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Advances in Applied Science Research, 2012, 3 (2):962-979

ISSN: 0976-8610
CODEN (USA): AASRFC

Sequence Stratigraphy and Palynological Analysis of late Campanian to Maastrichtian Sediments in the Upper-Cretaceous, Anambra Basin. A Case Study of Okigwe and its Environs, South-Eastern, Nigeria

Chiaghanam O.I.[1*], Ikegwuonu, O.N.[1], Chiadikobi K.C.[1], Nwozor K.K.[1], Ofoma A.E.[2] and Omoboriowo, A.O[3]

[1]Department of Geology, Anambra State University, Uli, Anambra State, Nigeria
[2]Halliburton Energy Services, Port Harcourt, Rivers State, Nigeria
[3]University of Port Harcourt, Port Harcourt, Rivers State, Nigeria

ABSTRACT

Sediments recovered from Leru, Uturu and Ihube area in Anambra Basin, South-eastern Nigeria was analysed for their palynological and sequence stratigraphic potentials. Using palynological evidence, Late Campanian age was assigned to Nkporo Shale (Leru), and Early-Middle Maastrichtian to Mamu Formation (Uturu) on the basis of some age diagnostic taxa e.g Longapertites marginatus, Cingulatisporites ornatus, Buttinia andreevi and Retidiporites magdalenensis, Rugulatisporites caperatus and Gleicheniidites senonicus. The lower unit of Nsukka Formation at Ihube was dated late Maastrichtian age based on stratigraphic age makers such as Dinogymnium sp. and Spinizonocolpites baculatus. A marine to brackish water environment was suggested for Nkporo Shale and brackish to fresh water environment for Mamu Formation while near shore water environment was assigned to Nsukka Formation, based on the important environmentally significant species encountered. The logged outcrops show presence of key stratigraphic surfaces and also system tracts with highstand systems tracts dominating.

Keywords: Sequence Stratigraphy, palynological evidence, Anambra Basin, formation, system tract.

INTRODUCTION

The Anambra Basin, which is a post Santonian synclinal sedimentary structure located southern Benue Trough, contains over 5,000m thick of upper- cretaceous to Recent sediments, which represents the third phase of marine sedimentation in the Benue Trough (Ladipo, 1988; Akande and Erdtmann, 1998).

Okigwe and its environs, which is the study area is composed of upper Cretaceous succession of Nkporo Shale, Mamu Formation, Ajali Formation and Nsukka Formation. Major towns covered by the study includes Umuchieze, Aku- Ihube, Ihube, Otanzo, Okigwe, Isuochi, Leru, Uturu and Isukwato, with major outcrops being exposed along Enugu/ Port Harcourt express-way, good exposures where also accessible in Road cuts, stream channels and quarry sites. The studied section is described by longitude E 7° 15' and E 7° 30' and latitude N 5° 45' and N 6° 00'. See Fig 1.

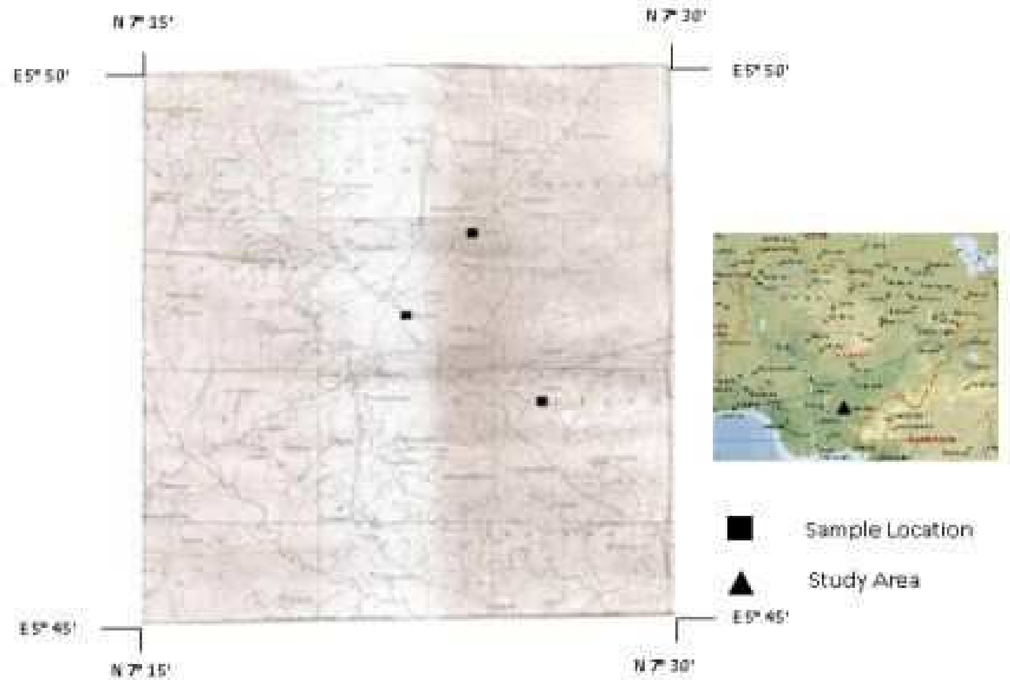

Fig. 1: Location map of the study area

The area has attracted numerous studies Tattam (1944), Grove (1951), Simpson (1954), Reyment (1965), Murat (1972), Obi et al (2001), Oboh-Okuenobe et al (2005), Nwajide and Reijers (1996) and Onyekuru and Iwuagwu (2010), recorded that Nkporo Shale consists of dark fossile shales and mudstones with occasional thin beds of sandy shale and sandstone. Thin bands of shaly limestone may be present. They are of shallow water origin and rich in fossil assemblages. It has a wide distribution of zone of l*ibycoceras afikpoense.* Tattam (1944), Simpson (1955), Reyment (1965), Murat (1972), Dessavggie (1974), Obi et al (2001), Oboh-Okuenobe et al (2005), Nwajide and Reijers (1996) described that Mamu Formation contains a distinctive assemblage of Sandstone, Shale, Mudstone and Sandy Shale, with Coal Seams at several horizons. The sandstones which are fine to medium grained and white or yellow in colour, are normally well-bedded and occasionally crossbedded. Carbonaceous material is present in varying amounts and or as irregular ramifications. They are regarded as the lower coal measures. Onyekuru and Iwuagwu(2010), noted that the upper layer of the formation is barren while the deeper part is sparse in Fauna consisting of Ostracods and arenaceous Foraminifera, mainly *Haplophragmoides.* Tattam (1944), Reyment and Barber (1965), Murat (1972), Kogbe (1989), Oboh-Okuenobe et al (2005), Nwajide and Reijers (1996), Reyment (1965) described Ajali sandstone as a thick friable, poorly sorted sandstone, typically white in colour, sometimes iron-stained. A marked banding of coarse and fine layer occasionally displayed. The sand grains and larger fragment are subangular with a sparse cement of white clay; generally have large-scale cross-beddings. Biogenic structures commonly associated with sandy facies are *ophiomorpha*, *skolithos*, and the escape burrow *Diplocraterion yoyo*, because of its characteristics friability and weak consolidation,the formation is highly erodible.

Tattam (1944), Simpson (1955), Reyment (1965), Reyment and Barber (1965), Kogbe (1989), Nwajide and Reijers (1996), Obi et al (2000), noted that Nsukka Formation consist of an alternating succession of sandstone, dark Shale and sandy shale, with thin coal seams at various horizons. Fragmentary plant remains are abundant in the Nsukka Formation and where the carbonaceous shales have been ferruginised in the zone of laterization, leaf impressions are preserved. Limestones which occur towards the top of the formation contain *Veniella undata* which suggests upper cretaceous age. The upper most unit has been recorded as containing Paleocene fauna in Southern Nigeria (Cratchley and Jones, 1965).

The study presents detailed sedimentological palynological and sequence stratigraphic interpretations for the late Campanian- Maastrichtian sedimentary rocks of Nkporo Shale, Mamu Formation, and Nsukka Formation in the Anambra Basin. A comprehensive outcrop study of the rocks was carried out to establish sedimentological characteristics, sequence stratigraphic and palynological record of the area, which was aimed at presenting a more detailed and comprehensive Age determination and paleoenvironment of the area.

GEOLOGICAL SETTING

The studied area lies in the Anambra basin. The Basin is a NE-SW trending syncline that is part of the Central African Rift System which developed in response to the stretching and subsidence of major crustal blocks during a lower Cretaceous break-up phase of the Gondwana super-continent (Ogala, et al, 2009). The movement were re-activated by further plate activity in lower Tertiary soon after the intermittent Upper Cretaceous rifting (Ogala, et al, 2009). The separation of the African and South American plates left the Benue Trough as an Aulacogen, a failed arm of an RRR Triple Junction (Burke, 1972; Olade, 1975; Onyekoro and Iwuagwu 2010). The Basin is an expensive west and Central African rift system in which it opened as an extensive sinistral wrench complex (Emery et al., 1975; Whiteman, 1982; Genik, 1993). Based on the work done by Murat (1972), Southern part of the Benue Trough was interpreted to have longitudinal fault with its eastern half subsiding preferentially to become the Abakaliki depression.

