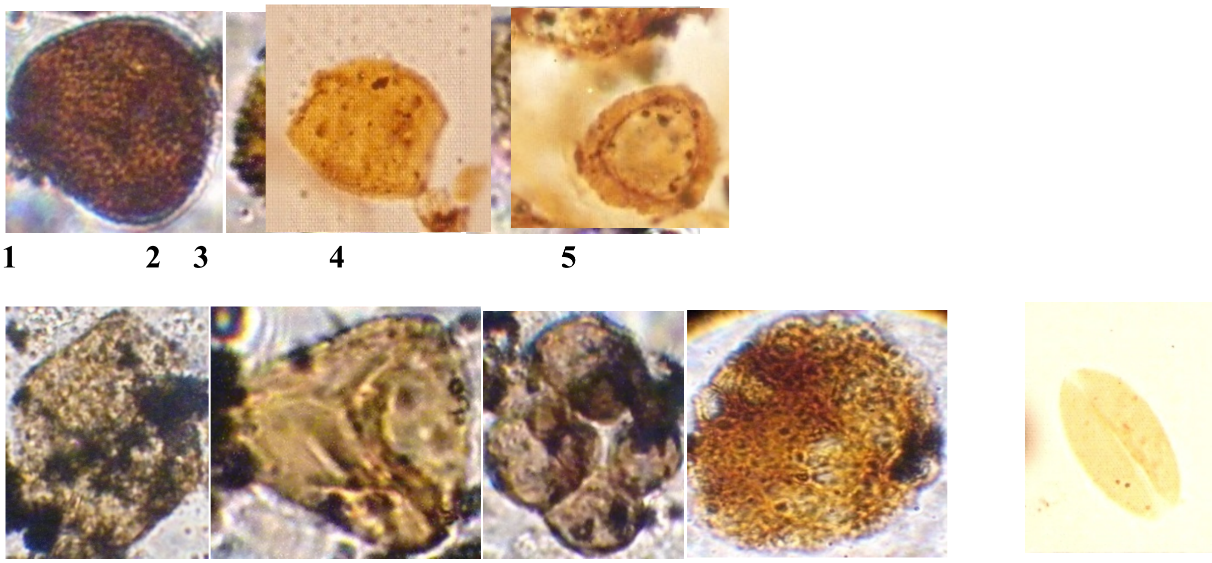


Plate4.52. Palynomorph assemblage of interval 2475-2758 mfor Akukwa- 2 well

1 *Proxapertites cursus*
2*Longapertitesmarginatus*
3 *Tricolporopollenites* sp.
4 *Monocolpitessmarginatus*
5 *Inaperturopollenites* sp.
6 *Monocolpopollenites sphaeroidites*
7*Cyathidites* sp.
8 *Laevigatosporites* sp.
9*Araucariacites* sp.
10 Auriculiidites sp.
11 *Phelodinium bolonienae*
12 *Syncolporites* sp.
13 *Retistephanocolpiteswilliamsi*
14 *Longapertites marginatus*
15 *Caningia* sp.

Magnification ×800



1 2 3 4 5

6 7 8 9 10

Plate4.53. Palynomorph assemblage of interval 2475-2758 m for Akukwa- 2 wel

1 *Foveotriletes margaritae*

2 *Retidiporites magdalenensis*

3 *Cingulatisporites ornatus*

4 *Constructipollenites ineffectus*

5 *Echitriporites trianguliformis*

6 *Phelodinium belonienae*

7 *Cyathidites* sp.

8 Microforamoiniferal wall lining

9 *Periretisyncolpites* sp.

10 *Monosulcites* sp.

Table 4.7. Chronostratigraphy and palynological zones of the Akukwa-2 Well

Depth (m)	**Formation**	**Palynological Zone**	**Age**
2475 2758	Mamu	*Foveotriletes Margaritae* Assemblage Zone 5	Early Maasrichtian
3075	Nkporo	*Milfordia* spp Assemblage Zone 4	Campanian
	Awgu	*Zlivisporites blanensis* Assemblage zone 3	?Santonian to Coniacian
3200 3653	Eze Aku	*Cretacaeiporites* spp. Assemblage Zone 2	Turoian to Upper Cenomanian

4.6 Palynozone Synthesis and Chronostratigraphy Correlation

The palynozone interpretation of the three wells was carried out following the conventional method whereby index fossils of stratigraphic importance were compared with established palynological works. The Nzam-1 well is a complete well and one of the deepest of the three borehole wells, it ranges in depth from 113 to 2906 m. It was taken as the reference well from which other wells were compared with. Eight palynological zones were erected for the Nzam-1 well ranging in age from Middle Cretaceous to Tertiary (Coniacian to Pliocene; Figure 4.1, Table 4.5). It is pertinent to note that there is no record of the presence of Ajali Formation in the reference well and the other two wells analysed for this study.

The Umuna-1 well ranges in depth from 24-1689 m. It shows similar pollen assemblages like the reference well but characterised by hiatus (diastems) or major unconformities apart from the Santonian erosional surface that is widely known in Anambra Basin. This feature was noted by the missing *Zlivisporites blanensis* assemblage Zone 3 dated Coniacian to ?Santonian, *Longapertites* spp. Acme Zone 6 (of the upper Mamu Formation), undifferentiated Ajali Sandstone, and *Spinizonocolpitesbaculatus* zone 5 (Nsukka Formation) . These geologic time gaps are prominent in the Umuna-1 well (Tables 4.6, 4.9).

Akukwa-2 well ranges in depth from 2475-3261 m. It is a fairly deep well, but the samples supllied started from depth 2475 m. The palynomorphs recovered show similarity to those obtained from the other two wells. The geologic age of the Akukwa-2 well ranges from Cenomanian to Early Maastrichtian(Figure 4.3; Tables 4.7, 4.9).

The stratigraphy showed conformable and unconformable relationships. The Asu-River Group and the adjacentyounger Eze-Aku Formation show conformable relationship. There was no sharp lithofacies difference between the two. The same phenomenon exists betwen Awgu Shale and the underlying Eze-Aku Formation in Nzam-1 and Akukwa-2 wells; the situation is not the same in Umuna-1 well because there is complete erosional removal of Coniacian to Santonian sediments or a suggested fault that have displaced the rock block from being encountered during drilling; or probably the Awgu Formation thin-out in the well. Therefore, hiatus or fault exists between the Nkporo and Eze-Aku Formations in the Umuna-1 well (Figur 4.22; Table 4.9).

Table 4.8. Chronostratigraphy, Formation and Palynozones of the Anambra Basin, Nigeria

AGE/CHRONOSTRATIGRAPHY			LITHOLOGY	FORMATION	PALYNOZONE (This study)
MY	PERIOD/EPOCH				
2-23	Late Miocene-Pliocene			Ogwasi-Asaba	*Echitricolporites spinosus*
38-52	Middle Eocene			Ameki	*Monoporites annulatus* Assemblage Zone
63-67	Lower Paleocene			Imo	*Mauritiidites crssibaculatus* Assemblage Zone
72	Upper	Maastrichtian		Nsukka Formation	*Spinizonocolpites baculatus* Assemblage Zone
	Middle			Mamu	*Longapertites marginatus* Acme Zone
	Lower				*Foveotriletes margaritae* Assemblage Zone
81.5	Campanian			Nkporo Shale	*Milfordia spp.* Acme Zone
					HIATUS
84	Santonian			Awgu Shale	*Zlivisporites blanensis* Interval Zone
85	Coniacian				
92.5	Turonian			Eze Aku	*Cretacaeiporites spp.* Acme Zone
	Cenomanian				

However, the Nkporo and Awgu formations show an unconformable relation; first by the Santonian episode marked by wide spread upliftment, folding and erosional removal; secondly, manifestation from the paleoenvironmental deduction which varies from marginal marine to continental at the basal part of Nkporo Shale in Akukwa-2 well (Tables 5.4 and 5.6). This situation was not traceable to the other two wells (Figure 4.3; Tables 4.7, 4.9).

