

A palynology and paleoenvironmental study of a section from the Amansiodo-1 well, Anambra Basin, southeastern Nigeria

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Abstract: Palynological analysis was carried out on twenty (20) ditch cutting samples from a section (1284.73–1496.57 m) of the Amansiodo-1 well, Anambra Basin, southeastern Nigeria with the aim of determining the age, biozone, and depositional environment of the sediments within the depth interval. The laboratory techniques of digesting sediments in hydrochloric and hydrofluoric acids for silicates and carbonates removal were followed to process the samples for the recovery of palynomorphs. Fifty two (52) palynomorph specimens were recovered. An assemblage zone of *Echitriporites trianguliformis* Zone has been established. The section was dated to the upper Maastrichtian due to the occurrences of age diagnostic marker species such as: *Cingulatisporites ornatus*, *Ditaverrusporites simplex*, *Proteacidites sigalii*, *Dinogymnium cf auclaense*, *Echitriporites trianguliformis* and *Retidiporites magdalenensis*. Based on the palynomorph marine index and environmental indicator flora, the section was inferred to be deposited in marine to brackish (coastal) environments with little influence of fresh water.

Keywords: southeastern Nigeria, Anambra Basin, palynology, paleoenvironment, Amansiodo-1 well

INTRODUCTION

The Amansiodo-1 well is located at the latitude 6°87'15"N and longitude 7°68'25"E in the Anambra Basin, in eastern Nigeria (Fig. 1). Palynological information about the age and paleoenvironment of deposition of sedimentary rocks within the Anambra Basin has been published. Ola-Buraimo & Akaegbobi (2013) carried out sedimentological, palynological age dating and the paleoenvironment reconstruction of the Nzam-1 well in Anambra Basin. Chiaghanam et al. (2013) carried out lithofacies, palynology and paleoenvironmental studies of early Campanian to mid-Maastrichtian deposits of Udi and environs in the Anambra Basin, south eastern Nigeria.

The researchers used diagnostic palynomorph species and the coarsening upward sequence of the lithofacies in the Mamu Formation to suggest a decrease in sea level, and the intercalation of siltstone/sandstone and shale in the lithofacies of Enugu Shale, with a high abundance and diversity of palynomorphs taken to infer a shallow-marine environment with tidal influence. The diagnostic palynomorph species recovered include; *Laevigatosporites ovatus*, *Leiotriletes adriennis*, *Echitriporites trianguliformis*, *Longapertites marginatus*, *Cyathidites minor*, *Operculodinium centrocarpum*, *Areoligera senoniensis*, *Spiniferites ramosus*, *Ceratiopsis* sp., *Paleocystodinium* sp., *Dinogymnium acummatum*, *Spiniferites ramosus* and *Cordosphaeridium inorders*.

