PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
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J. Appl. Sci. Environ. Manage.
Vol. 28 (6) 1697-1708 June 2024

Palynological and Sequence Stratigraphy Framework of Campanian-Maastrichtian Deposit of Anambra Basin, Awgu Section, Southeast Nigeria

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ABSTRACT: A combination of palynological and palynofacies data are used as lithological evidence to describe sequence stratigraphic framework. Hence, the objective of this paper as to deploy the palynological and sequence stratigraphy framework of Campanian-Maastrichtian deposit of Anambra Basin, Awgu Section, Southeast Nigeria using standard techniques. The sequence stratigraphic analysis of the various succession in the studied outcrop sections identified parasequences limited by flooding surfaces with no evidence of erosion. The Nkporo and Mamu Formations were dated using the associated palynomorphs. The Anambra Basin show some complexity in terms of depositional style, sequence stratigraphy and control during the early and post infill of the structurally control basin. The outcrop sections logged reveals the presence of key stratigraphic surfaces and system tracts. The results from this study provides useful information of reservoir and seal rocks that are essential for hydrocarbon accumulation and stratigraphic trapping on the bases of the alternating high stand, low stand and transgressive system tracts.

DOI: https://dx.doi.org/10.4314/jasem.v28i6.7

Cite this Article as: DIDEI, I. S; AJAEGWU, N. E (2024). Palynological and Sequence Stratigraphy Framework of Campanian-Maastrichtian Deposit of Anambra Basin, Awgu Section, Southeast Nigeria. *J. Appl. Sci. Environ. Manage.* 28 (6) 1697-1708

Dates: Received: 21 February 2024; Revised: 22 March 2024; Accepted: 20 April 2024 Published: 01 June 2024

Keywords: Palynological; Sequence Stratigraphy; Playnomorphs; Lithology; Anambra Basin

Sequence stratigraphy is the study of rocks relationship within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition or their correlative conformities. Sequence is the fundamental unit of sequence stratigraphy which is bounded by unconformities and their correlative conformities, Van Wagoner (1988, 1990). Sequence stratigraphy is a well-defined tools employed in an attempt to subdivide sedimentary deposits into unconformity bounded units in terms of variations in sediment supply, and rate of change in accommodation space which is often associated with relative seal level change. Several studies of the sequence stratigraphy of the Southern Benue Trough have been on a local scale, often been restricted to a single formation/outcrop or borehole section. To further expatiate the study of the various formation to establish, correlate and model a system tracts and stacking pattern gave rise to this research work. This research will be to produce a sequence stratigraphic framework of the entire Anambra Basin in order to understand the petroleum system elements of the Anambra Basin. This study will help in characterizing the system tracts, stacking patterns and undertake a detailed palynological and lithostratigraphic analysis of outcrops found within the Western flank of the Lower Benue Trough. Hence, the objective of this paper as to deploy the palynological and sequence stratigraphy framework of campanian-maastrichtian deposit of Anambra Basin, Awgu

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Section, Southeast Nigeria using standard techniques using outcrop sections.

MATERIALS AND METHODS

Geological Setting of the Anambra Basin: The Anambra Basin originated during the Santonian orogeny in the upper Cretaceous time, during the Santonian tectonism; older strata were folded, faulted, intruded and uplifted. The folding result in the formation of the Anambra Basin, the depressed platform became a major depocenters after the deformation and uplift of the Benue-Abakaliki Trough, thereby making it a basin for the deposition of the Pre-Santonian and Post-Santonian sediments, Ajaegwu, Okoro, Obiadi, Anakwuba and Ounba (2015); Odigi (2008). The Anambra Basin is a sedimentary succession that directly overlies the facies of the Southern Benue Trough and consists of Campanian to early Paleocene lithofacies (Nwajide, 2013). The Anambra Basin is a NE-SW trending syncline that is part of the central Africa Rift system which developed in response to the stretching and subsidence of major central blocks during a lower cretaceous break-up phase of the Gondwana Super-Continent (Ogala et al 2009, Chiaghanam et al, 2012). The deposition of sediments in the Anambra Basin began during the Campanian (Chiaghanam et al, 2012). The deposition is as a result of alternative sequence of transgressions and regressions. There is evidence of deltaic sedimentation which give rise to over 2,500m thickness of sediment (Akpokodje, 2005). Three major lithofacies are identified in the Anambra Basin. The recognized three lithofacies are the Nkporo group deposited during the Campanian period, the Mamu deposited during the Late-Campanian to Early-Maastrichtian and the Ajali sandstone deposited during the Maastrichtian. These three major units represents the three lithofacies in a typical deltaic sequence. The Nkporo deposit consist of fluvial and deltaic phase, the Mamu constitute the deltaic plain and the Ajali in a pro-deltaic facies. The Enugu and Nkporo shale represent brackish environment and marshes that occurred in the Campanian. The Nkporo represent a shallow marine shale environment. Behind the fore-shores, there are swamp deposit represented by Enugu shale and bar-point deposit represented by Owelli sandstones. The coal bearing Mamu Formation occurred during regression that followed the Nporo shale transgression. The deltaic deposits of the Mamu Formation that is regarded as the lower coal measure in overlaid by the Ajali Formation that is referred to as the false bedded sandstone. (Obi, 2000) and followed by Nsukka formation which is a fluvio-sediment (Obi, 2000). The depositional environment of the Anambra Basin can be interpreted in terms of a single transgression and regression cycle.

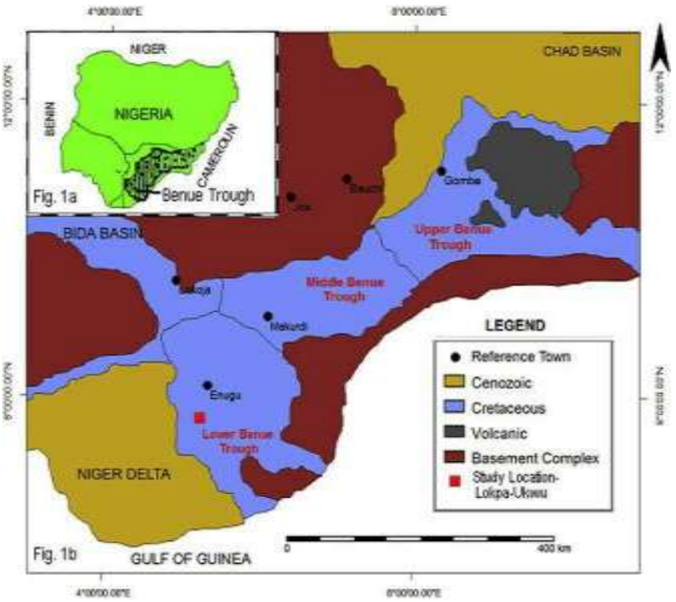


Fig 1: Map showing Geological Units of Benue Trough (Adapted from Short and Staubble, 1967)

Location and Accessibility of the Study Area: The area of study, Awgu and its environs which is part of the Lower Benue Trough and the Anambra Basin is situated within the eastern part of Nigeria and at the western flank of the Abakaliki Anticlinorium. It lies between latitudes 6^0N and $6^0$08'N and longitudes $7^0$26'E and $7^0$30'E of Awgu and its environs. The area has been affected by the Santonian tectonic events which gave rise to the undulating nature of the environment. This gave rise to the Abakaliki-Okigwe anticlinorium geological feature to the North, the Anambra Basin to the West and Afipko-Basin to the East. The study area is located within Awgu and its environs in Awgu Local Government Area and is easily accessible by major and minor roads and foot paths.