TheMamu Formation conformably overlies the Nkporo Shale. There is a sharp environment of deposition between the uppermost Mamu Formation deposited in an open marine setting compared to the lowermost Nsukka Formation deposited in the continental srtting. Such continental sediment is an indication of fluvial processes characterized by gravelly or clast size sand grains and paucity or non recovery of palynomorphs (Figure 4.3).

However, the same phenomenon operated between the uppermost part of the Nsukka Formation characterised by continental deposit and lowermost part of the Imo Formation which was deposited in an openmarine setting. The Ameki Formation dated Middle Eocene lie unconformably on the Early Paleocene Imo Formation. This suggests that the Middle Paleocene to Early Eocene sediments were not deposited or they were erosionally removed (Table 4.8).

Table 4.9. Correlation of the Geologic ages, Formation and Palynozones of the Nzam-1, Umuna-1 and Akukwa-2 wells in the Anambra Basin, Southeastern Nigeria.

ERA	AGE (ma)	PERIOD		EPOCH	AGE	EVENT	FORMA-TION	PALYNOLOGICAL ZONES (This study) NZAM-1	UMUNA-1	AKUKWA-1
CENOZOIC	2-23	TERTIARY	NEOGENE	LATE MIOCENE-PLIOCENE	ZANCLEAN TO TORTON-IAN	POST SANTONIAN	OGWASHI-ASABA	*ECHITRICOLPORITES SPINOSUS* ZONE 9	ZONE 9	NO DATA
	38-52		PALEOGENE	MIDDLE EOCENE	LUTENIAN		AMEKI	*MONOPORITES ANNULATUS* ZONE 8	ZONE 8	
	63-67			EARLY PALEOCENE	DANIAN		IMO	*MAURITIIDITES CRASSIBACULATUS* ASSEMBLAGE ZONE 7	ZONE 7	
MESOZOIC	68	CRETACEOUS	LATE	MAASTRICTIAN	L		NSUKKA	*SPINIZONOCOLPITES BACULATUS* ASSEMBLAGE ZONE 6	HIATUS	
	70				M		MAMU	*LONGAPERTITES MARGINATUS* ACME ZONE 5		
	74				E			*FOVEOTRILETES MARGARITAE* ASSEMBLAGE ZONE 4	ZONE 4	ZONE 4
	81.5		MIDDLE	CAMPANIAN			NKPORO	*MILFORDIA* SPP. ACME ZONE 3	ZONE 3	ZONE 3
	84			SANTONIAN		PRE-SANTONIAN	HIATUS	HIATUS	HIATUS	HIATUS
	84.5						AWGU	*ZLIVISPORITES BLANENSIS* ASSEMBLAGE ZONE 2	HIATUS	ZONE 2
	85			CONIACIAN						
	92.5			TURONIAN			EZE AKU	NON-DEPOSITION	ZONE 1	*CRETACAEIP-ORITES* SPP. ACME ZONE 1
	96			LATE CENOMANIAN						

The youngest Ogwashi/Asaba Formation was dated Late Miocene to Pliocene in the Nzam-1 well (2-23 ma) unlike the Oligocene age given to it by Nwajide (1990). It is posited that the assigned ages by earlier authors are questionable. The Ogwashi-Asaba Formation is characterised by unconformable relationship with the older underlying Ameki Formation (Tables 4.8 and 4.9). A geologic age interval from Upper Eocene to Middle Miocene is not present within the well section. This could as well be as a result of erosional removal or non deposition of the sediments (Table 4.8). Therefore, in this study five unconformity surfaces that are regional in extent are correlatable from one well to another were established (Table 4.9).

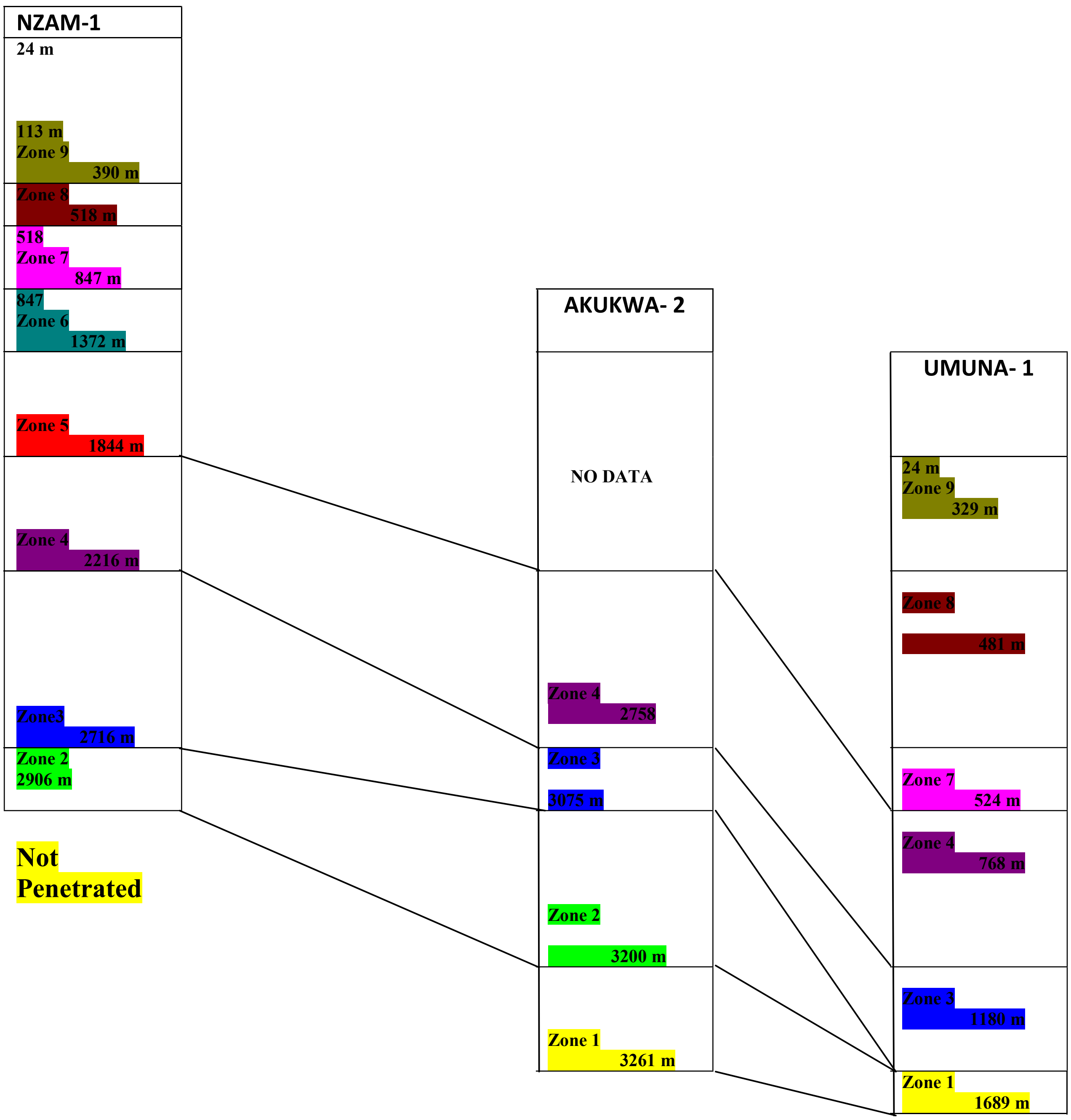


Figure 4.22. Palynozone correlation of Nzam-1, Umuna-1 and Akukwa-2 wells located in Anambra Basin, southeastern Nigeria (Not to scale)

4.7 Sequence stratigraphy

Sequence stratigraphy application has been widely used by many workers to solve problem of correlation and understanding the architectural stacking pattern of stratigraphic sequences. Among well documented reports are the works of Vail and Wornardt (1990); Wornardt and Vail (1991); Morley (1992, 1995); Umeji (2007, 2010); Ehinola (2010); Ola-Buraimo and Akaegbobi (2013); Odunze and Obi (2013); Adebayo *et al.* (2015) for the Nkporo Formation in Anambra Basin, Nigeria and Akaegbobi *et al.* (2016) on three wells located in Forcados Yorkri Field, Niger Delta, Nigeria. Therefore, the Nzam-1 well taken as the reference well was studied in detail by generating data on palynomorph abundance and diversity in order to deduce systems tracts (Fig. 4.23). Palynological systems tracts delineated are Lowstand Systems Tract (LST), Transgressive Systems Tract (TST) and Highstand Systems Tract (HST). Other sections and surfaces that permitted identification of the sysyems tracts are the condenced section (CS), maximum Flooding Surface (MFS) and Sequence Boundary (SB). Definitions of the terms used are given below according to Morley (1995).