The Proto- Anambra Basin was a platform that eventually became thin sediment- draped at the time the Abakaliki-Benue sector of the Benue Trough was being filled which occurred during Albian- Santonian (Nwajide and Reijers, 1997). Their was differential in the rate of subsidence in the Southern Benue Trough e.g, high in Pre-Albian time, low in lower Cenomanian and very high in Turonian; the latter was an important phase of platform subsidence (Ojoh, 1990). The period of subsidence in Southern Benue Trough corresponds to the time of the initiation of the Anambra Basin, which started during the Coniacian and reached its peak at the Santonian thermotectonic event (Nwajide, 2005).

Several authors (Murat, 1972; Nwachukwu, 1972; Weber and Doukoro, 1975; benkhelil, 1982; Nwajide and Reijers, 1996; Obi, 2000; Mode and Onuoha, 2001) demonstrated that the Santonian tectonic pulses dating back to 84ma, was associated with intensive magmatism. Folding and faulting which resulted in Abakaliki area becoming flexurally inverted to form the Abakaliki Anticlinorium. The Santonian tectonic pulses caused the displacement of the depocentres to the west and Southeastwards thereby resulting in the formation of Anambra Basin and Afikpo Syncline (Murat, !972; Burke, 1972). The anticlinorium later became a sediment dispersal centre from which mineralogically mature detritus was shed into Anambra Basin and Afikpo Syncline (Akaegbobi and Schmitt, 1998; Akaegbobi and Boboye, 1999). Other sources of texturally matured sediments which finds it way into Anambra Basin include Southwestern Nigerian Craton, crystalline basement areas of the Oban Massif and Cameroon basement granites which had undergone prolonged chemical weathering (Hoque and Ezepue, 1977; Amajor, 1987; Nwajide and Reijers, 1996; Akaegbobi and Schmitt, 1998; Akaegbobi and Boboye, 1999, Obi, 2000).fig 2(murat 1972)

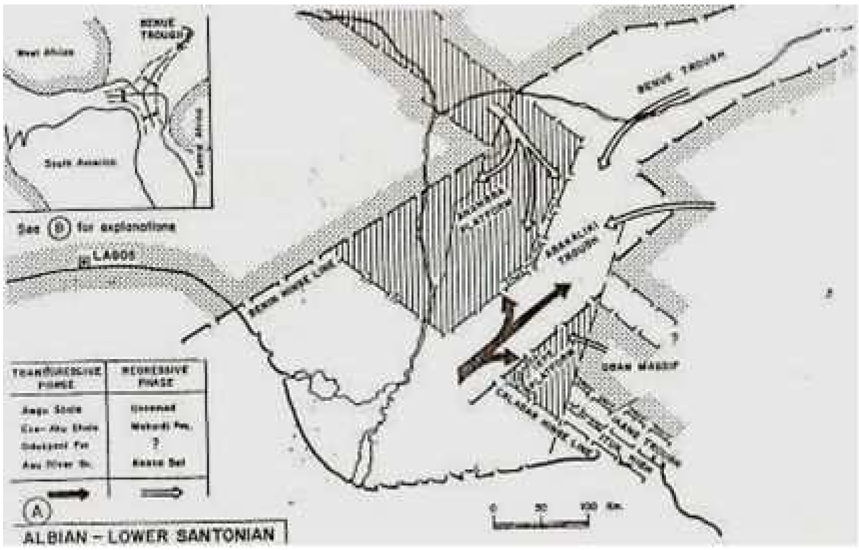

Fig 2: Tectonic map of South – Eastern Nigeria showing Anambra Basin during the Santonian event.
(Adapted from Murat, 1972).

Deposition of sediments in the Anambra Basin commensed during the Campanian, with Nkporo Shale, Enugu Shale and Owelli Sandstone which are regarded as the Nkporo Group, constituting the basal beds of the Campanian period.The campanian was a period of short marine transgression and regression, the shallow- sea later became shallower due to subsidence, thereby resulting in a regressive phase during the Maastrichtian which deposited the flood plain sediments and deltaic foresets of Mamu Formation that was regarded as the Lower Coal Measures. Mamu Formation is overlained by the Ajali Formation which is regarded as the false-bedded sandstone (Obi, 2000) and followed by Nsukka Formation which is a Fluvio-deltaic sediment (Obi, 2000).

The stratigraphic sequence of Anambra Basin, Delta Basin and Southern Benue Trough are presented in Table 1.

Table 1: Stratigraphic Sequences in Anambra Basin (after Nwajide, 2005)

Age	Basin	Stratigraphic Units						
Thanctian	Niger Delta	Imo Formation						
Danian								
	Anambra Basin	Coal Measures	Nsukka Formation					
Maastrichtian			Ajali Formation					
			Mamu Formation					
Campanian		Nkporo Fm	Nkporo Shale	Enugu Fm	Owelli Ss	Afikpo Ss	Otobi Ss	Lafia Ss
Santonian	Southern Benue Trough	Awgu Formation						

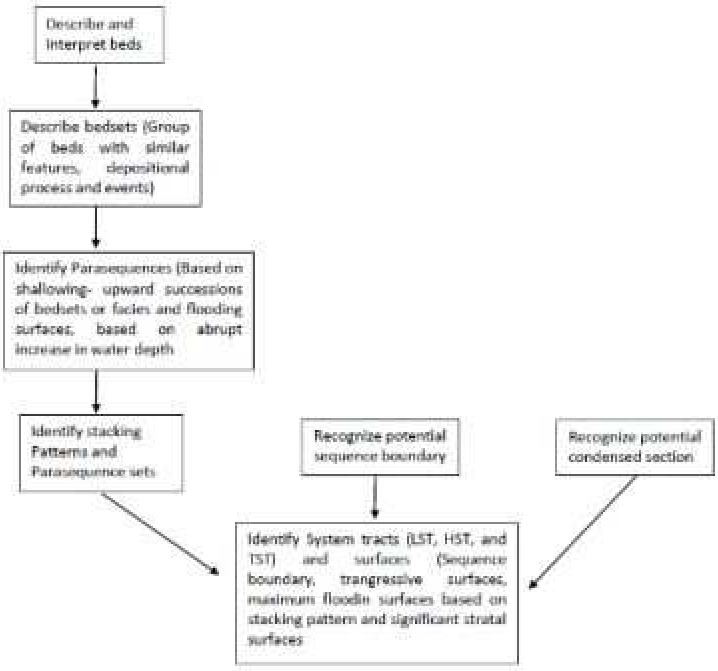

Fig 3: Sequence Stratigraphic Interpretation (After Van wagoner et al., 1990)

METHODS

sections of the late Campanian to Maastrichtian succession outcropping in the Okigwe, Isiukwuato, Ihube, Leru, Uturu, Umuchieze, Aku- Ihube, Isuochi area of Southeastern Nigeria were studied to obtain data on the textural and lithologic variations, stratigraphic succession, sedimentary structures and palynological features.

The sediments were processed for their palynomorph contents. Samples preparation was carried out using conventional maceration technique for recovering acid insoluble organic- walled microfossils from sediments. Each sample was digested for 30 minutes in 40% hydrochloric acid to remove traces of Carbonate and 72 hours in 48% hydrofluoric acid for removal of silicate (Traverse, 1988). The extracts were sieve- wasted through 10 microns nylon mash. The extracts were sieve- washed residues were oxidized for 30 minutes in 70% HNO_3 to render the fossils translucent for transmitted light microscopy rinsed in 2% KOH solution to neutralize the acid; swirled to sediment resistant coarse mineral particles and organic matter and stained with Safranin- 0 to increase the contrast for study and photography. More classification schemes or dispersed organic matter can be found in the literature (e.g. Boulter and Riddick, 1986; Van Bergen et al., 1990; Tyson, 1995; Batten, 1996; Oboh- Ikuenobe et al, 2005) Aliquots were dispersed with polyvinyl alcohol, dried on lower- slips and mounted in Canada balsam. Five slides were made from each sample, from which 200 grains were counted. The occurances of each species were converted to percentage frequencies in counting.

Lithofacies associations and palynofacies assemblages were used to interprete depositional envronments (Oboh-Ikuenobe et al 2005).Van wagoner et al.,1990 technique was applied in the sequence stratigraphic interpretation, see graphical presentation in fig 3.

RESULTS AND DISCUSSION

Palynological Investigation

Systematic description was not undertaken because the forms encountered in this work have been formally described. Table 2 shows the occurances and distribution of palynomorph species in the study areas. The results from each of the studied formation were described based on systematic logging from base to top.

LERU SHALE

Formation: Nkporo Shale:
The species encountered in this unit included both marine and terrigienous speices.
Marine species: *Dinoflagellate* cysts species include *Senegalinium bicavatum*, *Dinogyimnium acuminatum*, *Phelodinium gaditanum*, and *Spiniferites ramosus*.