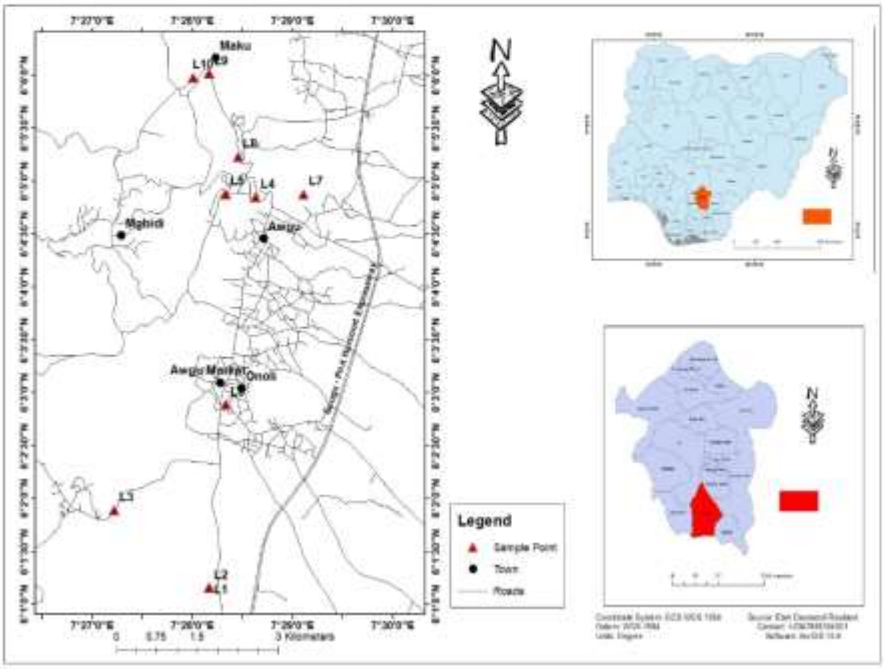


Fig. 2: Location Map of the study area

Methodology: Outcropping section of the Campanian-Maastrichtian succession in the Awgu area of southeastern Nigeria were carefully studied and logged form base to top to obtain information and data on textural, lithologic variation, stratigraphic succession, sedimentary structures and palynological features. Fresh rock samples were collected from different stratigraphic leves in the various outcrop units studied and these samples were subjected to palynological analysis using maceration method. A combination of lithofacies associations and successions, and palynofacies were used in the interpretation of the depositional environment and the sequence stratigraphic interpretation was carried through the application of Van Wagner et al, 1990, techniques.

RESULT AND DISCUSSION

Palynological Analysis: Palynofloral occurrences from the analysed samples were used to determine the palyonlogical study of the area. The samples consist of five locations and the palynofloral assemblages identified include:

Location: Mmaku (Nkporo Formation): This location consists two sample (Oolitic ironstone and Mmaku Nkporo Shale). Palynostratigraphy include very rare miospores occurring in Mmaku Nkporo Shale sample and complete barren in oolitic ironstone sample. The palynofloral assemblage in Mmaku Nkporo Shale sample consists of *Triplanosporites sp., Cyathidites minor* and *Leiotriletes adriennis.* Occurrences of miospores in Mmaku Nkporo Shale sample is rare ranging from 1 to 3 occurrences with a total abundance of 5 occurrences and diversity of 3 species (Fig. 3).

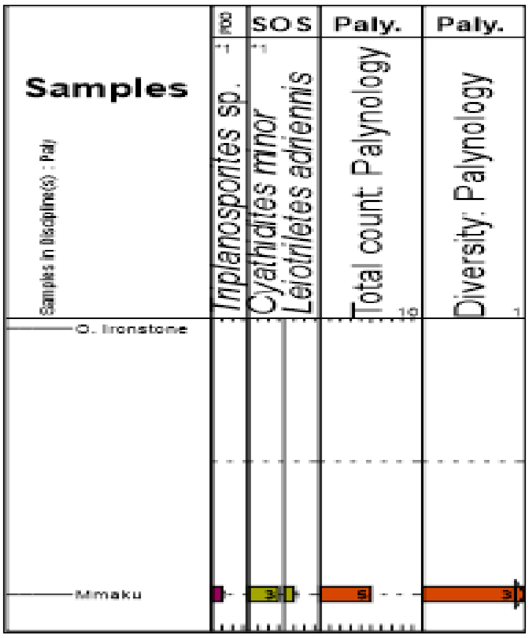


Fig 3: Palynological distribution chart of Nkporo Shale at Mmaku outcrop

Location: Ugwueme (Nkporo Formation): This location consists of two samples. The two samples from Ugwueme yielded mioepores that are rare to frequent occurring. Ugwueme basal sample consists of rare occurrence of *Longapertites marginatus, Classopollis classoides, Cyathidites sp, Batiacasphaera sp., Crassitricolporites brasiliensis, Crybelosporites striatus, Deltoidospora delicate, Echiperiporites stelae, Echitriporites trianguliformis, Ephedripites sp., Kallosphaeridium yorubaense, Magnastriatites grandiosus, Monoporites marginatus, Proxapertites operculatus, Trichotomosulcites sp.,* and frequent occurrence of *Achrostichum aureum* and *Operculodinium centrocarpum.*

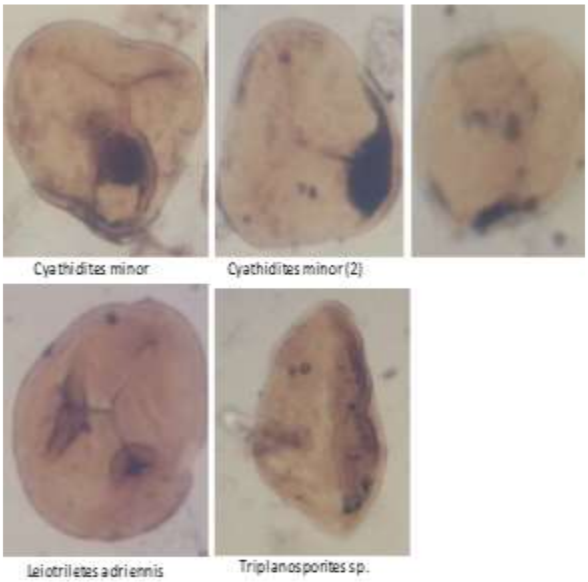


Plate 1: Photographs of some important Palynomorphs as analysed from the samples picked from the Mmaku Section of Ñkporo Formation in the study area