Lowstand systems tract: These are sediments deposited during the lowest sea levels following a type 1 sequence boundary. The geometry of its constituent parts differs according to whether deposition occurred in a basin with a shelf break or ramp margin.

Transgrssive systems tract: It is the middle systems tract in both type 1 and type 2 sequences. It is characterised by one or more retrogradational parasequence sets. The base of the transgressive systems tract is the transgressive surface at the top of the lowstand or shelf margin systems tracts.

Highstand systems tract: Deposited during the highest sea levels during either type 1 or type 2 sequence, widespread on the shelf and may be characterised by one or more aggradational parasequence sets that are succeeded by one or more progradational parasequence sets with prograding clinoform geometries.

Sequence stratigraphy: It is the study of relationship within a chronostratigraphic framework wherein the succession of rocks is cyclic and composed of genetically related strata unit.

Sequence: A relatively conformable succession of genetically related strata bounded by unconformity and their correlative conformities. It is composed of a succession of systems tract and is interpreted to be deposited between eustatic fall inflection points.

Systems tract: It is the linkage of contemporaneous depositional systems, each defined objectively by strata geometries at boundary surfaces position within a sequence and internal parasequence stacking patterns.

Thus, the interpretation of the sequence stratigraphy of the Nzam-1 well was established through the integration of lithological and palynological data (Tables 4.1 and 4.4). The method entails total abundance and diversity of palynomorphs and cognizance of two types of dinoflagellates such as ganyaulacaceans and peridinaceans. The preponderance of ganyaulacaceans in addition to high abundance and diversity of palynomorphs defines a stratigraphic condensed section (CS) within which is maximum flooding surface (MFS), characterizes highstand systems tract (HST). On the other hand, intervals characterized by barren to poor recovery of palynomorphs suggest lowest position of sea level, equivalent to lowstand systems tract (LST) at the base of which is a sequence boundary (SB). The rising sea level is the transgressive systems tract (TST) characterized by relative increase in palynomorph abundance, diversity and higher occurrence of peridinacean dinoflagellate cysts compared to LST.

The result shows that there are six sequences of events of deposition from the Middle Cretaceous to the Pliocene time (Fig. 5.27). The lowest part of the section dated Coniacian and lowest part of Akukwa -2 wells are characterised by highstand systems tract which suggest the incursion of the marine water due to splitting of the Gondwana landmass. This observation is similar to the Latest Albian transgression noted by Ramanathan and Fayose (1990) on the Calabar Flank, southeast Nigeria; also in consonant with the work of Ehinola (2010) on oil shale deposit in the Abakaliki fold belt.The marine transgression was responsible for the contemporaneous sedimentation of pre-Santanian sediments in Anambra Basin as noted in this study, Abakaliki Anticlinorium as indicated by Ehinola (2010) and its facies equivalent in the Benue Trough, Nigeria (Reyment and Morane, 1977) and Calabar Flank, Nigeria(Ramanathan and Fayose, 1990) (Fig. 5.5). Seven maximum flooding surfaces were delineated in the Anambra Basin when that of Akuwa-2 containing Eze Aku Formation is considered compared to four transgressions reported by Ramanathan and Fayose (1990) for Calabar Flank and Benue Trough (Reyment and Morner

(1977). The maximum floding surfaces (MFS) established were located within the condensed section (CS) (Fig.4.23).

The periods of maximum flooding surface is equivalent to the time of increase in sea level resulting to retrogradation and deposition of fine materials such as shale (Wornardt and Vail, 1991). The sequence boundary was located at 2966 m in Akukwa-2 well. The second maximumflooding surface is present at 3261m in the Upper Cenomanian marking the transition from the Asu-River Group to Eze Aku Formation.The second MFS that marks Eze Aku Formation was also reported in the work of Ehinola (2010) characterised by highest abundance recovery of microfaraminifera. This is a type 2 sequence (Morley, 1995).

However, the third transgressive cycle noted by Ramanathan and Fayose (1990) for the Turonian seems not to be present.Only one transgressive phase was responsible for the deposition of Cenomanian-Turonian sediments (Eze-Aku Formation) unlike two phases suggested by Ramanathan and Fayose (1990) (Figure 4.25). The two transgressions mentioned by them were flooding surfaces rather than maximum flooding surface whichwas supposed to be the shaliest facies formed as a result of highest increase in sea level (Fig. 4.25).

The regressive phase represented by lowstand systems tract (LST) was responsible for the deposition of the Awgu Formation in the Coniacian time (Fig. 4.23). A comparison of the transgressions noted in the Cretaceous sediments of this study to that of Reyment and Morner (1977) show some correlations except their third cycle that differs, in that, this study shows that Awgu Formation was deposited under lowstand systems tract (regressive phase) which is in contrast to transgressive phase suggested by them (Figures. 4.2 and 4.25). In the work of Ehinola (2010) similar transgression cyle was noted in the Abakaliki Anticlinorium which suggests that the eastern flank of Anambra Basin experienced favourable ecological factors, where sediments were deposited under anoxic condition. In the contrary, Anambra Basin witnessed poor ecological factors at the time and the sediments were deposited under oxic condition. These are suggested to account for lowstand systems tract interpreted in this study and highstand systems tract suggested by other workers.

This same view was shared and reported in the work of Umeji (2007) that lowstand systems tract was responsible for the deposition of Awgu Shale but the awgu Shale was not recorded (missing) in some parts of Anambra Basin, Nigeria such as in Umuna-1 well of this study and at an outcrop at Leru in Anambra Basin (Umeji, 2006; Fig. 4.25). The absence of the Awgu Shale may as well be due to thinning out of the facies. The adverse drop in marine water level (regression) in conjunction with tectonic activity accounted for the removal of deposited sediments or non deposition of sediments during the Santonian period (Figs. 4.23, 4.24 and 4.25).

The lowest part of the Nkporo Formation was formed during the Earliest Campanian under the influence of marine retrogradation and major parts of the Nkporo Formation was under the influence of marine incursion. Maximum flooding surface was placed at 2411m within the Nkporo Formation; dated Upper Campanian (Fig. 4.23).