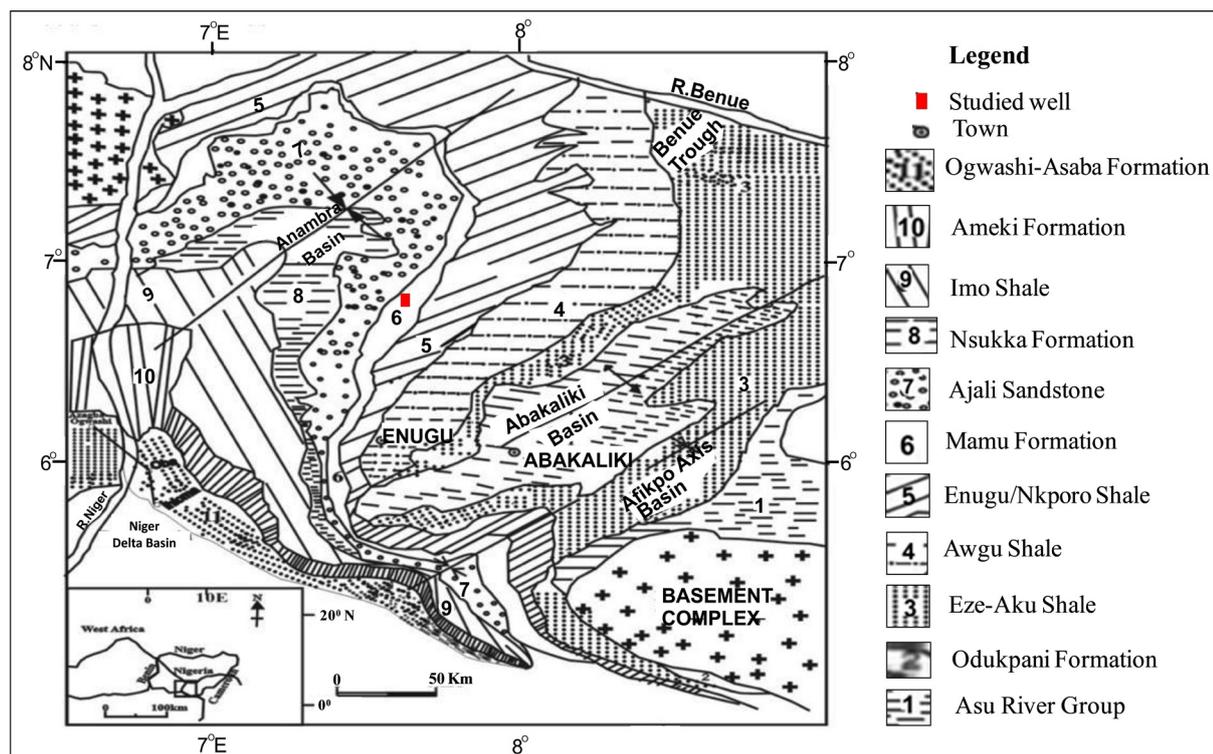


Fig. 1. Geological map of south-eastern Nigeria and the location of the Amansiodo-1 well (modified after Chiaghanam et al. 2013)

Van Hoeken-Klinkenberg (1964) carried out palynological analysis of the sediment from the upper Enugu Shale, Mamu and Nsukka formations using materials collected from G.S.N. Boreholes number 1001, 1108 and 1122. The author ascribed a Maastrichtian age to the formations based on the presence of marker species such as *Cingulatisporites ornatus*, *Germmatricolpites scrabatus*, *Longapertites marginatus* and *Syncolporites marginatus*. Salami (1990) worked on the palynology of the lower coal measures (Mamu Formation) and dated the sediments to the Campanian-Maastrichtian and as well inferring the depositional environment as a freshwater swamp to a marsh environment using the recovered palynomorphs. Umeji & Edet (2008) noted that the paleoenvironments of the deposition of Nsukka Formation in the Anambra Basin oscillated from the lower to upper deltaic plains, varying from tidal flat, lagoon, tidal bar, raised bogs and reed swamp in the north to near shore open marine condition in the south. Ogala et al. (2009) used palynological data to study the middle-upper Maastrichtian Mamu coal facies.

Ogala (2010) carried out palynological and biostratigraphic studies of coal measures in the Anambra Basin, southeastern Nigeria. The researcher established a *Longapertites marginatus* acme zone in the lower section, dated to the middle Maastrichtian, and a *Spinizonocolpites baculatus* assemblage zone in the upper part, dated to the upper Maastrichtian. Okoro (2012) described the palynology of the Afikpo sub-basin of the Anambra Basin. The researcher recovered palynomorphs such as *Longapertites marginatus*, *Monocolpites marginatus*, *Proxapertites cursus*, *Mauritidites crassi bacculatus* and *Andallussiella polymorpha*, *Senegalinium biva-catum* and *Coronifera tubulosa*, which were used to date the studied section to the Campanian-Maastrichtian. Soronnadi-Ononiwu et al. (2012) carried out palynological and paleoenvironmental studies on the Mamu Formation in the Anambra Basin. The authors dated the Mamu Formation to the Maastrichtian using palynomorphs recovered such as *Echitriporites trianguliformis*, *Ephedripites magdalensis* and *Cingulatisporites ornatus*. Seventy percent (70%) of the recovered palynomorphs were terrestrial in origin, suggesting a continental

depositional environment with minor marine incursion. However, palynological work on the Amansiodo-1 well has not been reported or published. This work, therefore, aims to identify the recovered palynomorphs and use them to zone, date and infer the depositional environment of the section of the Amansiodo-1 well. An understanding of the age and paleoenvironment of the deposition of sediments is important in basin evaluation and the successful exploration of both organic and inorganic mineral resources.

THE GEOLOGICAL SETTING AND STRATIGRAPHY OF THE ANAMBRA BASIN

The Anambra Basin is associated with the tectonic event episode that occurred in the Benue Trough in the Santonian age and resulted in the deformation, folding, faulting and uplift of the pre-Santonian sediments. The Anambra Basin evolved as a depression to the west of the uplift (Benkhelil

& Guiraud 1980). The Anambra Basin is a depocenter in which sediments from the Campanian to the Maastrichtian were laid.