Ugwueme sample II consists of rare occurrence of *Classopollis classoides, Cyathidites sp., Deltoidospora delicate, Echitriporites trianguliformis, Monoporites marginatus, Operculodinium centrocarpum, Proxapertites operculatus, Leiotriletes adriennis, Cinctiporipollis mulleri, Baculatisporites sp., Cf. Graminidites sp., Cicatricosisporites dorogensis, Cicatricososporites parallatus, Dictyophyllidites harrissii, Gleicheniidites senonicus, Graminidites annulatus, Hystrichodinium pulchrum, Proteacidites sigalii* and frequent occurrence of *Striatopollis variabilis* and *Echiperiporites stelae.* The Ugwueme basal sample palynofloral assemblage consists of an abundance of 48 miospores occurrences from fossil diversity of 19 species while Ugwueme II palynofloral assemblage consists of an abundance of 49 miospores occurrence from fossil diversity of 16 species

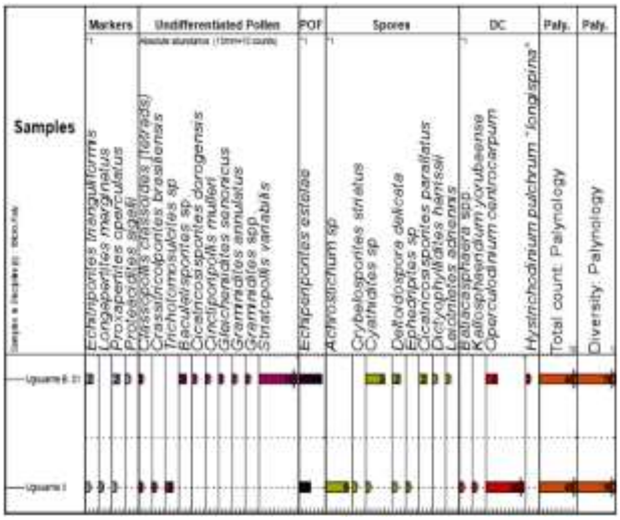
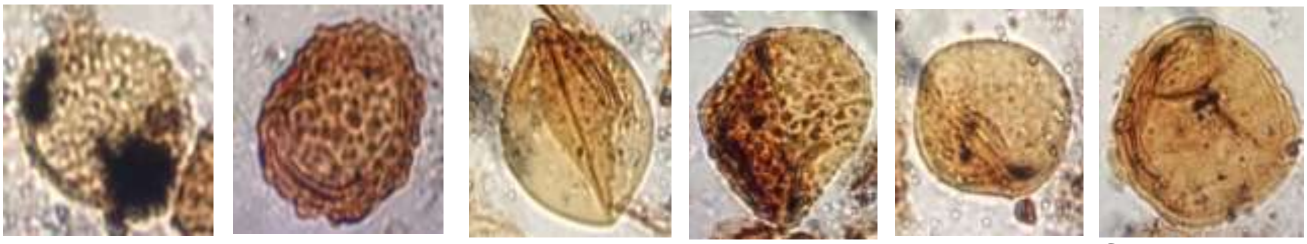
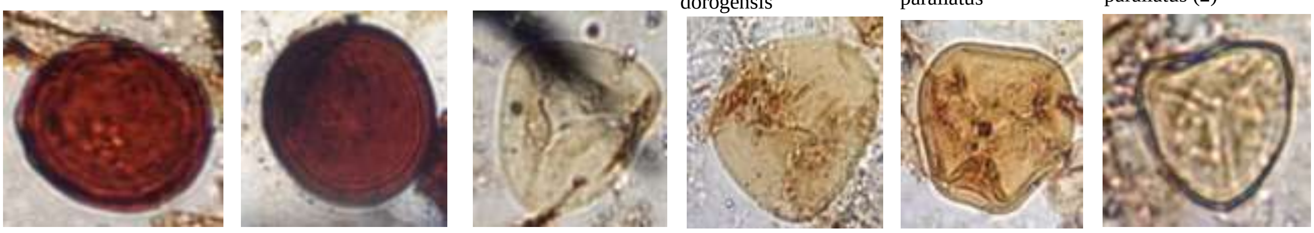


Fig 4: Palynological distribution chart of Nkporo Shale at Ugwueme Section.



Baculatisporites sp. Baculatisporites sp Cf. Graminidites sp Cicatricosisporites dorogensis Cicatricososporites parallatus Cicatricososporites parallatus (2)



Cinctiporipollis mulleri Classopollis classoides Cyathidites sp Cyathidites sp (2) Cyathidites sp (3) Cyathidites sp (4)