STAGE	EPOCH	TRANSGRESSION	NAME	CYCLE
Piocne Miocene	U	7TH	Owashi/Asaba Cycle	
	M			
	L			
Oligocene		HIATUS	HIATUS	
Eocene	U			
	M	6TH	Ameki	
	L			
Paleocene	U		HIATUS	
	M			
	L	5TH	Imo Cycle	
Maastrichtian	U	4TH	Nsukka Cycle	
	M	3RD	Mamu Transgression	
	L			Regression
Campanian	U	2ND	Nkporo Cycle	
	L			
Santonian	U			
	L		HIATUS	
Coniacian			Awgu Regression	
Turonian		1ST	Eze Aku Cycle	
Cenomanian	U			
	L			

Figure 4.24. Transgressive and regressive cycles in Nzam- 1 well (Present study)

Stages/Epoch		Benue Trough After Reyment and Morner, (1977)		Calabar Flank After Ramanathan and Fayose, (1990)		Anambra Basin Present Study	
		Transgression	Name	Transgression	Name	Transgression	Name
Pliocene						7TH	Ogwashi/Asaba Cycle
Maastrichtian	U						
	M						
	L					HIATUS	HIATUS
Oligocene							
Eocene	U						
	M	NO DATA	NO DATA	NO DATA		6TH	Ameki Cycle
	L						
Paleocene	U				NO DATA	HIATUS	HIATUS
	M						
	L					5TH	Imo Cycle
Maastrichtian	U					4TH	Nsukka Cycle
	M					3RD	Mamu Cycle
	L	4TH	Nkporo Cycle	4TH			Regression
Campanian	U					2ND	Nkporo Cycle
	L						
Santonian	U	HIATUS	HIATUS	HIATUS		HIATUS	HIATUS
	L						
Turonian		2ND	Eze Aku Cycle	3RD		1ST	Eze Aku Cycle
Cenomanian	U	Non-Deposition		2ND			
	L					NO DATA	NO DATA
Albian		1ST	Asu River Cycle	1ST			

Figure 4.25. Comparison of sea level cycles in Anambra Basin with Benue Trough (Reyment and Moraner, 1977) and Calabar Flank (Ramanathan and Fayose, 1990) Nigeria

Similar phenomenon was reported by Umeji (2010), Odunze and Obi (2013) on the Nkporo Formation outcrop at Leru in Anambra Basin, Nigeria. The position of the third trasgressive phase is similar to the observation of Reyment and Morner (1977), Ramanathan and Fayose (1990) for Benue Trough and Calabar Flank respectively (Fig. 4.25).

The highstand systems tract that was responsible for the deposition of Nkporo Shale did not continued and was not responsible for deposition of lower Mamu Formation (Fig. 4.23). The lower part of Mamu Formation was deposited under the influence of lowstand systems tract (regression), dated Lower Maastrichtian.A sequence boundary was placed at 2057 m and a conformable facies relationship exists between the Campo/Maastrichtian sediments. The Middle Maastrichtian was marked bythe forth cycle in this study but not identified by Reyment and Morner (1977); but partially identified by Ramanathan and Fayose (1990) (Fig.4.25).Mamu Formation was categorised into lower and upper Mamu Formation (Fig. 4.24). The upper Mamu is characterised by the forth transgressive cycle of Middle Maastrichtian age.

The fourth maximum flooding surface (MFS) represents maximum landward movement of the shoreline as result of increase in sea water level during Middle Maastrichtian time. The wet fovourable climatic condition was responsiblefor the maximum development of *Longapertites marginatus.* The upper boundary of the Mamu Formation is marked by the top of HST, while the lower boundary of Nsukka Formation is marked by lowstand systems tract (regression), characterised by pausity of palynomorph abundance and diversity. Sequence boundary (SB)was placed at 1256m, while a short transgressive phase followed. Fifth maximum flooding surface was place at 1234m, tentatively dated Lowermost Upper Maastrichtian age located within the Nsukka Formation (Fig.4.24).

The uppermost part of the Nsukka Formation is characterised by very high recovery of palynomorph abundance and diversity depictive of a condensed section (Fig.4.23); within this is the location of MFS at 847m. The sixth major marine transgression commenced deposition of the Imo Formatiom. Thereby, a conformable facies relationship exists between the Imo Formation and the underlying Nsukka Formation.

A regressive phase followed the marine transgression during the Early Paleocene and the effect of the lowstand systems tract of type 1 unconformity resulted and responsible for the removal or starvation of sediments till seventh marine transgression occurred during the Middle Eocene. This was responsible for the deposition of Ameki Formation (Fig.5.28). An unconformity exists between the Ameki Formation (Middle Eocene) and the younger Ogwashi/Asaba Formation (Upper Miocene-Pliocene). The eighth maximum flooding surface was placed at 232m within the Ogwashi-Asaba Formation.

4.8 Depositional paleoenvironments

The paleoenvironments of deposition of sediments for the formations in each well were interpreted statistically both qualitatively and quantitatively, also by considering other parameters. The details for the paleoenvironment of deposition for each well are presented below.

4.8.1 Depositional Paleoenvironments in Nzam-1 well

Nzam-1 well is characterised by various paleoenvironments of deposition. The sedimentary deposits at the basal part of the well are of marginal marine environment. The paleoenvironment of the stratigraphic sequence varies upward from continental to typical marine settings. The paleoenvironmental inferences interpreted for this study was based on the combination of different data obtained from non-pollen palynomorphs such as algae, fungi, microforaminiferal wall linings; gonyaulacacean/peridinacean ratio (G/P) after Harland (1973) and various pollen and spores assemblages that characterise continental and mangrove paleoenvironments.

Interpretation of paleoenvironments had been carried out by diffent workers using different methods from palynological data such as the work of Batten (1973, 1982); Van Bergen*et al.*(1990) and Vadja-Santivanez (1998). Relative abundance of terrestrial pollen and spores, abundance of dinoflagellates derived from marine are documented in the works of Lawal(1982), Schrank(1984), Edet and Nyong(1992), Ojo and Akande (2000), Ogala *et al*. (2009), Umeji (2010), Adebayo *et al*. (2015), Ola-Buraimo and Abdulganiyu (2017).

Paleoenvironmental interpretation based on the use of palmae pollen of mangrove environment with affinity for sub-saline waters, sculptural and structural similarities had been used by earlier workers such Salami (1984, 1988) and Frederiksen (1985). Sowunmi (1986) and Poumot

(1987)opined that mangrove plants are ecologically significant lithoral plants that are not usually carried away from their source, thereby, useful as environmental marker forms.

Dinoflagellatesoccurrences had been used for reconstruction of paleoenvironments by various workers including Clarke and Verdier (1967), Kjellstrom (1973) Hansen (1977), Ola-Buraimo and Akaegbobi (2012). Application of microplanktons towards determining paleoenvironment of depositionwas carried out by Cookson and Eisenack (1958, 1960, 1962, 1968, 1970 and 1974) in Australia; in Newzealand by Wilson (1976a, 1976b and 1984). Significant application of dinoflagellate studies were carried out by other researchers including Drugg (1967), Harland (1973), Williams (1975),Williams and Brideaux (1975), Mc Intype (1975), Benson (1976), Bujak and Williams (1978), May (1980), Whirtney (1984), Umeji (2010), Ola-Buraimo and Abdulganiyu (2017).

In this study, gonyaulacacean/peridinacean ratio (G/P) after Harland (1973)was adopted. The G/P ratiowas interpreted to have positive value (+ve), negative value (-ve) and zero value.The zero value is when there is no microplankton recovered, but palynomorph recovery is dominated by land derived miospores only. The positive value was interepreted to represent marine environment dominated by gonyaulacacean forms which were described as chorate dinoflagellate cysts and cosmopolitan in nature; these include*Spiniferites*sp.,*Florentinia*sp.,*Oligosphaeridium*sp. (Schrank, 1991); *Polysphaeridium*sp.,*Gochtodinium*sp. 1, *Gonyaulacacean*sp.,*Spinidinium*sp. and *Subtilisphaera*sp.(Tables 5 and 8). They are cosmopolitan forms with Tethyan affininities(Davey and Verdier, 1973, 1976; Below, 1984; Battern and Uwins, 1985; Ojo and Akande, 2001) present at the basal part of the analysed wells.The stratigraphic horizon belonging to marine environment is 2878-2906 m (Table 4.10).

Negative value (-ve) suggests lateral movement from the deeper part of the marine environment to the marginal environment which encompasses mangrove, the barrier island, and the marine shelf. Dinoflagellates that characterise this depositional systems are peridinoid forms such as *Andalusiellalaevigata*, *Andalusiellapolymorpha*, *Andalusiella*sp.,*Phelodiniumbolonienae*, *Senegalinium*spp.,*Paleocystodiniumaustralinium*, *Odontochitina*sp.,*Odontochitinacostata* and so on (Table 4.10).

They are dinocysts with long processes which are usually high in abundance than the gonyaulacaceanscharacterised by short spines.The intervals delineated with marginal marine setting are 2960-2933 m and 2771-2744 m. Peridinoids are higher in abundance than the short spines (gonyaulacacean). Peridinoids are associated sub-saline water. Dinoflagellates as tool for paleoenvironment interpretation is documented in the works of Upshaw (1964), Sarjent (1970), Jain and Millepied (1973), Oloto (1987), Ogala *et al*. (2009) and Umeji (2010).