Terrigenous species: *Sporomorph* species were very diverse and abundance which included *Cingulatisporites ornatus, Distaverrusporites simplex, Foveotriletes margaritae, Gleichenidites senonicus, Leiotriletes adriennis, Cyathidites australis, Ariadnaesporites nigeriensis., Zlivisporis blanensis,* and fungal spores. These ssemblage dominated this unit with (up to 70% terrigenous influence).

Among the pollen were *Longapertites marginatus, Spinizonocolpites baculatus, Proteacidites miniporatus, Retidiporites magdalenensis, Monocolpities marginatus, Ephedripites sp., Echitriporites trianguliformis, Buttinia andreevi* and *Striamonocolpites undulatostriatus.*

UTURU SHALES

Formation: Mamu Formation:
The species encountered included the terrigenous species dominated by trilete spores and with few fresh water spores. Among the terrigenous species are *Cingulatisporites ornatus, Gleichenidites senonicus, Leiotriletes adriennis, Ariadnaesporites nigeriensis, Cyathidites austrialis, Foveotriletes margaritae and Cicatricosisporites dorogensis.* The pollen species includes *Constructipollenites ineffectus, Spinizonocolpites baculatus, Echitriporites trianguliformis, Inaperturopollenites teradus, Syncolporites marginatus, Monocolpites marginatus, Retidiporites magdalenensis, Auricullidites sp. and Longapertites marginatus.*

Marine species includes dinoflagellate cysts such as *Phelodinium gaditanum*, *Andalusiella polymorpha*, and *Areoligera senoniensis* and forams test lining.

IHUBE SHALE

Formation: Basal Nsukka Formation:
The terrigenous species include *Lonapertites marginatus, L. vaneedenburgi, Spinizonocolpites baculatus, Syncolpites sp., Laevigatosporites sp., Retitricolpites triangulatus, Gemmamonocolpites gemmatus, Retidiporites magdalenensis and Proteacidites dehaani.*

AGE DETERMINATION

Assignment of ages to the sediments from the study areas in the Anambra basin was based on the following stratigraphic ranges of selected key age diagnostic taxa, **(*Fig 4***) Taxa which shows a typical Campanian age according to Umeji (2011) which were also recovered include *Cingulatisporites ornatus, Gleicheniidites senonicus, Leiotriletes adriennis, Laevigatosporites sp., Cyathidites austrialis, Cicatricosisporites dorogensis, Ariadnaesporites nigeriensis, and Disterverrusporites simplex,* ***(fig 5.)*** **plate1**

The Late Campanian sporomorphs encountered included the following; *Spinizonocolpites baculatus, Retidiporites magdalenensis, Monocolpites marginatus, Retibrevitricolpites trangulatus, Echitriporites tranguliformis, Buttinia andreevi, Inaperturopollenites tetratus and Tricolpites sp.* **(*Fig* 6) plate 2.**

However, the sporomorphs assemblage of *Foveotriletes margaritae, Zlivisporis blanensis, Distaverrusporites simplex, Ariadnaesporites sp. Rugulatisporites caperatus, Auriculidites reticulatus, Spinizonocolpites baculatus, Echitriporites trianguliformis, Longapertites marginatus, Proteacidites miniporatus, Monocolpites marginatus, Constructipollenites ineffectus, Tubistephanocolpites cylindricus and Retidiporites magdalenensis,* was typical of the late Cretaceous (Campanian-Maastrichtian) of West Africa-South America phytogeographical province of Herngreen & Chlonova (1981)

Samples from Uturu (Mamu formation) was dated Middle Maastrichitian on the bases of the following age diagnostic taxa such as *Longapertites marginatus* with almost 65% dominant. Others include *Spinozonocolpites baculatus, Echitriporites trianguliformis, Retidiporites magdalenensis, Longapertites vaneendenburgi, Cingulatisporites ornatus, Constructipollenites ineffectus, Distaverrusporites simplex, Monosulcites sp., Leiotriletes adriennis* ***(Fig* 7) Plate 3.**

Germeraad et al (1968) found the species of *Foveotriletes margaritae* in the Maastrichtian and Lower Paleocene, which seems to be definitely absent in the Senonian. This species was also encountered in some of the samples mostly those from Ututu and Ihube, which therefore overrule an age younger than Campanian for the Nkporo Shale. The age diagnostic palynomorph species recovered from Ihube samples (Nsukka Formation) gave an age range not younger than the Late Maastrichitian. However, the taxa included as follows: *Longapertites martginatus* occurring in preponderance amount followed by *Spinozonocolpites baculatus.* Other species which were also common in assemblage include *Retidiportes magdalenensis, Proteacidites dehaani, Longapertites vaneedenburgi, Echitriporites trianguliformis, Retitricolporites triangulatus, Syncolporites marginatus and Milfordia jardinei*.**(Fig.8)plate 4.**

However, the stratigraphic age ranges of the selected sporomorph species were compared and complied from the works of Van Hoeken-Klinkenberg (1964), Van der Hammen (1954 & 1957), Jardine and Magloire (1955), Muller et al (1968), Edet and Nyong (1994), Salami (1985, 1990), Schrank (1987), Boltenhagen (1965), Herngreen (1975, 1981). Other works include Germeraad et al. (1968), Lawal and Moullade (1968), Jan du Chene and Salami (1978), Jan du Chene et al (1978b), Herngreen et al (1996), Umeji (2005, 2006a, 2007, 2008, 2010, 2011), and Oboh-Ikuenobe et al (1998). It is worthy to note that the presence of taxa typical of Late Maastrichitian age which was also encountered in Ihube samples such as *Longapertites vaneedenburgi and Buttinia andreevi* have only been known to be restricted to the upper Cretaceous and absence in the Paleocene (Germeraad et al 1968).

PALEOENVIRONMENTAL INTERPRETATION

Fig.7. shows the percentage frequency distribution of the selected key sporomorph species in the studied areas. Bustin (1988) reported significant variation in palynofacies abundance in different depositional environment. Opaque structureless organic matter is most abundant in barrier/beach and offshore sand, whereas cuticles, spores, and pollen are most common in shoreface and overbank deposits. Umeji (2011) establish three biofacies zone in the Nkporo Shale and Mamu Formation on the bases of the recovered palynomorphs. She suggested that Nkporo Shale was deposited in an oscillating shoreline in which the salinity fluctuated between marine at the base and brackish water at the top as it gives way to the overlying Mamu Formation which began with brackish water at the base and fresh water at its top, concluding that the sedimentary environments ranged from lower upper shoreface to backshore swamp or lagoon for Nkporo Shale; while Mamu Formation ranged from lake or swamp to alluvial plain. In this study, only the terrestrial sporomorphs (pollen & spores) were fully observed with few marine species and was used in assessing the various paleo-depositional environments of the formations. It is observed that the basal unit of Nkporo Shale was dominated by terrigenous species (up to 65 to 70%) Fig.7, mostly the fresh water fern spores with few triletes spores and the fresh water algal spores, *Ariadnaesporites nigerienses*. These, therefore, strongly suggest a brackish to fresh water depositional environment. However, the freshwater species tend to decreased in abundance up the section with the corresponding increase in Palm/pollen such as *Longapertites,* and *Spinizonocolpites* species at the topmost unit of both Nkporo and the basal Mamu Formations. Marine species such as those with chorate and proximate cysts affinities occasionally occur in this section alongside together with the microforamninifera inner lining indicating a marginal marine and/or marine to brackish water depositional environment (Jan du chene et al, 1978). It is also observed that *Longapertites marginatus* reached its maximum peak in the Uturu samples (Mamu Formation), while *Spinizonocolpites baculatus* peak in Ihube samples (Basal Nsukka Formation). These, therefore, corresponds to the Lawal and Moullade (1968) *Longapertites marginatus* and *Spinizonocolpites baculatus* Assemblage zones of Campanian-Maastrichtian of the upper benue basin. The monocolpate pollen grains especially those belonging to the palmae dominated the miospores assemblage found in Ihube samples. The high abundance of these species alongside with co-occurrences of the Pteridophytic spore, algal and fugal spores is probably an

indicative of mangrove swamp and/or brackish water environment of deposition with low salinity fluctuation. Schrank (1984) posited that a palynomorph assemblage with higher content of land derived miospores indicates terrestrial condition. Terrigenous species, however, occurs in high abundance over marine species which also supports terrestrial conditions, tending towards near shore brackish water environment. Umeji & Nwajide (2007) reported that the basal part of the Nsukka Formation was deposited under near shore brackish water dominated by the proximate cysts, while the uppermost part near Umulolo area was deposited in a more open marine condition dominated by the chorate cyst species.