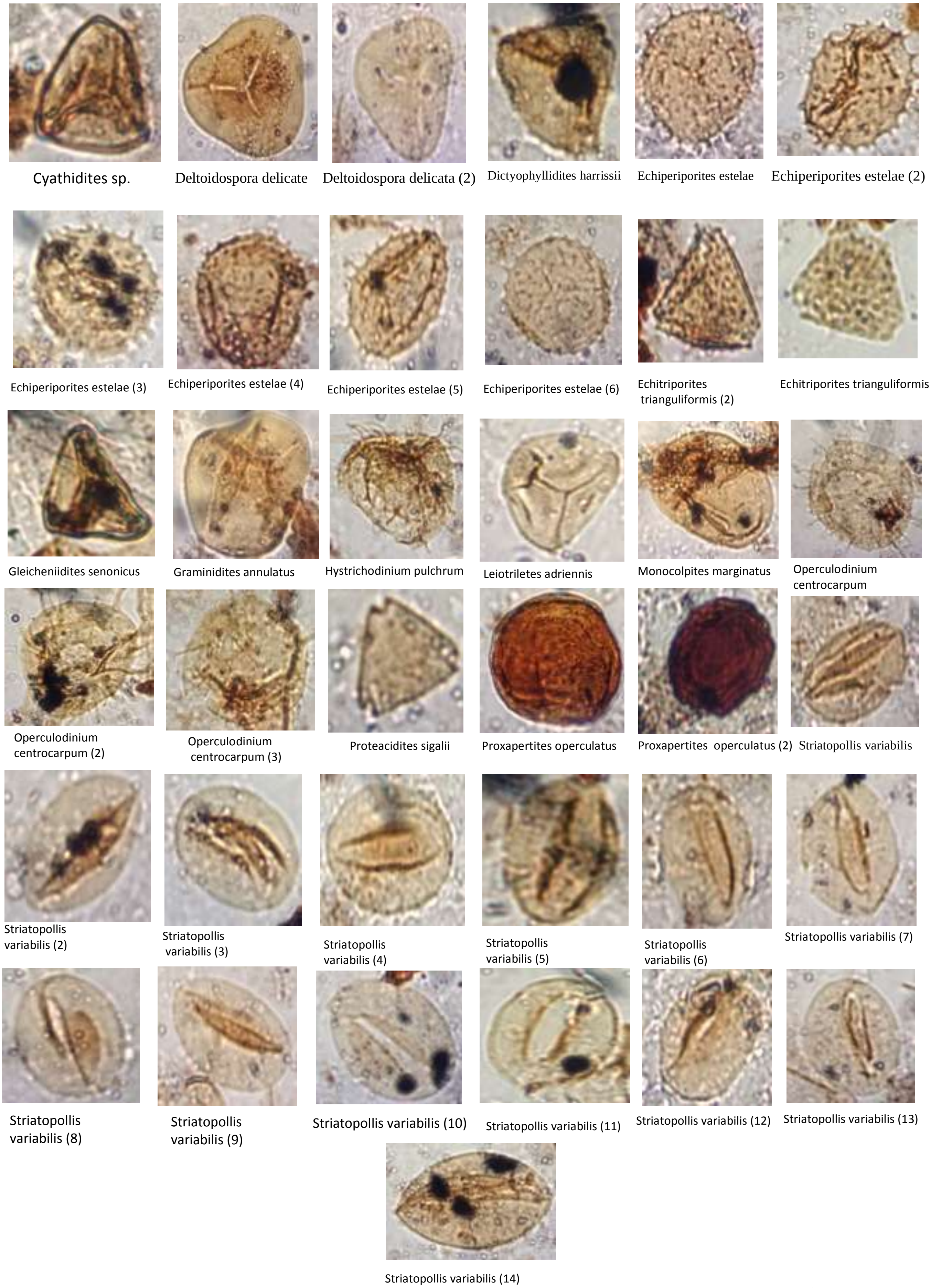


Plate 2: Photographs of some important Palynomorphs as analysed from the samples picked from the Ugwueme Town Section of Ñkporo Formation in the study area

Location: Ugwe-Ise Archi Road (Mamu Formation): This location consists of two sampling points (sample 1 and sample 2). Identified Miospores from analysed samples in this outcrop location are rare in occurrences having species abundance occurred in the range of 1-4 (rare) in most identified miospores and a single frequent occurrence of *Longapertites marginatus* in sample 2, with a total abundance of 8 occurrences. A palynofloral assemblage with a total abundance of 1 occurrence from a diversity of 1 species was identified in sample 1 while 27 occurrences from a diversity of 14 species was identified in sample 2 Carbonaceous shale. The miospores identified include, (*Classopollis classoides*, *Peromonolites sp.*, *Racemonocolpites hians*, *Retimonocolpites pluribaculatus*, *Semitectotriporites gratus, Undulatisporites sinuosis*, *Undulatisporites undulapolus*, *Varirugosisporites perverrucatus*, *Cyathidites minor*, *Leiotriletes adriennis*, *Triplanosporites sp.*, *Achrostichum aureum*, *Cycadopites follicularis*, *Distaverrusporites sp.*, and *Mauritiidites crassibaculatus.* Ugwe-Ise-Archi road sample II palynofloral assemblage consists of a total abundance of 27 occurrences from 14 miospores, while only 1 miospore (*Classopollis classoides*) was identified from sample 1 (Dide and Ajaegwu 2024).

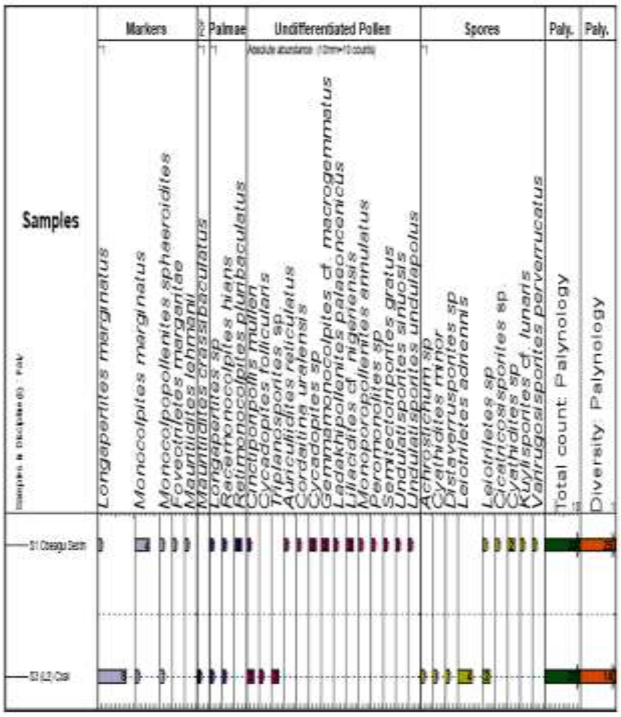


Fig 5: Palynological distribution chart of Mamu Shale at Ugwe-Ise-Archi road Section


Classopollis classoides

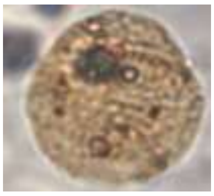

Achrostichum aureum


Triplanosporites sp.


Triplanosporites sp. (2)


Cyathidites minor


Cycadopites follicularis


Distaverrusporites sp


Leiotriletes adriennis


Leiotriletes adriennis (2)


Leiotriletes adriennis (3)


Leiotriletes adriennis (4)


Leiotriletes sp


Leiotriletes sp (2)


Longapertites marginatus


Longapertites marginatus (2)


Longapertites marginatus (3)


Longapertites marginatus (5)


Longapertites marginatus (6)