The stratigraphic setting of the southern part of Nigeria comprises three major cycles. The first two have been dated to the pre-Santonian while the third cycle belongs to the post-Santonian which is found in the Anambra Basin (Nwajide 1990, 2005). The strongly folded Albian-Coniacian succession (pre-Santonian) sediments are overlain by the nearly flat-lying Campanian-Maastrichtian succession. The oldest sediment in the Anambra Basin is the Nkporo Group (Nwajide 1990). This was deposited in the basin in the late Campanian, comprising Nkporo Shale, Enugu Shale, Owelli Sandstone, Afikpo Sandstone, Otobi Sandstone and Lafia Sandstone (Tab. 1) (Reyment 1965, Onyekuru et al. 2017). The Mamu Formation overlies the Nkporo Group and was deposited in the early Maastrichtian (Fig. 1). It comprises a succession of siltstone, shale, coal seam and sandstone (Kogbe 1989).

Table 1
Stratigraphic correlation of the southeastern Nigerian basins (Nwajide 2005, Onyekuru et al. 2017)

Age	Basin	Stratigraphic Units						
Oligocene-Recent	Niger Delta	Ogwasbi-Asaba Fm				Benin Formation		
Eocene		Arneki/Nanka Fm/Nsugbe Sandstone (Amekei Group)				Agbada Formation		
Thanetian		Imo Formation				Akata Formation		
Danian	Anambra Basin	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	Agwu Formation						

The Ajali Formation (Maastrichtian) overlies the Mamu Formation (Reyment 1965, Nwajide 1990). The Ajali Formation is dominantly unconsolidated, coarse – fine grained, poorly indurated with mudstone and siltstone facies (Kogbe 1989). The Ajali Sandstone is overlain by the diachronous Nsukka Formation (Maastrichtian-Danian) which is also known as the Upper Coal Measure (Reyment 1965). On top of the Nsukka Formation is the Imo Shale which is dated to the Paleocene age (Nwajide 1990). It comprises clayey shale with occasional ironstone and thin beds of ironstone in which carbonized plant remains may occur (Kogbe 1989). The Eocene stage was characterized by a regressive phase that led to the deposition of the Ameki Formation.

METHODS

A total number of twenty (20) ditch cutting samples from the Amansiodo-1 well collected from Nigerian Geological Survey Agency (NGSA) Kaduna, were subjected to palynological analysis. The sample preparation and analysis were made in the Crystal Age Laboratory Nigeria Limited, Ikorodu, Lagos State, Nigeria.

The lithologic description of the ditch cutting samples for preparation of lithologic log was based on the physical inspection of the samples with the aid of magnifying hand lens and a chart for the textural analysis of clastic sediments. Texturally, clastic sediments made of particles smaller than 0.004 mm with varying degrees of fissility, breaking into thin layers (those split easily with a pen-knife into mm-thick flakes); often splintery and usually parallel to the indistinguishable bedding plane because of the parallel orientation of clay mineral flakes are known as shale (Hallsworth & Knox 1999).

The laboratory techniques of digesting sediments in hydrochloric and hydrofluoric acids for silicates and carbonates removal were followed to process the samples for the recovery of palynomorphs. Twenty five grams of each sample was weighed, poured into well labeled plastic cups and arranged in a fume cupboard. Each sample was digested for 35 minutes in 40% hydrochloric acid for removal of carbonate and 24 hours in

40% hydrofluoric acid for the removal of silicate. Sieving was done using a brason sonifier to filter away any remaining inorganic matter (silicates, clay, and mud) and heavy minerals to concentrate organic matters present in the sample. Controlled oxidation was given to the sieved residue using concentrated nitric acid (HNO₃). The residue was stained with Safranin O, before being mounted on glass slides and analyzed with the aid of an Olympus Binocular light transmitted microscope.

The paleoenvironment of the deposition of the studied section was deduced using the palynomorph marine index (PMI). The palynomorph marine index is a semi quantitative interpretation technique, useful in the determination of depositional environment (Helenes et al. 1998). PMI is the ratio of the abundance of marine derived palynomorphs to terrestrially derived palynomorphs, expressed in percentages. It is calculated using the formula (Helenes et al. 1998):

$$PMI = (R_m/R_t + 1) \times 100,$$

where R_m is richness or number of marine derived palynomorph (Dinoflagellates + Acritarch + Foraminifera lining + Prasinophytes) taxa per sample and R_t is richness or number of terrestrially derived palynomorphs (Pollen + Spores + Fungal remains) taxa per sample.

High, low and nil values of palynomorph marine index indicate a marine, brackish and fresh water environment respectively.