Table 2. The occurrences and distribution of pollen and spores species in the study areas

SPOROMORPH SPECIES	LERU	UTURU	IHUBE
POLLEN			
Longapertites vaneedenburgi	-	-	x
Longapertites marginatus	x	x	x
Retidiporites magdalenensis	-	x	x
Proteacidites miniporatus	x	x	x
Poxapertites operculatus	-	-	x
Retitricolpites irregularis	x	-	-
Spinizonocolpites baculatus	x	x	x
Proteacidites dehaani	x	-	x
Buttinia andreevi	-	x	-
Constructipollenites ineffectus	x	x	x
Syncolporites marginatus	-	x	x
Monocolpopollenites sphaeroidites	x	x	-
Hexeporotricolpites emelianova	x	x	-
Tubistephanocolpites cylindricus	-	x	x
Spinizonocolpites echinatus	-	x	-
Proteacidites miniporatus	x	-	x
Ephedripites ambonoides	x	x	x
Striamonocolpites undulostriatus	x	-	-
Proteacidites longispinosum	x	-	-
Echitriporites trianguliformis	x	x	x
Milfordia jardinei	-	-	x
Monocolpites marginatus	-	-	x
Inaperturopollenites tetradus	x	-	-
SPORES			
Cyathidites australis	x	x	-
Laevigatosporites sp.	x	x	-
Gleichenidites senonicus	x	x	-
Leiotrilletes adriennis	x	x	x
Cingulatisporites ornatus	x	x	x
Foveotriletes margaritae	-	x	x
Ariadmaesporites nigeriensis	x	x	-
Lycopodiumsporites sp.	x	x	-
Fungal spore	x	x	x

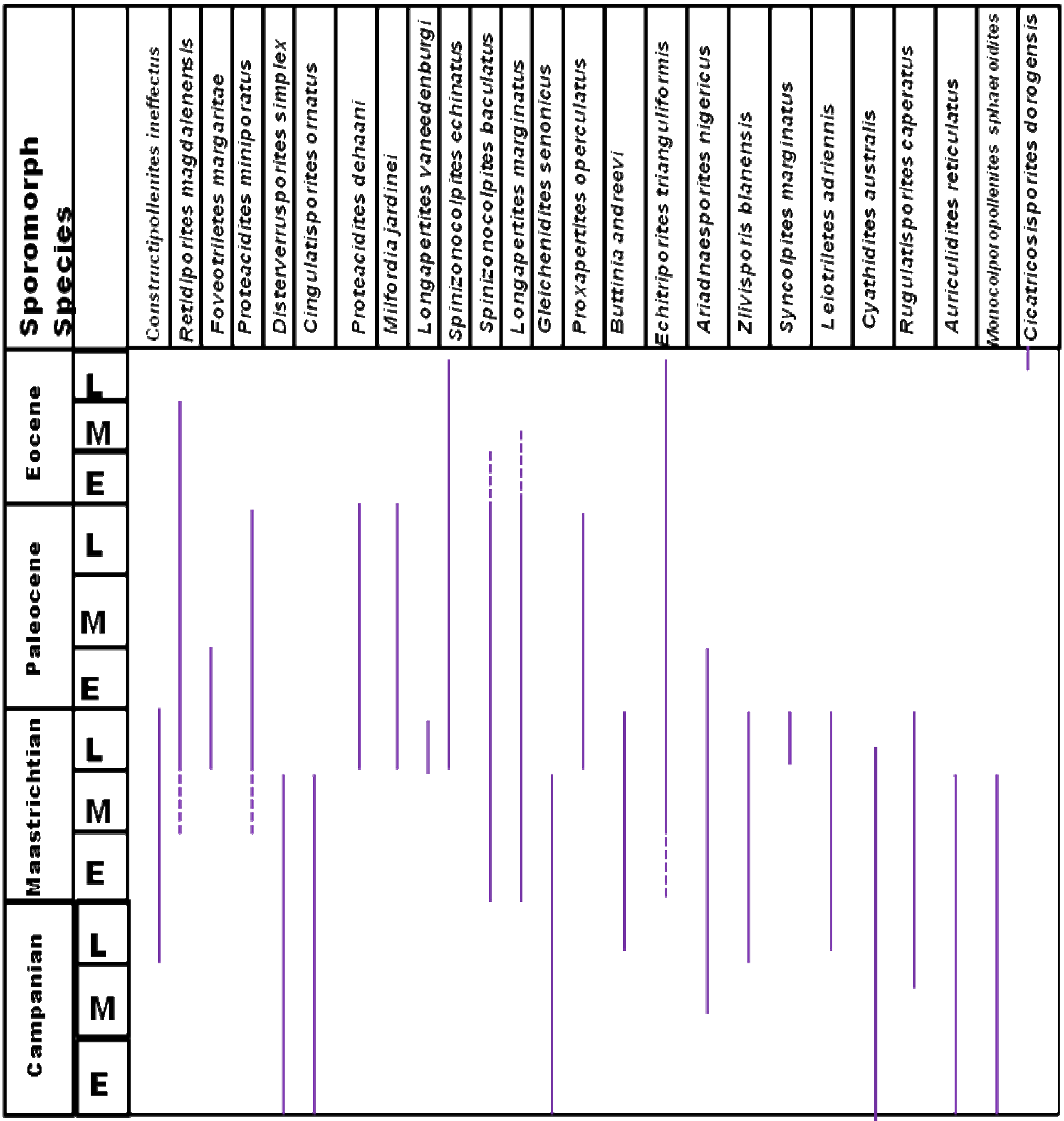

Fig. 4: The stratigraphic range chart of the selected key sporomorph species in the study areas.

Plate 1

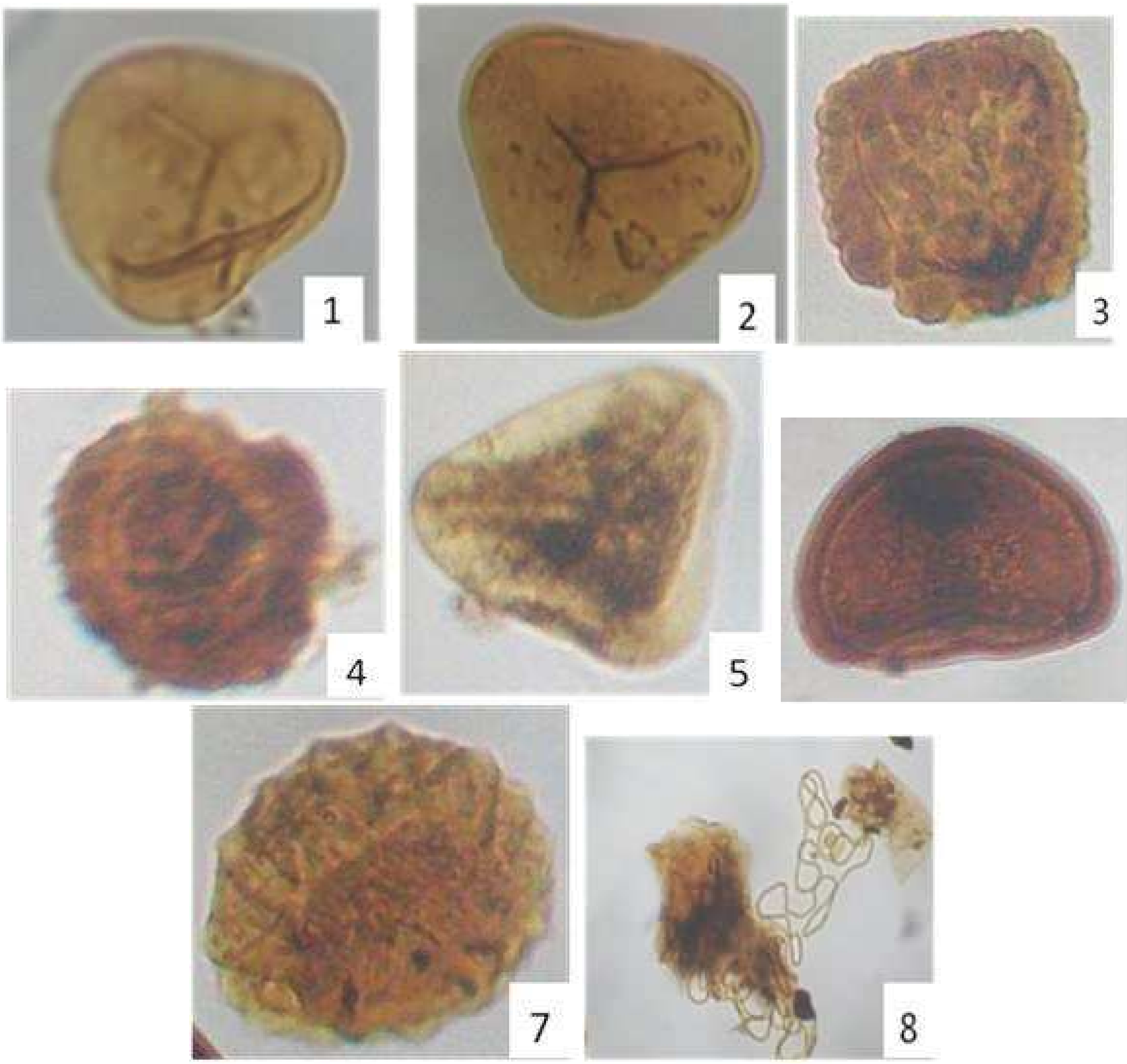

Fig. 5 . Campanian sporomorphs from Nkporo Shale, Leru (x 400)