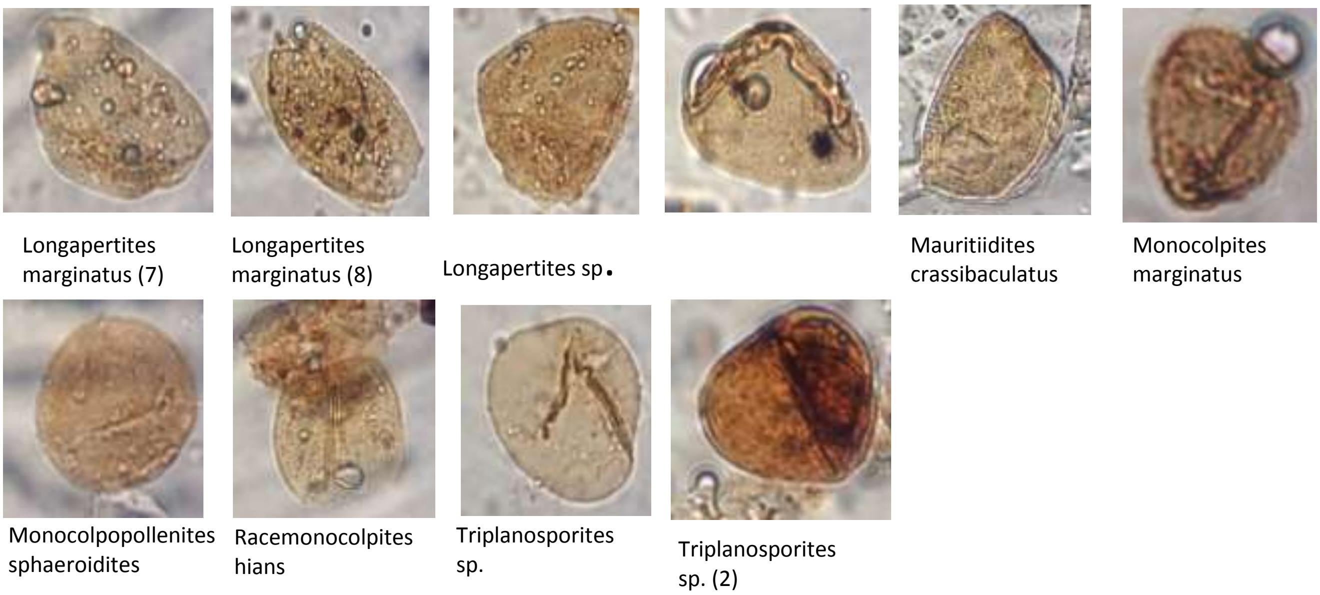


Plate 3: Photographs of some important Palynomorphs as analysed from the samples picked from the Ugwe-Ise-Archi Road Section Section of Mamu Formation in the study area.

Location: Obeagu (Mamu Formation): Obeagu location consists of two samples (sample 1 and sample). The diversity of miospores occurring in sample 1 Obeagu section is relatively high. Miospores in Obeagu II sample is rare in occurrence, and occur within the range of 1 to 3. A palynofloral assemblage with a total abundance of 33 occurrences from a diversity of 25 species was identified in sample 1 Obeagu section. Frequencies in most of the identified species with one species (*Longapertites marginatus*) occurring at a frequency of 7 (Frequent). The miospores include *Cinctiporipollis mulleri*, *Longapertites marginatus*, *Monocolpites marginatus*, *Cicatricosisporites sp.*, *Cordaitina uralensis*, *Cyathidites sp.*, *Cycadopites sp.*, *Foveotriletes margaritae*, *Kuylisporites cf. lunaris*, *Gemmamonocolpites cf. macrogemmatus*, *Gemmamonocolpites macrogemmatus*, *Ladakhipollenites palaeoncenicus*, *Leiotriletes sp.*, *Liliacidites cf. nigeriensis*, *Longapertites sp.*, *Mauritiidites lehmanii*, *Monocolpopollenites sphaeroidites*, *Monoporopollenites annulatusLongapertites marginatus*, *monocolpites marginatus*, *Leiotriletes adriennis*, *Laevigatosporites discordatus*, *Cinctiporipollis mulleri*, *Laevigatosporites josensis*, *Longapertites discordis*, *Retitrescolpites cf. splendens*, *Retitrescolpites cf. splendens* and *Triplanosporites microsinuosus* (Dide and Ajaegwu 2024).