The intervals with zero value are characterised by abundant land derived forms delineated in interval 2878-2802 m. The intervals belong to continental environment (Table 5.8). Sedimentological evidence shows that the intervals are characterised by coarse to pebbly-sized sand grains that suggest deposition over ravinement surface by fluvial processes during low sea level position. Thus, a progradation phenomenon was suggested for the deltaic depositional system in the intervals. Palynologically,such continental environment is usually associated with low miospore recovery; suggested to be due to harsh ecological condition arisen from dry climate.

Table 4.10. Paleoenvironment of deposition of Cretaceous-Tertiary sediments in Nzam-1 well, Anambra Basin, Nigeria.

Depth (m)	Formation	Age	Miospore Frequency	Dinoflagellate Frequency	Gonyaulacacean frequency	Peridinacean Frequency	G/P Ratio After Harland, 1983	Microfofaminiferal wall lining	Algal Frequency	Fungal Frequency	Paleo-Environment
113	OGWASHI/ ASABA	Late Miocene To Pliocene	10	-	-	-	0	-	1		Open Marine
128			51	9	9	-	9	2	4		
151			32	5	5	-	5	-	1		
232			66	10	10	-	10	-	3		
256			55	11	11	-	11	-	-		
287			48	5	5	-	5	-	-		
311			32	4	4	-	4	-	-		
355			20	-	-	-	-	-	-		
366			40	8	8	-	8	1	7		
390	AMEKI	Middle Eocene	13	8	7	1	7	2	3		
412			13	13	13	-	13	1	2		
445			19	4	4	-	4	-	2		
469			20	3	2	1	2	1	14		
494			32	5	5	1	5	-	-		
518	IMO	Early Paleocene	28	12	12	-	12	-	7		
543			21	2	2	-	2	4	-		
567			7	-	-	-	-	-	1		Continental
591			9	1	1	-	1	-	2		Open Marine
628			7	1	1	-	1	1	1		
658			20	1	1	-	1	2	4		
689			6	-	-	-	-	2	-		
713			26	3	3	-	3	1	-		
738			36	-	-	-	-	2	3		
762			29	4	4	-	4	2	1		
792			69	26	21	-	26	-	2		
817			77	34	34	-	34	3	2		
847	NSUKKA	Late Maastrichtian	111	70	66	4	16.5	1	-		
872			36	25	24	1	24	4	1		
896			46	20	14	6	1.9	-	9		
924			5	-	-	-	-	-	-		Continental
951			2	-	-	-	-	-	-		
975			1	-	-	-	-	-	-		
1009			1	-	-	-	-	-	-		
1036			1	-	-	-	-	-	-		
1064						BARREN					
1088			-	-	-	-	-	-	1		
1106			6	-	-	-	-	-	-		
1131			4	-	-	-	-	-	-		
1158			2	-	-	-	-	-	-		
1180			13	2	2	-	2	-	3		Marginal Marine To Open Marine
1207			8	-	-	-	-	-	-		
1234			22	4	3	1	3	-	1		
1237			14	1	1	-	1	-	1		
1271			7	-	-	-	-	-	5		Continental
1286			1	-	-	-	-	-	-		
1292			2	-	-	-	-	-	-		
1320			4	-	-	-	-	-	-		
1372			30	16	10	6	1.7	1	1		Open Marine
1423			23	3	2	1	2	1	1		
1430			40	19	7	12	0.58	-	1		
1445			2	1	1	-	1	-	-		
1457			30	6	2	4	0.5	-	6		

1511	MAMU	Middle To Early Maastrichtian	32	12	8	4	2	-	2		
1640			1	-	-	-	-	-	1		Continental
1743			12	-	-	-	-	-	-		
1786			2	1	1	-	1	-	-		Open Marine
1817			81	18	8	10	0.8	4	5		
1844			13	-	-	-	-	-	-		Continental
1871			22	-	-	-	-	-	1		
1899			6	4	1	3	0.3	-	-		Open Marine
1926			7	5	1	4	0.25	-	-		
1954			23	4	3	1	3	1	5		
1981			11	1	-	1	-1	-	-		Marginal Marine
2003			10	1	-	1	-1	-	-		
2030			4	1	-	1	-1	-	-		
2057			2	-	-	-	-	-	-		Continental
2084			20	7	3	4	0.75	-	5		Marginal Marine To Open Marine
2112			44	5	2	3	0.66	-	4		
2135			3	3	-	3	-3	-	-		
2140			38	12	5	7	0.7	-	-		
2164			6	4	2	2	1	-	1		
2189			10	5	1	4	0.25	-	-		
2216	NKPORO	Campanian	23	9	3	6	0.5	2	1		
2271			23	8	1	7		-	2		Marginal Marine
2301			3		-	-	-	-	-		Continental
2304			8	3	-	3	-3	-	1		Marginal Marine
2335			3	3	1	2	0.5	-	-		
2356			3	-	-	-	-	-	-		Continental
2384			8	4	1	3	0.3	-	1		Marginal Marine
2411			29	9	2	7	0.9	-	-		
2434			18	9	6	3	2	-	1		Open Marine
2463			2	-	-	-	-	-	-		Continental
2493			6	-	-	-	-	-	2		
2521			14	2	-	2	-2	-	1		Marginal Marine
2548			7	3	-	3	-3	-	-		
2576			2	-	-	-	-	-	-		Continental
2603			26	2	-	2	-2	1	-		Marginal Marine
2630			1	-	-	-	-	-	-		Contiental To Marginal Marine
2658			2	1	1	-	1	-	1		
2688			3	-	-	-	-	-	-		
2716	AWGU	Coniacian	4	4	-	4	-4	-	1		Marginal Marine
2744			2	2	0	2	-2	0	0	0	
2771			3	4	0	4	-4	0	0	0	
2799			1	0	0	0	0	0	0	1	
2823			3	1	1	0	1	0	0	0	Open Marine
2851			2	0	0	0	0	0	0	0	Continental
2878			3	0	0	0	0	0	0	0	
2906			2	7	5	2	2.5	1	1	0	Open Marine
2933			2	16	5	11	-0.45	0	0	0	Marginal Marine
2960			1	3	1	2	-0.5	0	0	0	

4.8.2 Depositional Paleoenvironment in Umuna-1 well

The criteria used for the interpretation of the paleoenvironment of deposition of Umuna– 1 well are similar to that adopted for Nzam– 1 well of this study. The stratigraphic interval analysed for this well varies from 1689 m at the bottom to 524 m at the top, designated with various paleoenvironments of deposition. The lower part of the well corresponds to Eze-Aku Formation with stratigraphic interval range of 1689-1497 m. The interval shows paucity of palynomorphs. It further indicates an alternation of marginal marine and continental deposits. Marginal marine deposits with 1689-1497 m are characterised by fluviomarine algae- *Botryococcus braunii* which is an indicator of admixture of fesh water and salty marine water (Figure 4.2; Tables 4.11).

The Eze Aku Formation is characterised at the lowermost part by marine deposit, followed by continental deposit at 1661 m; marked by no recovery of palynomorphs. Overlying interval (1628-1180 m) which constitutes substantial part of the formation is defined by shallow marine environmentally significant forms such as *Senegalinium* sp. 6and *Senegalinium bicavatum*. Other microplanktons present are *Andalusiella* sp., *Batiacasphaera* sp., *Thalassiphora* sp., *Phelodinium bolonienae* and *Micrhysdinium* sp. The propotion of dinoflagellate grains present is greater than miospores present (Table 4.11), while the frequency of peridinoids recovered is greater than that of gonyaulacaceans; G/P ratio varies from -2 to 0.75 and the interval at some depths show presence of fresh water algae (Table 4.11). Therefore, marginal marine setting was assigned to the interval.