1. *Leiotriletes adriennis POTONIE & GELLETICH, 1933*
2. *Cyathidites australis COUPER, 1953*
3. *Distaverrusporites simplex MULLER, 1968*
4. *Cingulatisporites ornatus VAN HOEKEN-KLINLENBERG, 1964*
5. *Gleichenidites senonicus ROSS, 1949*
6. *Laevigatosporites sp.*
7. *Cicatricosisporites dorogensis POTONIE & GELLETICH, 1933*
8. *Araidnaesporites nigericus ODEBODE & SKARBY, 1980*

Plate 2

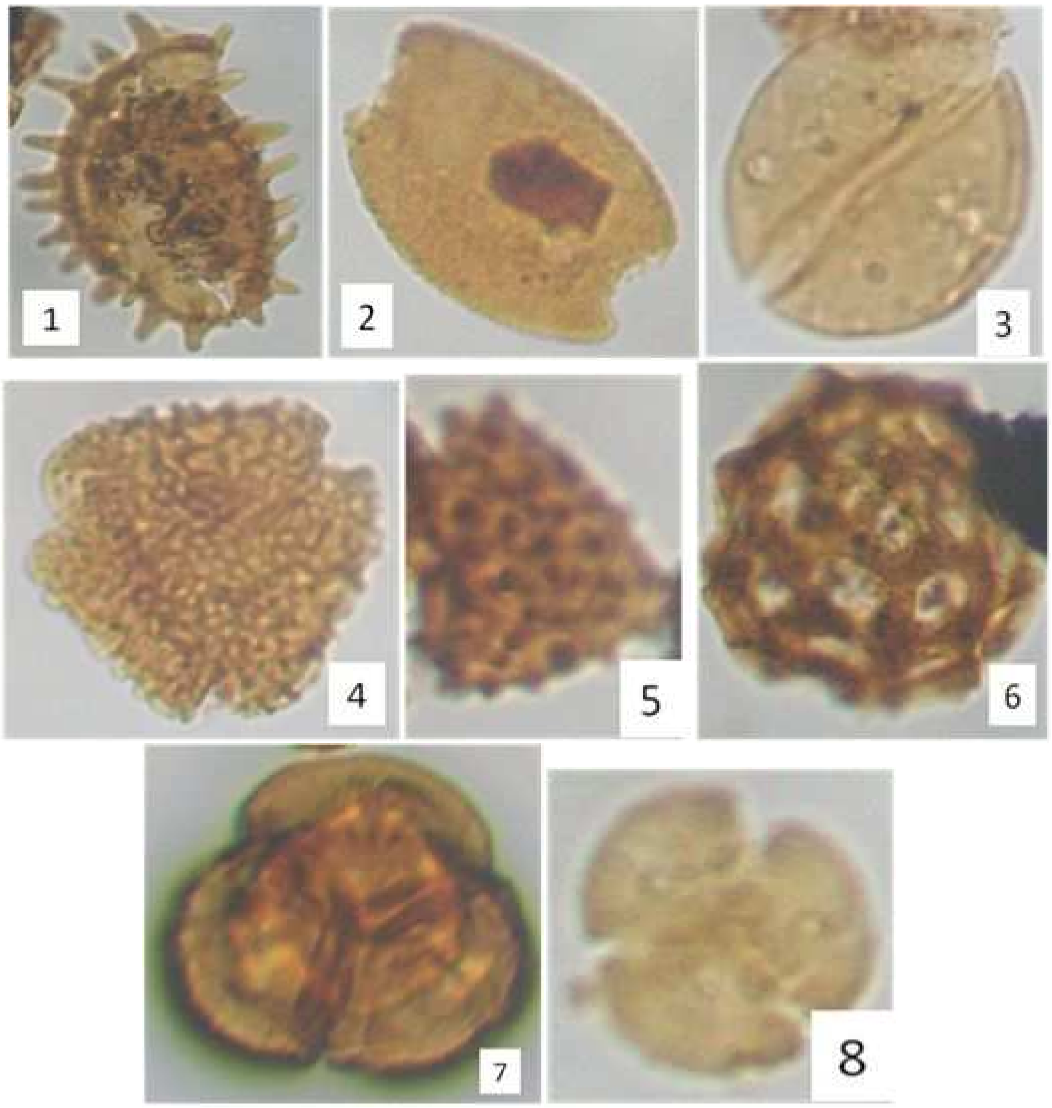

Fig. 6: Late Campanian sporomorphs from Nkporo Shale,Leru (x400)

1. *Spinizonocolpites baculatus* MULLER, 1968
2. *Retidiporites magdalenensis* VAN DER HAMMEN AND GARCI, 1965
3. *Monocolpites marginatus* VAN DER HAMMEN, 1954
4. *Retibrevitricolpites triangulates* VAN HOEKEN-KLINKENBERG, 1964
5. *Echitriporites trianguliformis* VAN HOEKEN-KLINKENBERG,1964
6. *Buttinia andreevi* BOLTENHAGEN, 1967
7. *Inaperturopollenites tetradus* SALARD-CHEBOLDAEFF,
8. *Psilatricolpites sp.*

Plate 3

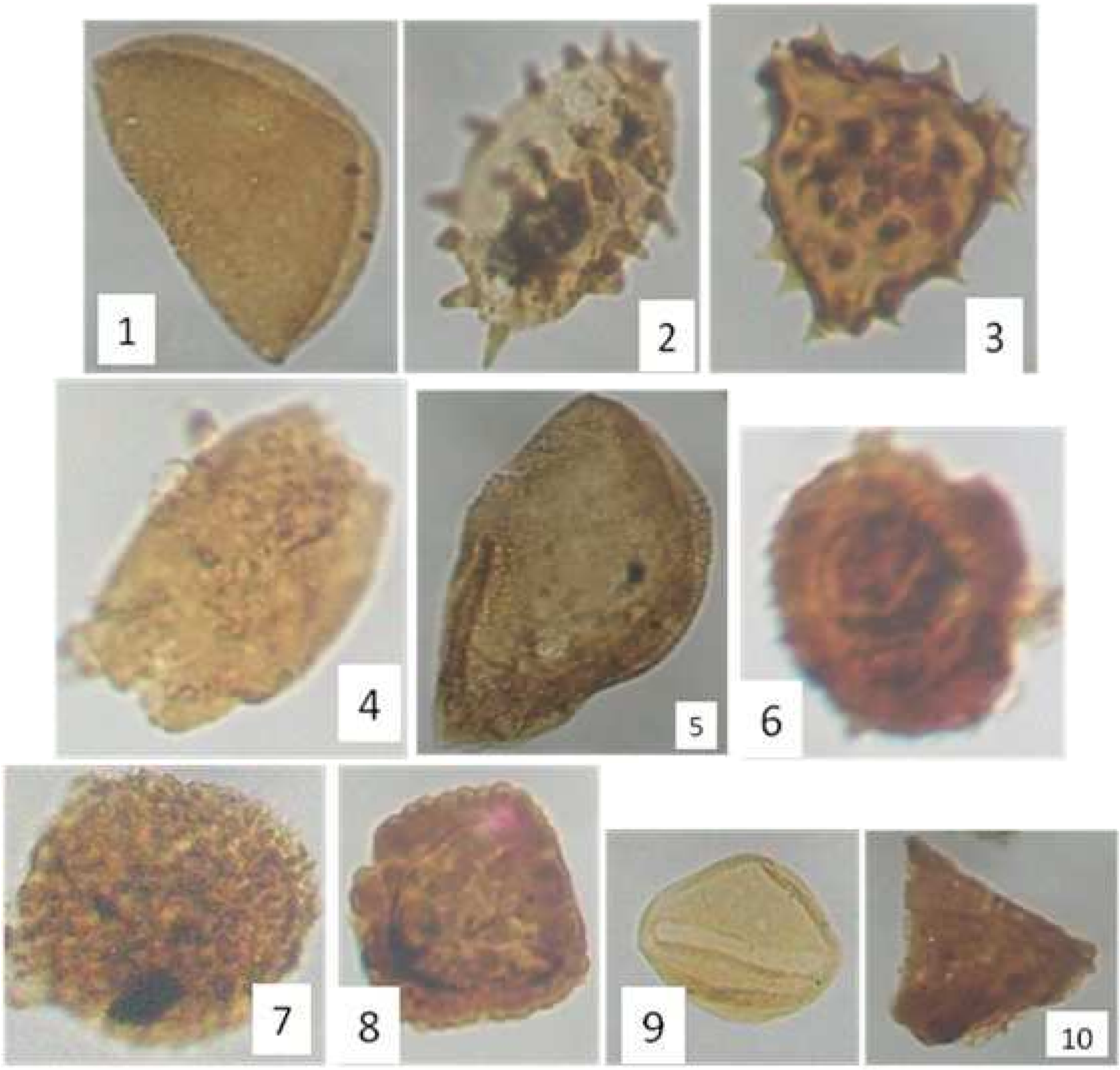

Fig. 7: Photomicrograph of the palynomorph species from Mamu Formation, Uturu (x400)