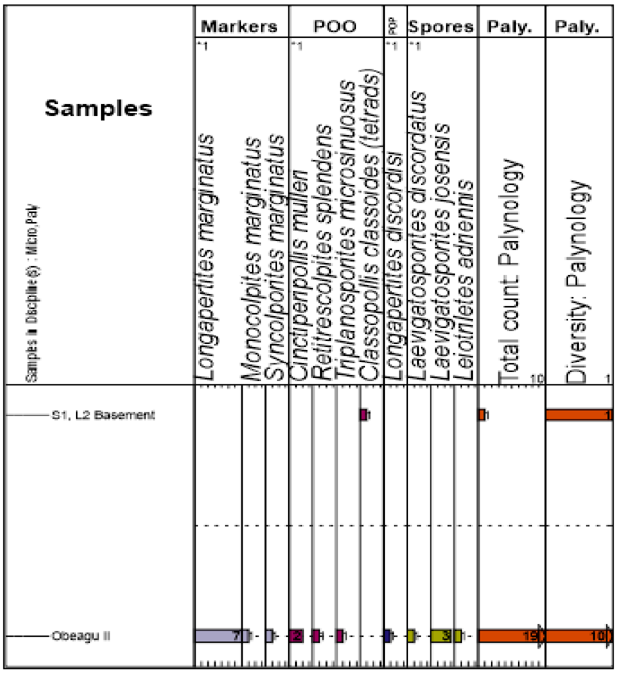


Fig. 6: Palynological distribution chart of Mamu Shale at Obeagu Section

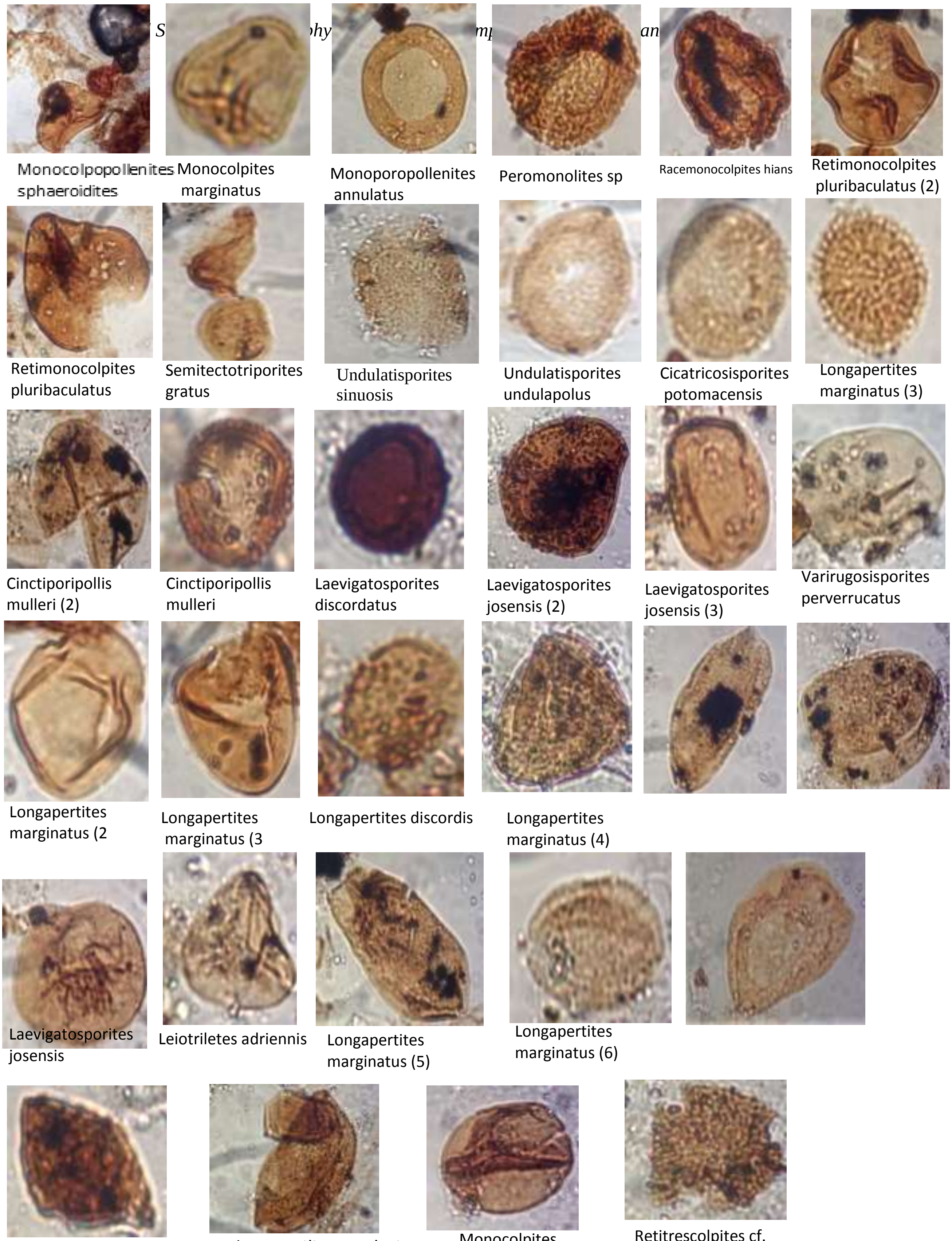


Plate 4: Photographs of some important Palynomorphs as analysed from the samples picked from Obeagu Section Section of Mamu Formation in the study area

Paleogeographic Reconstruction: The paleogeographic reconstruction of the various formations studied will help to infer the environment in which the sediments were deposited. Tectonic event in the Santonian resulted in the uplift, faulting, folding and erosoin of the previously deposited formation destroyed other evidences that would have supported and reveal sea level movement that occurred during the regressive phase. Thereafter, depositional centers where created at both flanks of the uplifted Lower Benue Trough where the Anambra Basin was created. The basin formation began with the another transgressive phase that leads to the formation of the Nkporo Group at the base of the basin with the deposition of the Owelli Sandstones in a stillsand stacking pattern. The Owelli Sandstones is interpreted to be deposited in a tidally influenced estuary as an incised valley fill. This transgressive phase also leads to the deposition of marine influenced Nkporo shale, thus, the Nkporo shale is interpreted to be deposited in a marine environment. Thereafter, this was followed by a regressive phase that leads to the deposition of distributary to tidal channels and coastal swamp deposit of the Mamu Formation and the tidal influence deposit of the Ajali sandstones.

Sequence Stratigraphy Framework of the Studied Outcrop Sections: Sequence stratigraphic interpretation involves the identification of the subdividing surfaces that developed and enclose discrete geometric bodies of sediments. It tracks these in order of oldest to youngest in an outcropping section. They are usually disassembled (back stripped) and then reassembled in order in which they are formed.

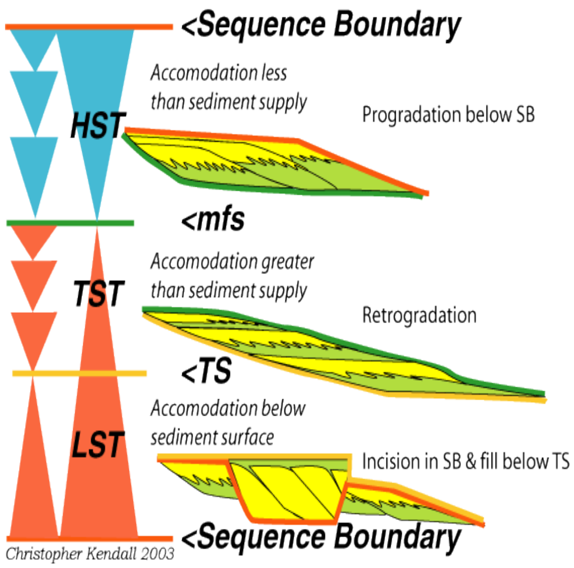


Fig. 7: Sequence stratigraphic model for system tract interpretation (After Van Wagoner et al., 1988, Christopher Kendall 2003)

This reassembly considers the subdividing surfaces, geometry, lithofacies and fauna and their evolving character in terms of the depositional setting. Each strata unit is defined and identified only by physical relationship of the strata including lateral continuity and geometry of the subsurface bounding the units, vertical stacking patterns and lateral geometry of the strata within the units (Van Wagoner *et al.,* 1990). From the above description, the sequence stratigraphic framework interpretation of the studied outcrop sections is based on the outcrop data derived from the studied area on the vertical relationship of the lithofacies with well-defined stacking pattern and as well as the biostratigraphic information from palynomorphs sequence strategraphic model adopted from Van Wagoner et al, 1988. The age chronostratigraphic surface was tied to global chromostrategraphic chart of Hag et al, (1988) and other existing sequence stratigraphic frameworks of the southern Nigeria of late Cretaceous to tertiary sediments of nuigbo et al. (2012), Petters (1983), Nwajide and Reijers (1996), Obi (2000), Obi and Okogbue (2003). The various formations studied was interpreted based on their main System Tracts (ST), Sequence Boundaries (SB), Transgressive Surface of Erosion (TSE) and their maximum Flooding Surface (MFS).