Nkporo Shale unconformably lies over the older Eze Aku Formation. The Nkporo Formation ranges in depth from 1110–765 m. It was deposited at the base in an open marine environment characterised by high abundant recovery of palynomorph. The open marine sediments were deposited in interval 1152-1125 m, rich in palynomorphs (Table 4.11). The miospore frequency is relatively high, while the organic wall microplankton frequency is also moderate. The gonyaulacacean grains are dominant while the G/P ratio varies from 1 to 2.75.

Presence of microforaminiferal wall linings corroborated that the sediment was deposited in an open marine system. Dinoflagellates present are *Senegalinium* sp., *Andalusiella polymorpha, Ceratiosis diebelii, Lejeuncysta cowiei, Paleocystodinium australinium, Odontochitina* sp., *Oligosphaeridium* sp.and *Phelodinium bolonienae.*

Table 4.11. Paleoenvironment of deposition of Cretaceous sediments (524-1689 m) in Umuna- 1 well

Depth (m)	Formation		Miospore Frquency	Dinoflagellate Frequency	Gauyanlacacean Frequency	Peridinacean Frequency	G/P Ratio After Harland,1983	Algae Frequency	Microforam Wall Lining Frequency	Paleo-Environment
524	MAMU	Middle To Early Maastrichtian	15	1	-	1	-1	4	-	Marginal Marine
549			5	2	-	2	-2	-	-	
579			19	-	-	-	0	-	-	Continental
610			6	2	1	1	2	-	-	Open Marine
643			19	1	-	1	1	4	-	
671			3	2	-	2	2	-	-	
695			20	4	3	1	1.33	-	-	
732			6	3	2	1	1.5	1	-	
765	NKPORO	Campanian	11	4	-	4	-4	-	-	Marginal Marine
786			11	4	-	4	-4	1	2	
811			21	3	-	3	-3	-	-	
841			13	4	-	4	-4	-	-	
863			9	1	1	-	1	-	-	Open Marine
930			3	1	1	-	1	1	-	
960			7	2	1	1	2	-	-	
988			36	8	5	3	1.6	5	-	
1033			7	10	3	7	0.43	1	-	Marginal Marine
1064			13	15	2	13	0.15	1	-	
1110			8	-	-	-	0	1	-	Continental
1125			22	15	11	4	2.75	2	1	Marginal To Open Marine
1152			26	4	-	4	-4	-	-	
1180			40	21	9	12	0.75	10	-	
1497			5	7	1	6	0.17	3	-	
1524			4	11	1	10	0.1	1	-	
1551			2	12	2	10	0.2	1	-	

1576	**EZE AKE**	**Coniacian**	**-**	**2**	**-**	**2**	**-2**	**-**	**-**	**Marginal Marine**
1600			**-**	**3**	**1**	**2**	**0.5**	**3**	**-**	
1628			**1**	**8**	**3**	**5**	**0.6**	**1**	**-**	
1661			**BARREN**							**Continental**
1689			**11**	**9**	**2**	**7**	**0.29**	**3**	**-**	**Marginal Marine**

The interval 1033-863 m share similarity with the interval 1152-1125 m, but contains organic wall microplankton such as *Senegalinium* sp., *Diconodinium* sp., *Cyclonephelium distinctum, Spiniferites* sp.and *Histrochodinium* sp. which are environmentally diagnostic forms present in the interval. Apart from *Senegalinium* sp.and *Phelodinium bolonienae* that are peridinoids, others are predominantly gonyaulacacean forms which are depictive of of open marine setting (Harland, 1983; Schrank, 1984; Ojo and Akande, 2007). Thus, minor part of the Nkporo Shale was deposited under fluvialtile setting which may be lacustrine in nature, while the greater part of it was deposited in marginal marine system.

Marginal marine environments of deposition in Nkporo Shale are located in intervals 1110-1033 m and 863-765 m at the top where the boundary of the formation was placed palynostratigraphically. The intervals are characterised by dominance of peridinacean forms over gonyaulacaceans, G/P ratio varies from -4 to 0.43; significantly, there is absence of microforaminiferal wall lining. Among the peridinoid forms that are present are *Phelodinium bolonienae, Senegalinium* sp., *Odontochitina costata and Senegalinium* sp. 5;others are *Andalusiella laevigata, Senegalinium* sp. 8and *Andalusiella polymorpha*. The presence of peridinoids, their dominance and low G/P ratio indicated marginal marine environment (Table 5.10) The continental environment established for the Nkporo Shale is characterised by the presence of miospores, rare algae, no recovery of dinoflagellate cysts and microforaminiferal wall lining.

Mamu Formation occupies interval 765-524 m at the top. The paleoenvironment is defined by open marine at the base, fluviatile at the middle part and marginal marine setting at the upper section. The open marine depositional environment (765-579 m) is characterised by moderate abundance of palynomorphs and dominance of gonyaulacaceans over peridinoid cysts. The paleoenvironment marker fossils include *Isabelidinium* sp. 6, *Batiacasphaera* sp.and *Cyclonephelium distinctum;* some peridinacean like *Deflandre* sp., *Senegalinium* spp.and *Andalusiella* spp.

The continental environment depth was placed at 579 m based on dominance of pollen and spores and lack of both dinoflagellates and foram lining. However, relative increase in *Botryococcus braunii* (algae) suggested distal fluviatile setting tending towards deltaic system.

The uppermost marginal marine paleoenvironment of deposition delineated in interval 1800 to 524 m of the Mamu Formation was marked on the basis of high proportion of peridinoids over gonyaulacacean forms; represented by *Andalusiella polymorpha* and *Senegalinium* sp. The two forms suggested marginal marine setting (Schrank, 1984).

4.8.3 Depositional paleoenvironments in Akukwa-2 well

Interpretation of the paleoenvironment of deposition of sediments in the Akukwa– 2 well was based on the integration of morphology of the pollen and spores that are depictive of depositional systems, total miospores recovered, total dinoflagellates, relative proportion of miospores to organic walled microplanktons, total dinoflagellates, total gonyaulacacean forms, total peridinacean present, Gayaulacacean/Peridinacean ratio, total microforaminiferal lining and total algae recovered per slide. All these parameters were synthesised and gven due consideration in determining the paleoenvironment of deposition of the sediments delineated in Akukwa– 2 well.

Interval 3234–3075 m is relatively rich in pollen, spores and dinoflagellate cysts. It contains more of long process dinocysts than the short process forms known as the gonyaulacaceans. Jain (1977), Oloto (1987), Lawal (1982), Umeji (2010) Ola-Buraimo and Abdulganiyu (2017) have shown that the dominance of the peridinoids (long spines) is indicative of marginal marine deposits. The G/P ratio values also indicate negative values, varying from -9 to -1, suggestive of marginal marine setting. The stratigraphic interval (3234-3075 m) encompasses both the Eze-Aku Formation and Awgu Shale deposited in shallow marine system (Table 4.12).

Interval 2475-2813 m is poor in miospores, no recovery of dinoflagellate cysts except at interval 2926 m which is suggested to be a short marine incursion followed by dominance of progradation processes (Table 4.12). Depth 2823 m is barren of palynomorphs while the topmost horizon (2813 m) contains very few miospores and rare fresh water algae similar to depths 2965 m and 2859 m. The interval 3021-2813 m is here suggested to belong to continental setting. The interval corresponds to lower part of Nkporo Shale. Upper part of the Nkporo Shale is characterised by relatively high pollen and spores and relatively moderate dinoflagellate cysts. The upper part of the Nkporo shale (2813-2758 m) was deposited in an open marine environment, characterised by ccurrence of gonyaulacaceans and microforaminiferal wall linings (Table 4.12). Interval 2758-2475 m corresponds to Mamu Formation. The interval is characterised by alternation of open marine and marginal marine settings covering considerable part of the interval, while the topmost part is continental in nature. Thus, the marine water that was responsible for the deposition of the underlying Nkporo Shale also accounted for the continuous deposition of Mamu Formation.