1. *Longapertites marginatus* VAN HOEKEN-KLINKENBERG, 1964
2. *Spinizonocolpites baculatus* MULLER, 1968
3. *Echitriporites trianguliformis* VAN HOEKEN-KLINKENBERG, 1964 (form B)
4. *Retidiporites magdalenensis* VAN DER HAMMEN & GARCIA, 1965
5. *Longapertites vaneedenburgi* GERMERAAD, HOPPING AND MULLER, 1968
6. *Cingulatisporites ornatus* VAN HOEKEN-KLINLENBERG,1964
7. *Constructipollenites ineffectus* VAN HOEKEN-KLINLENBERG, 1964
8. *Distaverrusporites* simplex MULLER, 1968
9. *Monosulcites sp.*
10. *Proteacidites miniporatus* GERMERAAD, HOPPING AND MULLER, 1968

Plate 4

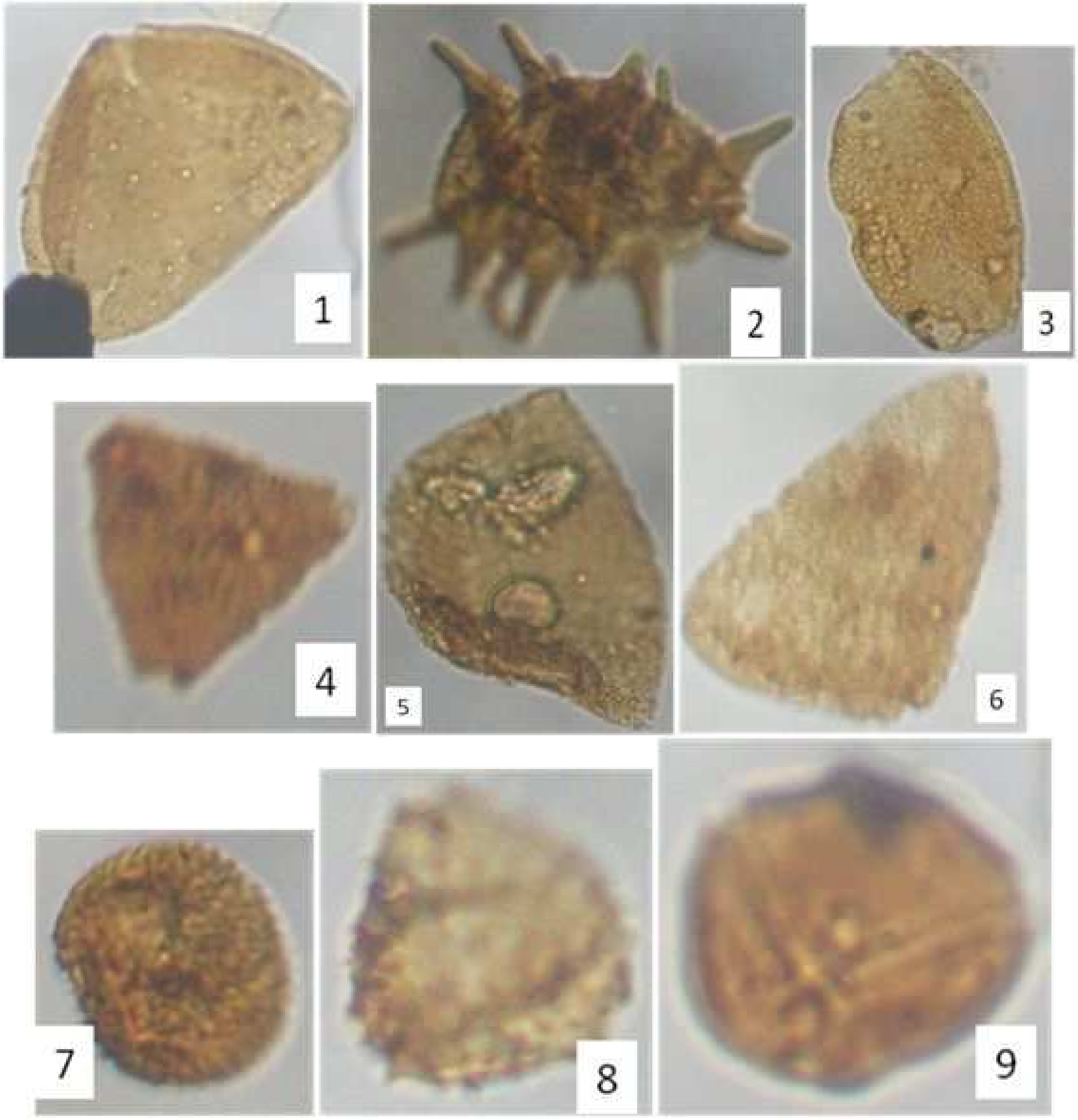

Fig. 8: Photomicrograph of the palynomorph species from Nsukka Formation, Ihube (x400)

1. *Longapertites marginatus* VAN HOEKEN-KLINKENBERG, 1964
2. *Spinizonocolpites baculatus* MULLER, 1968
3. *Retidiporites magdalenensis* VAN DER HAMMEN & GARCIA, 1965
4. *Proteacidites dehaani* GERMERAAD, HOPPING & MULLER, 1968

5&6.*Longapertites vaneedenburgi* GERMERAAD, HOPPING & MULLER, 1968
7. *Milfordia jardinei* HOCULI, 1979
8. *Echitriporites trianguliformis* VAN HOEKEN-KLINKENBERG, 1964
9. *Syncolporites sp.*

Table 3: Frequency % distribution of the selected key sporomorph species in the study areas

Species	Frequency%		
Locality	**Leru**	**Uturu**	**Ihube**
Longapertites marginatus	25%	10%	2%
Retidiporites magdalenensis	1%	5%	8%
Poxapertites operculatus	0%	2%	6%
Spinizonocolpites baculatus	4%	15%	25%
Proteacidites dehaani	0%	4%	7%
Longapertites vaneedenburgi	0%	1%	5%
Constructipollenites ineffectus	5%	8%	6%
Cingulatisporites ornatus	15%	7%	3%
Ariadnaesporites nigeriensis	5%	3%	0%
Laevigatosporites sp.	25%	10%	2%

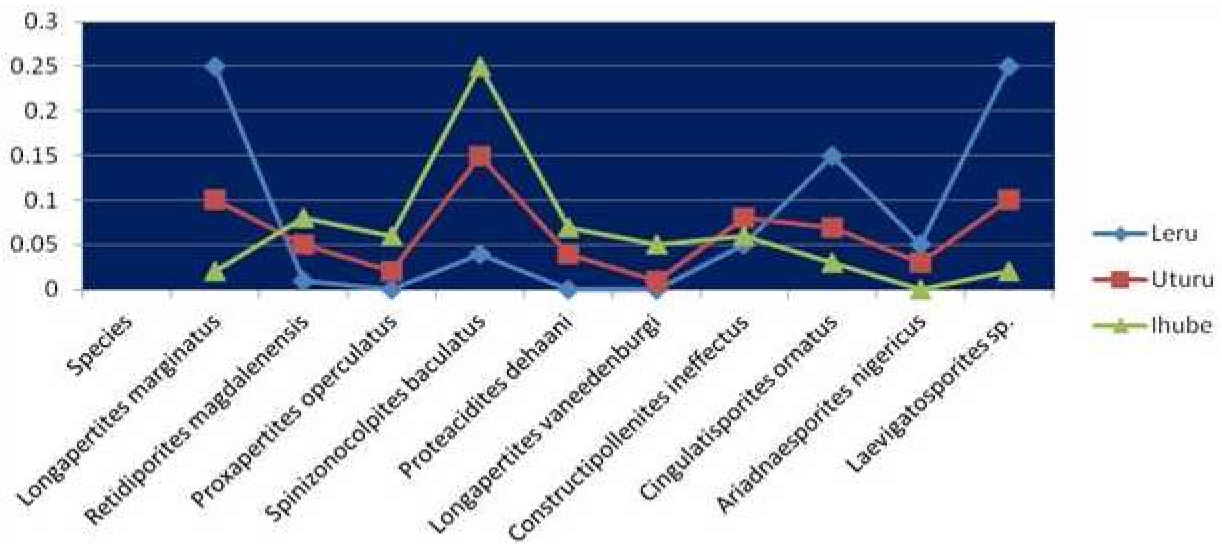

Fig.9. Frequency % distribution of the selected key sporomorph species in the study areas

SEQUENCE STRATIGRAPHIC ANALYSIS

The sequence stratigraphic analysis carried out at the outcrops was based on lithofacies, palynological, macrofossil and Van Wagoner et al (1990) sequence stratigraphic interpretation methodology.