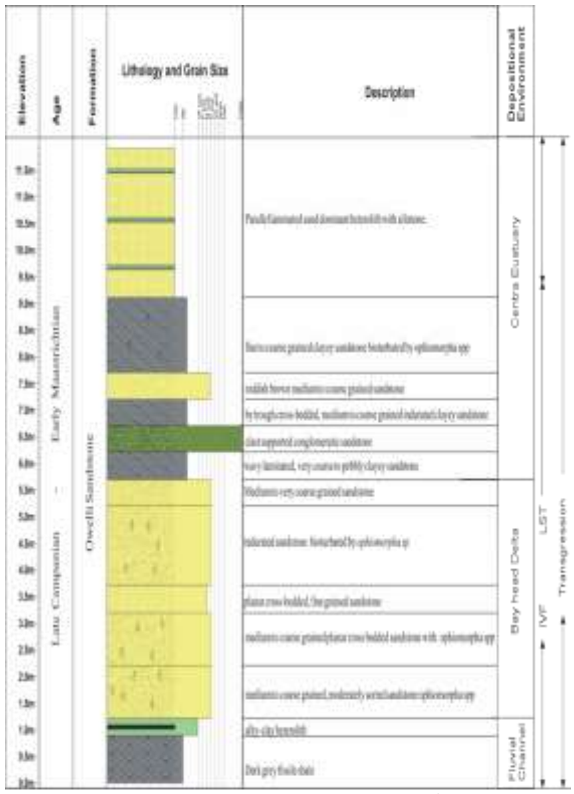


Fig. 8: Sequence stratigraphy interpretation of the Owelli sandstone outcropping unit in Awgu

Owelli Sandstone: Lying above the Benue trough in the Anambra basin that was deposited at the end of the Santonian tectonism (Post-Santonian). The Anambra basin begins with a display of retrogradational stacking pattern (the siltstone deposits recognized above the Agbani sandstone at Ugwueme, interpreted as deposits ranging from lagoon to shallow, open marine shoreface parasequence. However, the Anambra basin was not seen seated on the Awgu Formation, this is due to the fact that the Awgu formation was deeply seated and the incision created during the period of erosion of some of its was filled within. The deposition of the Owelli sandstone in the Anambra basin started with a distinctive aggradational stacking pattern of infill in a tidally influenced estuary. The estuarine system is a typical evidence of transgression of the sea. This is an indication that, as the sea regressed, the valley created during the Santonian tectonism began to fill and this gave rise to a system tract interpreted as the low stand system tract (LST) with the infilled deports described as the incised valley fill (IVF).

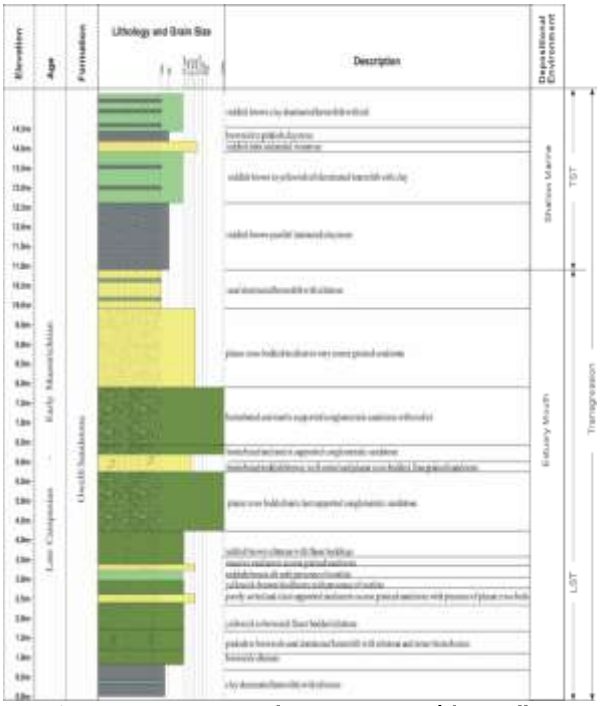


Fig. 9: Sequence stratigraphy interpretation of the Owelli sandstone outcropping unit in Awgu

Nkporo Shale: Lying above the Owelli sandstone is the Nkporo shale. The Nkporo shale characterized by a retrogradational stacking pattern. It is interpreted to be deposited in lagoon to shallow, offshore lower surface environment. This parasequence in a transgressive system tract (TST) terminated at the maximum flooding surface (MFS) marked at the overlying Oolitic ironstone bed. Palynological analysis of the Oolitic ironstone reveal the highest abundant and diversity of palynomorphs as well as the presence of dinoflagellates. The overlying rock want where the Oolitic ironstone bed is characterized by a progradational stacking patterns and the units are interpreted as high stand system tract (HST).

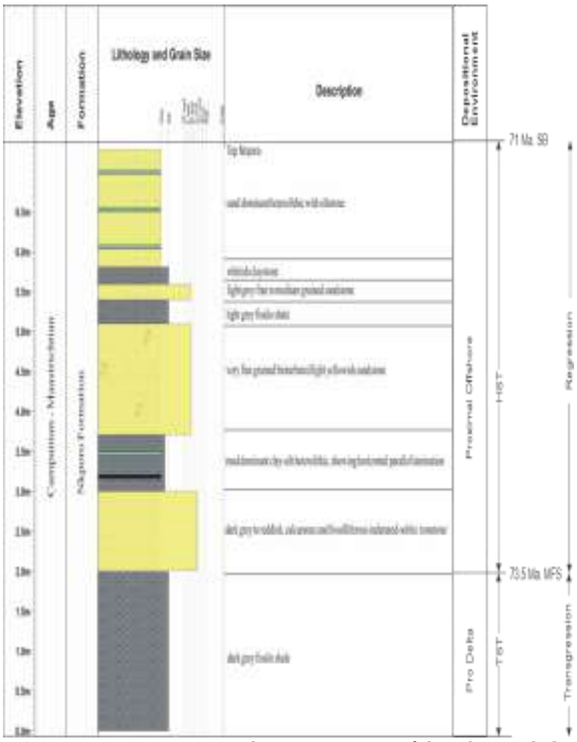


Fig. 10: Sequence stratigraphy interpretation of the Nkporo shale outcropping unit in Mmakko

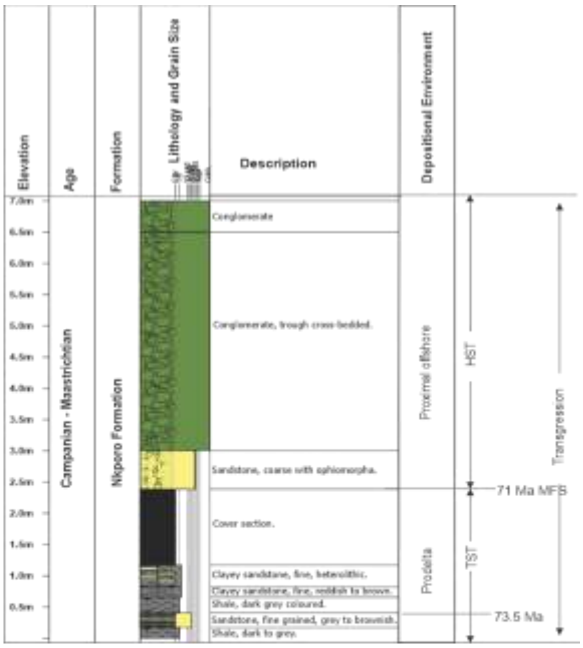


Fig. 11: Sequence stratigraphy interpretation of the Nkporo shale outcropping unit in Ugwueme

Mamu Formation: Overlying the Nkporo shale is the Mamu Formation. This unit marks a progradational stacking pattern. It marks the beginning of another sequence that reflects a high system tract (HST) that is overlying a sequence boundary (SB), Marked by maximum flooding surface (MFS). Another unit identified it's characterized by a transgressive stand system tract (HST). Generally, three sequence boundaries are identified in this unit characterized by different system tracts.