The open marine intervals (2682-2655 m and 2594-2509 m) are characterised by moderate frequency of miospores, dominance of gonyaulacacean forms over peridinoids; positive G/P ratio and rare fresh water algae (Table 4.12). Marginal marine intervals within the Mamu Formation are characterised by relatively lower frequency of pollen and spores compared to open marine section; other indicators include dominance of peridinod forms over gonyaulacaceans, -ve G/P ratio (modified after Harland, 1983) and rare fresh water algae (Table 4.12).

The topmost part of the Mamu Formation section is very poor in miospore recovery, no dinoflagellate, microforaminiferal wall lining and algae recovered. The depth is suggested to belong to continental setting (Akaegbobi *et al.,* 2016).

Table 4.12. Paleoenvironment of deposition of Mid-Cretaceous sediment (2475-3234 m) in Akukwa- 2 well

Depth (m)	Formation	Age	Total Miospore	Total Dinoflagellate	Total Gonyaulacacean	Total Peridinacean	G/P Ratio After Harland, 1983	Microforam Wall Lining	Total Algae	Paleo-Environment
2475	Mamu	Middle To Early Maastrichtian	1	-	-	-	-	-	-	Continental
2509			1	1	-	1	-1	-	-	Marginal Marine
2536			2	4	3	1	3	-	-	Marginal Marine To Open Marine
2563			1	2	1	1	1	-	-	
2594			11	5	3	2	1.5	-	1	
2624			2	2	-	2	-2	-	-	
2655			3	8	6	2	3	-	-	
2682			9	2	1	1	1	-	1	
2704			5	6	2	4	0.5	-	-	
2731			3	-	-	-	-	-	-	
2758	Nkporo	Campanian	3	1	1	-	1	-	-	
2789			4	2	2	-	2	-	-	
2813			3	-	-	-	-	-	1	Continental
2823			BARREN							
2859			-	-	-	-	-	-	4	
2974			2	-	-	-	-	-	-	
2902			1	-	-	-	-	-	-	
2926			1	3	3	-	3	-	-	
2966			1	-	-	-	-	-	1	
3021			1	-	-	-	-	-	-	
3075	Awgu	Coniacian	10	1	-	1	-1	-	-	Marginal Marine
3109			4	9	-	9	-9	-	-	
3139			3	3	-	3	-3	-	-	
3173			4	1	-	1	-1	-	-	

3200	**Eze-Aku**	**Upper Cenomanian To Turonian**	**27**	**1**	**-**	**1**	**-1**	**-**	**-**	
3234			**24**	**-**	**-**	**-**	**-**	**-**	**-**	

4.9 Paleoenvironmental synthesis of the wells

Paleoenvironments of deposition of the sedimets in each well have been fully discussed. The synthesisof the paleoenvironment was asessed by comparing the three wells (Nzam-1, Umuna-1, and Akukwa-2 wells) and considering each formation from the oldest (Eze-Aku) to the youngest (Ogwashi-Asaba Formation) deposit.

Eze-Aku Formation

Sedimentary deposition started in the Anambra Basin during Early Cenomanian.Marine incursion resulted to deposition of marine shale inshallow marine environment characterised by tethyal microplankton such as *Senegalinium* spp., *Andalusiella* spp., negative G/P ration suggesting prepondrance of peridinacean forms over the the gonyaulacaceans with no microforaminiferal wall lining recovery. There is shallowing upward trend of the stratigraphic sequence in terms of paleobathymetry. The marginalmarine was followed by a drop in sea level which resulted into progradation and deposition of fluviatile sediments marked by paucity of miospore, zero G/P ratio and lack of dinoflagellate cyst(Fig. 4.26).

This formation is mainly shale with minor sand or intercalated gypsum or ferruginised/ mineralised iron (Fe) as the case may be in the location. It is characterised bythe alternation of the three main environment of deposition (open marine, continental and marginal marine) at various positions of the formation. There is a sharppaleoenvironmetal contact between the continental and the open marine system which suggests ravinement, fault or unconformity surface within the formation(Fig. 4.26).

Awgu Shale

The Awgu Shale lies on the Eze-Aku Formation. They both have conformable facies relationship contact. The marginal marine environment of deposition that caps the Eze-Aku Formation continued into the Awgu Shale. A non-gradational paleobathymetry contact between the open marine and continental environment prevails in the Awgu Shale (Fig. 4.26). This phenomenon also suggests unconformity surface within the formation.

Event	Formation	Lithology	Age	Ma	Paleo-Environment
POST SANTONIAN SEDIMENT	**Ogwashi-Asaba**	___--_-_--_-__-- _-_-_--_--_-_---- _---__---_---__--- ___-_--_-__-_-_-_-	**Late Miocene To Pliocene**	2-23	**Marginal marine To Open marine**
	Ameki	_---_--_---_-_-_-_- _-_-_-_-_-_-_-_--_-- _-_-_-_-_-_-_--_- _-_--_-_---_----_--	Middle Eocene	38-52	**Marginal marine**
	Imo	--_--_--_---_---_--- -_-_-_--_-_--_-_- _-_-_----_----___-- -_---_--_--_---_--- _--__---_--_-___-- __-___--_-_--_-- ___-_---_--_-_-_-- _-_--_-__-_--_---	Early Paleocene	63-67	**Open marine**
	Nsukka	_--_---_---_---__- -_-__-_-----__--- __-_--_---_----_--- -_---___-_--_-- _---_-_-___----_--- __-_-_-_--_---_--	Late Maastrichtian	70	**Continental** **Marginal marine** **Continental**
	Mamu	■■■■■■■■■■■■■■■■■■■■■ ■■__--__-■■■■■■■-_- ___--_---_-_-___-- --___--_---__--_-	Middle Maastrichtian	72	**Open marine** **Continental** **Open marine**
		--_----_-**Gp**---___- -__-------__--_--- __**Gp**--_--_---__-- __---___--_--_-- __----_----___-_-	Early Maastrichtian		Marginal marine Continental Open marine
	Nkporo	__--_--_-_-- ___--__--_--_-- __--__**Gp**_--___-- __---_--__--_--- __--_--___--_--- -_-_--_--__-	Campanian	85	Marginal marine Open marine Continental Marginal marine
PRE - SANTONIAN DEPOSIT	Awgu Shale	___--__----___-- __----__**Gp**----- ____--___----__-- __---_-----___----	?Santonian To Coniacian	92.5	Marginal marine Continental Open marine
	Eze Aku	___----____----__- --**Gp**__----__--- __----__--_--___-	Turonian To Cenomanian	96	Marginal marine to Open marine

Figure 4.26. Integrated paleoenvironments of deposition of the formations in Anambra Basin, Nigeria

Nkporo

The post Santonian major tectonic event which was characterised by wide spread folding, upliftment and erosion is well documented in the Akukwa-2 well. The sequence interval is characterised by basal continental deposit, pausity in palynomorphs of zero G/P ratio, very poor dinoflagellate presence and moderate non pollen palynomorphs (NPP) such as algae and fungi(Figure 4.26).The lithofacies sequence of Nkporo Shale was deposited in open marine setting. The formation is characterised by monotonous facies relationship with overlying Mamu Formation but there exists an unconformity between the formations.

Mamu

Mamu Formation in Umuna-1 well shows basal open marine enviroment of deposition, whereas, in Akukwa-2 well the marginal marine depositional setting in the Nkporo Shale continued into the Mamu Formation. An unconformity surface is suggested to be present within the formation. However, in Akukwa-2 well there is alternation of marginal marine and open marine systems. The upper section of the formation is characterised by continental deposit defined by very poor palynomorph recovery, lack of dinoflagellate cyst and zero G/P ratio. These factors prevailed as a result of unfavourable ecological factors, climate and low sea level (Figure 4.26).

Nsukka

The Nsukka Formation was deposited by fluvial processes in a continental environment. The continental sediment overlies the open marine facies of the underlyingformation, thus, suggested an unconformity contact between the Nsukka and Mamu Formations. The Nsukka sequencewas deposited under continental processes through marginal marine to continental systems at the upper part(Fig. 4.26). This type of setting may suggest a deltaic form of deposition.