Leru outcrop Seqeunce 1

The outcrop at leru shown in Figure 10 has at its base an igneous rock (dolerite) which is fine to medium grained, it signifies an unconformity that represents a sequence boundary,which implies a low diversity/ abundance of micro/ macro fossil population. It also represents a non-marine depositional environment.

Leru outcrop Seqeunce 2

Above the igneous rock is massive black shale that is highly fossiiferous with a layer of limestone embedded in the shale. This interval represents transgressive system tract with high abundance and diversity of micro/macro fossil population, the section shows a retrogradational stacking pattern representing a shallow open marine environment. Above the limestone interval was recognized as the maximum flooding surface (maximum transgressive suface or final transgressive surface), marking the end of the shoreline transgression, this surface separates retrograding strata below from prograding (highstand normal regressive) strata above. The presence of prograding (highstand normal regressive) strata above. The presence of prograding strata above identifies the maximum floodind surface as a downlap surface. The change from retrogradational to overlying progradational stacking patterns means their was a base-level rise at the shoreline and that sedimentation rates outpace the rate of base level rise (Catuneanu, 2008).

Leru outcrop Seqeunce 3

The progradational stacking pattern recognized above the maximum flooding surface shows a lithology of medium to coarse grained sandstone with intervals that consists of pebbly sandstone. This interval shows a highstand systems tract which forms during the late stage of base- level rise, when the rates of rise drop below the sedimentation rates generating a normal regression of the shoreline (Catuneanu, 2008). The presence of syndepositional (intrabed) structures such as ripples, cross- lamination and Trough Crossbeds indicates sands that were subjected to traction current in fluvial Environment (shore face). After the well sorted sandstone with syndepositional structures lies an erosional (unconformity) based sandstone which signifies a break in deposition (Hiatus) and a sequence boundary which is a product of a fall in sea level that erodes the subaerially exposed sediment surface of the earlier sequences or sequence.

Leru outcrop Seqeunce 4

A heterolithic fine sandstone and shale which are well laminated with wave ripple and planer Crossbedded Sandstone with associated reactivation surfaces lies above the erosional unconformity.

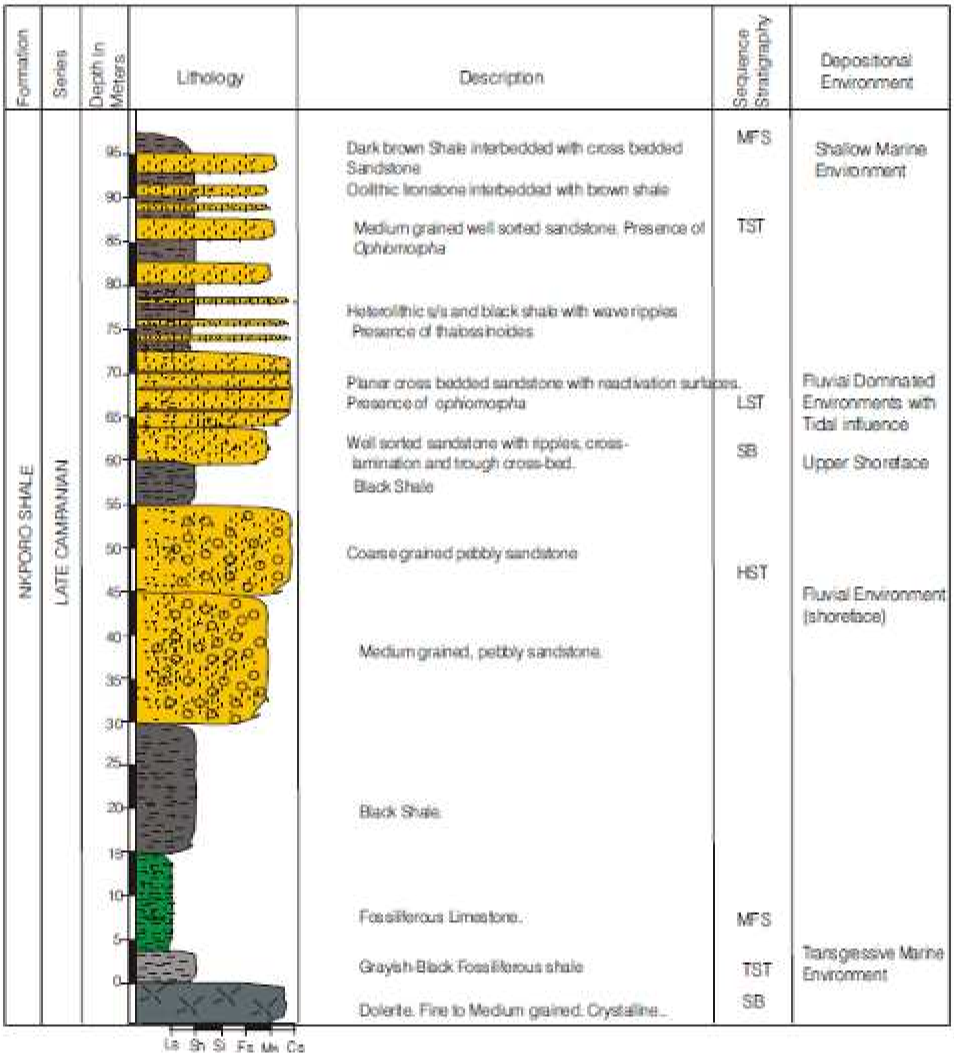

Fig. 10: Litho-Log Section of Nkporo Shale at Leru

The presence of reactivation surface represent short term changes in the flow conditions which caused modification to the shape of the bedform (Turker, 2003), it also represents a tidal-sand deposits through tidal current reversals or the effects of storms in fluvial sediments (Turker, 2003). The reactivation surfaces provide the most favourable conditions for the formation of substrate- controlled ichnofacies (Catuneanu, 2008). Trace fossils identified at this interval are *thalossinoides* and *ophiomorpha* (skolithos) which indicates a sandy shore. The zone represents a low-stand systems tract and transgressive systems tract which are deposits that accumulate after the onset of relative sea level rise and deposits that accumulated from the onset of coastal transgression until the next maximum transgression. The base of the sequence shows an aggradational stacking pattern in which successively younger parasequences are deposited above one another with no significant lateral changes. After which there was a steady rise in sea level (Transgressive System Tract) which got to its peak with a maximum flooding surface, signifying a marine environment. Dark- brown shale with sandstone interval and Oolitic ironstone were observed.