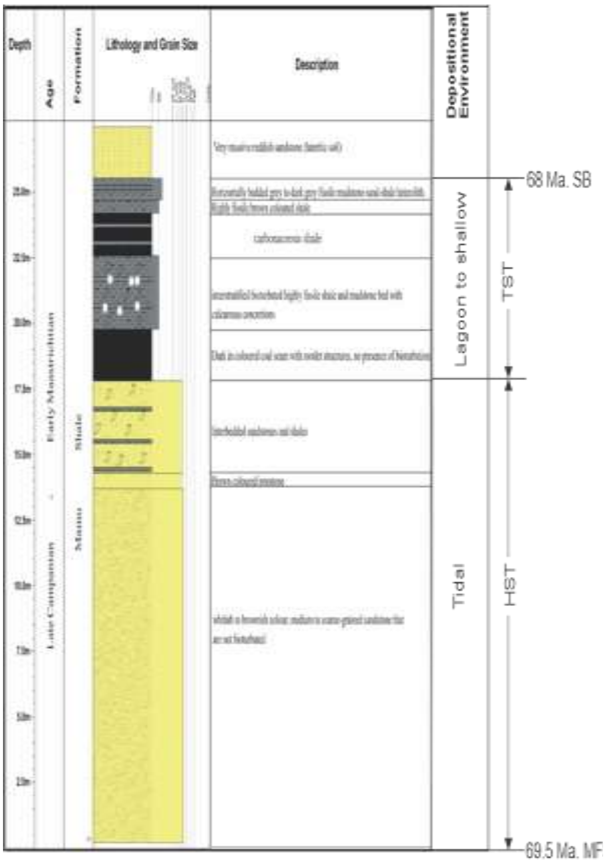


Fig. 12: Sequence stratigraphy interpretation of the Mamu Formation outcropping unit in Ugwe-Ise Road

*Ajali Sandstones***:** Overlying the Mmau Formation is the Ajali sandstone. This formation is interpreted to be deposited in a tidal to marginal marine environment. This unit is characterized by progradational stacking pattern. This formation shows a lithology of medium to coarse-grained sandstone with intervals consisting of pebbly sandstone. This interval exhibits a high stand system tracts formed doing the late stage of base-level, when the rates of rise falls below the sedimentation rates generating a normal regression of the shoreline (Catuneanu, 2008). The presence of syndepositional structures such as ripples, cross-lamination and trough cross-beds indicates sand that were subjected to traction cement in fluvial environment.

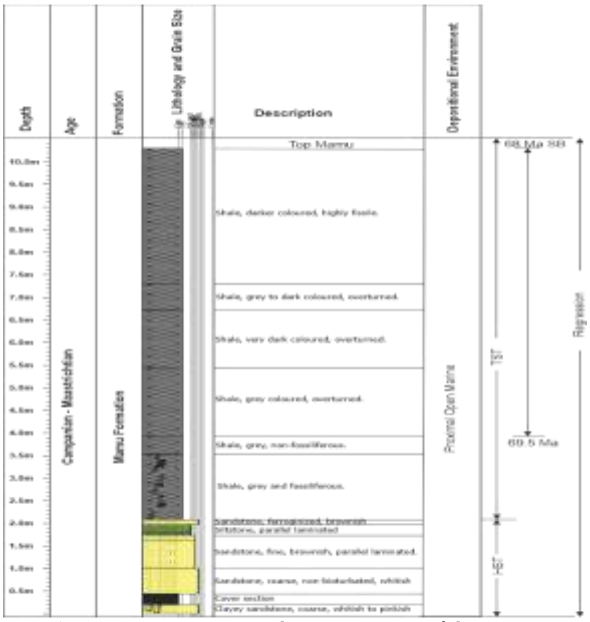


Fig.13: Sequence stratigraphy interpretation of the Mamu Formation outcropping unit in Obeagu

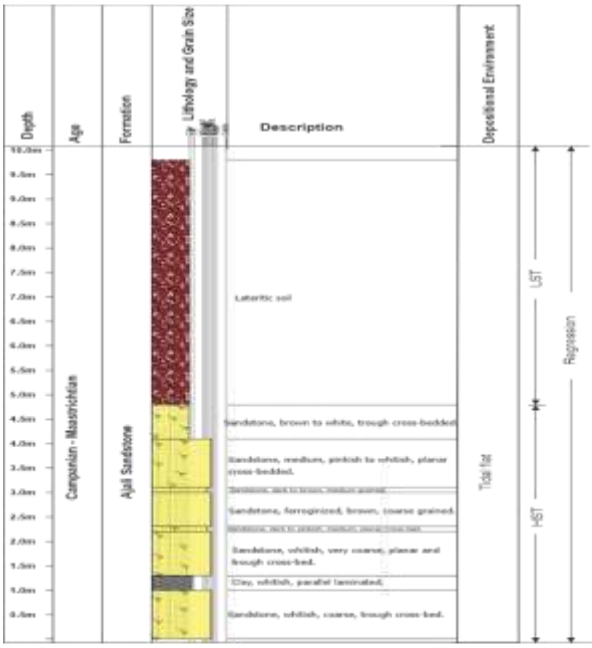


Fig. 14: Sequence stratigraphy interpretation of the Ajali Sandstone outcropping unit in Egwu Achi

Conclusion: The study examined the biostratigraphy, paleo-depositional environment and sequence stratigraphic interpretation of the Turonian-Maastrichtian sedimentary deposits in Awgu and its environment, Lower Benue Trough to Anambra basin in Southeastern Nigeria. This work has provided a regional sequence stratigraphic framework for a better understanding and interpretation of the facies, depositional system and mapping of the area. Through the integration of palynological analysis, facies association and sequence stratigraphic analysis from outcrop sections studied, this research work has been able to document the anatomy and Sequence stratigraphic framework of the Anambra Basin.

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