Imo

The Imo Formation is mainly shale, characterised principally by open marine paleoenvironment of deposition. The paleoenvironment relationship between the Imo and Nsukka Formations suggests an unconformable contact between the two formations. The open marine system of the Imo Formation is characterised by abundant and diverse miospores, abundant dinoflagellates dominated by gonyaulacaceans, presence of microforaminiferal wall linings and few non-pollen palynomorphs(Fig. 4.26). The lithofaciesis black in colour and calcareous in nature.

Ameki

The Ameki Formation is composed of shale deposited in an open marine to marginal marine environments. Stratigraphically, the facies have unconformable relationship with adjacent formations. The sediments of the upper section of the formation was deposited in a more shallower marne environment(Fig. 4.26). Thereby, there was gradual deepening from the marginalmarine at the top to an open marine system at the bottom.

Ogwashi-Asaba

This is the youngest formation in the Anambra Basin; composed ofneritic to open marine shales. The formation is characterised by abundant miospores and dinoflagellates. The dinoflagellates present include *Selenopemphix nephroides, Impagidinum* sp., *Impagidinium centrocarpum,Tuberculodinium vancampoae, Polysphaeridium zoharyi* and *Multispinula quanta*. All these microplanktons are depictive of neritic to open marine systems(Wrenn and Kokinos, 1985; Ola-Buraimo and Akaegbobi, 2012). The formation is further characterised by prepondrance of gonyaulaceans and presence of microforaminiferal wall lining(Fig. 4.26). Therefore, Ogwashi-Asaba Formation is described as product of neritic to Open marine setting.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Lithofacies present in the three studied wells (Nzam-1, Umuna-1 and Akukwa-2) are mainly shale, sandstone, siltstone, heterolith of sand and shale; intercalation of gypsum and ferruginised or mineralised iron shale. The variation in the facies might have been as a result of factors such as different depocenters responsible for deposition in the basin, chemical composition of the depositing medium and possibly the structural style of the basin defined by horst and graben architecture. Lithofacies present in the three wells are not similar in composition. The ambiguity of the lithofacies in vertical and lateral variations inhibited the correlation of the three wells. The lowest part of the three wells that is composed of shale was correlatable and suggests that sedimentation commenced at the same time and might have formed due to the inundation of the marine water as a result of rifting.

Formations thickness vary from one well to another, but the Pre-Santonian formations (Asu River Group and Eze-Aku Formation) in Umuna-1 well show higher thickness values compared to those in Nzam-1 and Akukwa-2 probably due to the fact that the Umuna-1 was sitting in a depressed depocenter (graben) relative to adjacent wells (horsts) as a result deep faults. However, during the Post–Santonian period the reverse was the case where the Umuna-1 became uplifted relative to Nzam-1 and Akukwa-2 wells which became structurally graben; contain thicker formations due to higher sedimentation rate and increase in sea level.

Nine palynological zones were established for the Nzam-1 well which serves as the reference (control) well. The established zones are:

- *Cretaceiporites* spp. acme zone 2, dated Upper Cenomanian to Turonian; stratigraphically equivalent to Eze Aku Formation

- *Zlivisporites blanensis* assemblage zone 3, dated Coniacian; stratigraphically equivalent to Awgu Shale
- *Milfordia spp.* acme zone 4, dated Campanian-Lowermost Early Maastrichtian; stratigraphically equivalent to Nkporo Shale
- *Foveotriletes margaritae* assemblage zone 5, dated Early Maastrichtian; stratigraphically equivalent to lower part of Mamu Formation
- *Longapertites margaritae* acme zone 6, dated Middle Maastrichtian; stratigraphically equivalent to upper part of Mamu Formation
- *Spinizonocolpites baculatus* assemblage zone 7, dated Late Maastrichtian; stratigraphically equivalent to Nsukka Formation
- *Mauritiidites crassibaculatus* zone 8, dated Early Paleocene; stratigraphically equivalent to Imo Formation
- *Monoporites annulatus* zone 9, dated Middle Eocene; stratigraphically equivalent to Ameki Formation
- *Echitricolporites spinosus* zone 10, dated Late Miocene to Pliocene; stratigraphically equivalent to Ogwashi/Asaba Formation

Deductions from the dating of the sediments show that the oldest age of the facies in the three wells is Albian.The results further show that there are pre-Santonian sediments with age range from Cenomanian to Coniacian. This further shows that there are indeed older sediments present in the the basin; this is contrary to the tectonic evolution theory which suggests that sedimentation commenced only during the post-Santonian period in Anambra Basin. The study firmly suggests that sedimentation in Anambra Basin was contemporaneously deposited during Albian along with those of Abakaliki Anticlinorium, Benue Trough and that of Calabar Flank in Nigeria.

Maastrichtian age was sub-divided into three zones: The *Foveotriletes margaritae* assemblage zone, dated Early Maastrichtian and equivalent stratigraphically to Lower Mamu Formation; the *Longapertites marginatus* Acme Zone, dated Middle Maastrichtian, equivalent to Upper Mamu Formation and the *Spinizonocolpites baculatus* assemblage zone, dated Late Maastrichtian, equivalent to Nsukka Formation.

In the the wells analysed Ajali Sandstone was not encountered in them which may suggest that Ajali Sandstone was a local deposit that does not transect the entire length and breadth of Anambra basin. It may also suggest that Ajali Sandstone facies-out, eroded or non-deposited in other parts of Anambra Basin.

A new palynological zone referred to as *Milfordia* spp. acme zone was proposed in this study. It was used to date Campanian sediments equivalent to Nkporo Shale.This taxa was found correlatable across the three wells.

The chronostratigraphy of the wells is significantly represented in the Nzam-1 well and fairly well represented in the Umuna-1 well.The wells consists of both Cretacceous and Tertiary sediments. The youngest sediment in the Anambra Basin was dated Pliocene age unlike Oligocene and Pleistocene ages given to it by earlier workers.

A major geologic age gap (hiatus) was identified in the Umuna-1 well indicating removal, non-deposition or thinning out of Agwu Formation within the well section. This is also applicable to upper Mamu and Nsukka formations. This was suggested to have been due to either erosional removal, non-deposition or presence of structural faults.

Seven transgressive cycles and five major unconformity surfaces synonymous to regressive and regressive surfaces were identified at different times which resulted from eustatic changes in sea levels. This and perharps other factors such as tectonics, structure, fluid composition, topography, climate and other local geologic factors were responsible for sedimentation in the Anambra Basin.

The paleoenvironment of deposition of the formations are of continental, marginal marine and open marine systems. The continental environment was characterised by low palynomorph content, lack of dinoflagellate cysts, zero G/P ratio associated with non-pollen palynomorph; the marginal marine is marked by moderate palynomorph frequency, moderate dinoflagellate cysts, negative G/P ratio, dominance of peridinacean forms, lack of microforaminiferal wall lining and few non-pollen palynomorphs. The open marine system is defined by abundant palynomorphs, dominance of gonyaulacacean forms, positive G/P ratio, presence of microforaminiferal wall lining and few or lack of non-pollen palynomorph.

The palynozonation and Chronostratigraphy framework generated in this study for the Anambra Basin was intended to serve as working tool and palynological zonation scheme established is to serve the purpose of correlation for the dynamic lithofacies present in the basin. The study further serves as tool for optimising hydrocarbon exploration in the basin.

5.2 Recommendations

It is recommended that other aspects of biostratigraphic study such as foraminifera and nannofossil studies may be carried in order to augment the palynological findings in this study. Experience and records have shown that foraminifera and nannofossil investigations on Cretaceous sediments in most parts of the sedimentary basins in Nigeria and Anambra Basin in particular rarely produce more detailed and more reliable results compared to palynological investigations. A more detail geophysical survey should also be carried out on the basin to further indicate the presence of deep faults and other associated structures which might be responsible for the graben and horst structures hidden in the subsurface of the thick sedimentary piles present in the Anambra Basin.

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