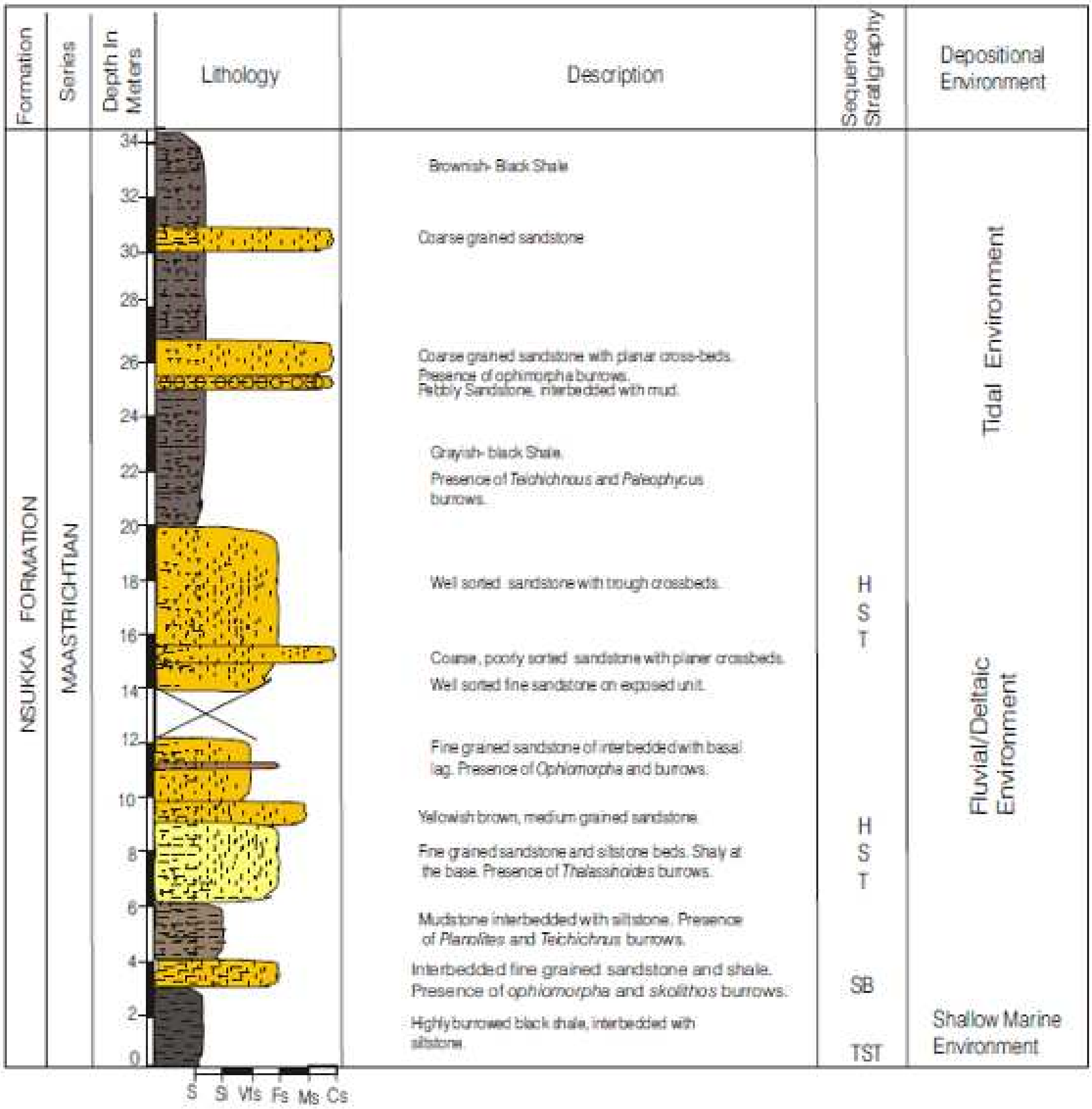

Fig. 11: Litho-Log Section of Nsukka Formation at Ihube

***Ihube outcrop sequence* 1:**
Highly burrowed black shale interbedded with siltstone. The interval represents a shallow marine environment which suggests Transgressive System Tract.

Ihube outcrop sequence 2:
A siltstone and fine sandstone that was interbedded with shale. The presence of trace fossils (planoides, ophiomorpha and teichichnos) suggest onshore continental plain which is most likely a fluvial environment. The base at this sequence indicates a sequence boundary. The interval shows a High System tract with its characteristics progradational parasequence sets of coastal plain sandstone and mudstone, shallow marine sandstone and shelf and slope mudstone with intercalated sandstones (Reijers, 1996).

Ihube outcrop sequence 3:
This interval represents sequence of very fine grained to coarse grained well sorted sandstone with presence of cross- stratification structures (planar and trough cross-beds), which suggests a fluvial environment. Trace fossils present are basically skolithos *(ophimorpha)*. It shows a progradational parasequence which indicates a High Stand tract.

Ihube outcrop sequence 4:
The interval shows a repetiotion of coarse graied sandstone and shale, which suggests a likely tidal environment with an Aggradational stacking pattern and High Stand systems tract. The presence of *teichichous* burrows in the shale indicates a sublittoral zone.

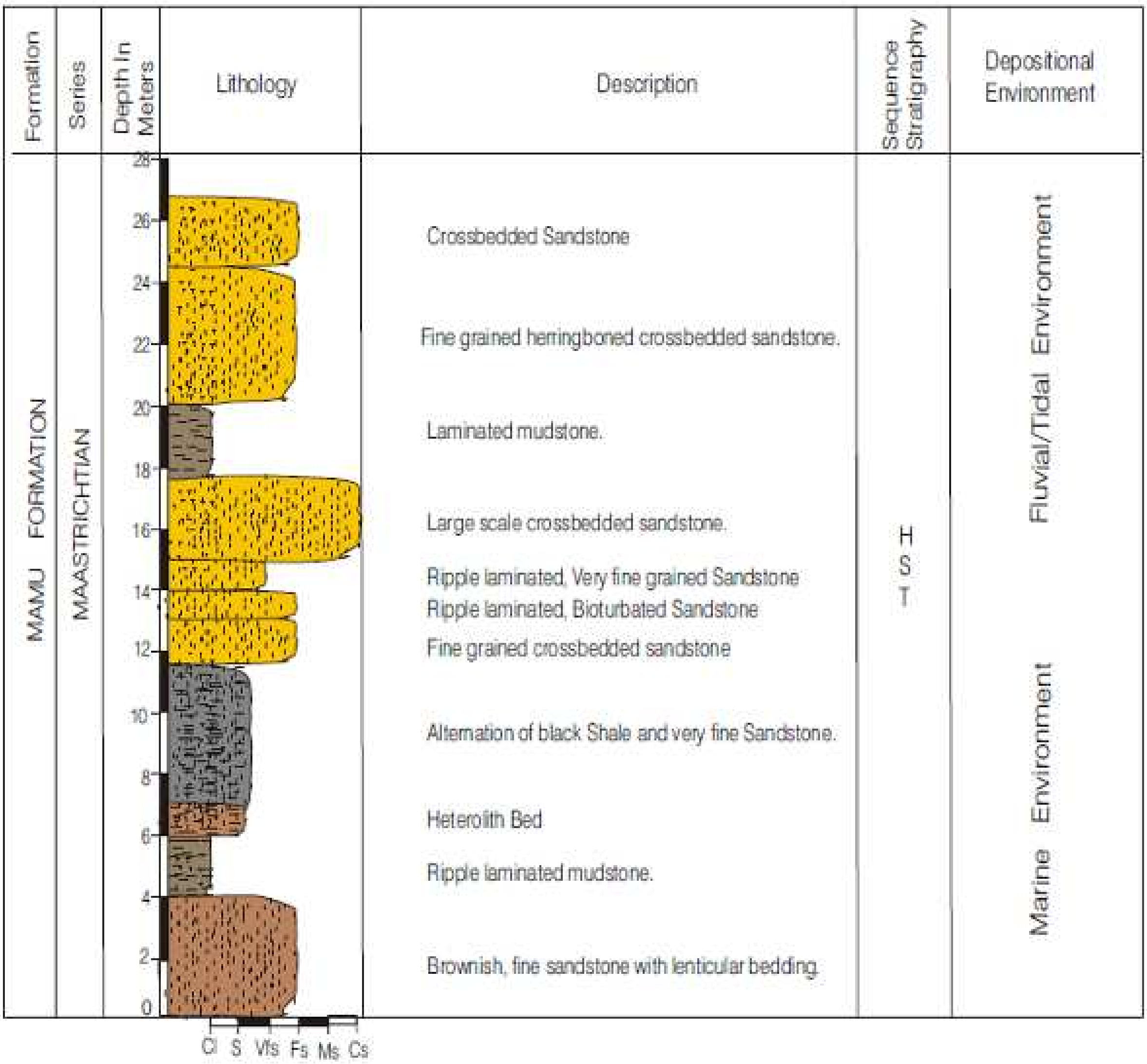

Fig.12: Litho- Log Section of Mamu Formation at Uturu

Uturu outcrop sequence 1:
The sequence is made up of thick brownish mud,with fine grained sanstone,that are lenticular bedded.the sands are cross –laminated and occurs in lenses.

Uturu outcrop sequence 2: Above the basal bed is a ripple laminated heterolithic mudstone and black shale with alternation of very fine grained sandstone. The presence of shale and mudstone at this interval shows an increase in sealevel and high abundance and diversity organisms; and a highstand systems tract and are of shallow marine setting.

Uturu outcrop sequence 3: This interval is made up of fine to medium grained sandstone, which are highly cross-bedded. The high thick sequence of sandstone indicates a fluvial environment. The presence of herribone cross-bedded sandstone refers to bipolar cross-bedding, which is produced by reversals of currents and indicate a tidal origin (Tucker, 2003). The intervals that are bioturbated reflects a high trace fossil density. It is assumed that the thin layer of mudstone at the interval was as a result of tidal influence.

CONCLUSION

Mioshores assemblage recovered from the sediments in Leru, Uturu and Ihube areas are well preserved and diverse in species. A Campanian age was assigned to the Nkoro Shale in Leru and Early to Middle Maastrichtian for Mamu Formation in Utruru on the bases of the selected age diagnostic palynomorhs taxa. The lower part of the Nsukka Formation in Ihube area was designated a late Maastrichtian age.

The presence of *Dinogymnium sp*. a typical Upper Maastrichtian marker forms and with rare occurrences of *Proxaperitites perculatus/cursus*, the Tertiary forms, though sometimes occurs in the Upper Cretaceous, also have strongly supported an age not younger than the late Maastrichtian for the lower part of Nsukka Formation.

The environmentally significant miospore species recovered from the studied formations generally have revealed an unstable depositional environment for formations. Nkporo Shale, however, was deposited in a marine to brackish water environment, while Mamu Formation was deposited in a brackish to fresh water environment. A near shore brackish water environment was suggested for the basal part of Nsukka Formation based on high monocolpate pollen species which bears strong affinity to the palmae and inhabited mangrove swamp environment.

The outcrop study of Nkporo Shale at Leru shows the presence of retrogradational and progradational stacking pattern with highstand, lowstand and Transgressive Systems Tracts while the Nsukka and Mamu Formations at Ihube and Uturu respectively shows a progradational dominated stacking pattern and a system tract that is basically Highstand Systems tract.

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