RESULTS

The results of the lithologic description and the palynological analysis are presented in Figure 2. The lithology of the studied section is composed of shale. This is because the samples were observed to be fissile and fine grained with a particle size of 0.004 mm. They were also hard, black in color and split into thin flakes along the bedding fissility. Fifty two (52) palynomorph specimens were recorded. The recovered palynomorphs are abundant, diverse, and well preserved at almost all depth intervals (Figs. 2, 3). The palynofloral assemblages were dominated by pollen, spores and dinoflagellate cysts.

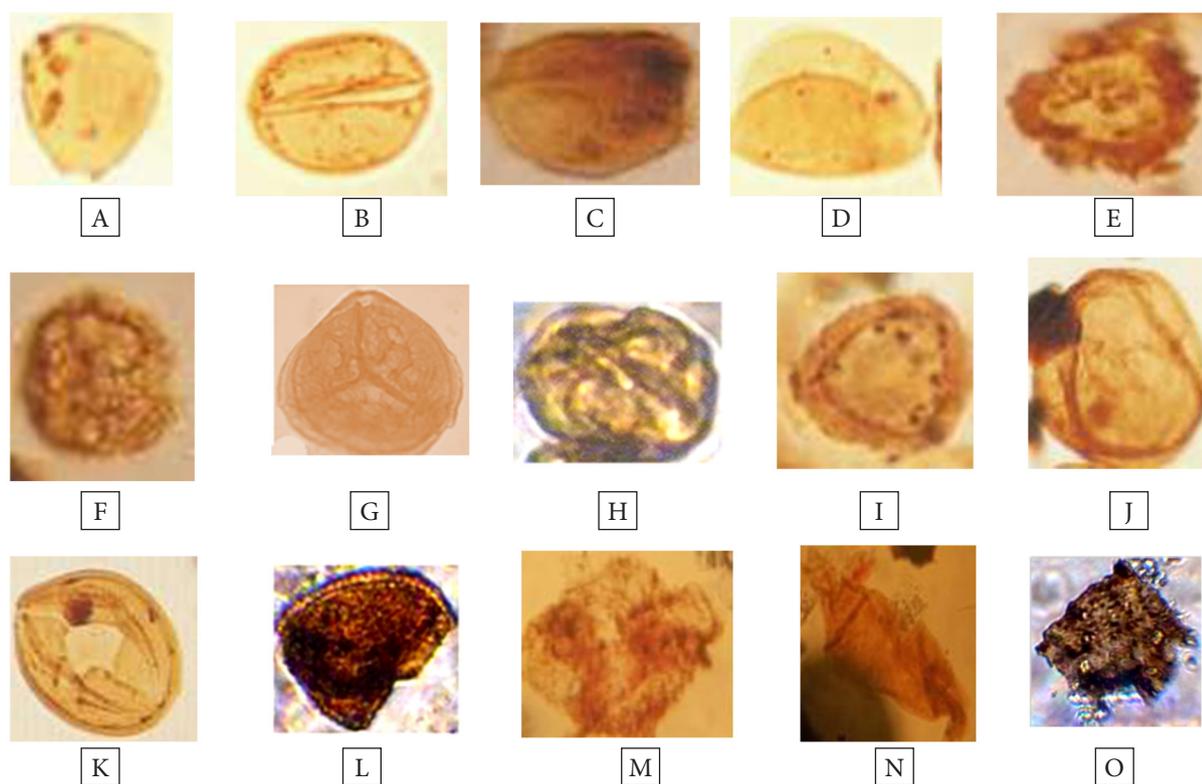


Fig. 3. Recovered palynomorphs photomontage ($\times 400$): A) *Echitriporites trianguliformis* Van Hoeken-Klinkenberg 1964; B) *Longapertites marginatus* Van Hoeken-Klinkenberg 1964; C) *Retidiporites magdalenensis* Van der Hammen and Garcia 1966; D) *Longapertites marginatus* Van Hoeken-Klinkenberg 1964; E) *Distaverrusporites simplex* Muller 1968; F) *Zlivisporis blanensis* Ogala et al. 2009; G) *Zlivisporis blanensis* Pacltova 1961; H) *Monocolpites marginatus* Van Der Hammen 1954; I) *Cingulatisporites ornatus* Van Hoeken-Klinlenberg 1964; J) *Tricolpites* sp.; K) *Tricolporopollenites* sp.; L) *Foveotriletes* sp.; M) *Dinogymnium accuminatum* Clarke and Verdier 1967; N) *Palaeocystodinium* sp. Alberti, 1961; O) *Senegalinium* sp.

The pollen taxa recovered are: *Echitriporites trianguliformis*, *Longapertites marginatus*, *Longapertites* sp, *Longapertites microfaveolatus*, *Monocolpites marginatus*, *Ephedripites* sp, *Retidiporites magdalenensis*, *Proteacidites sigalii*, *Auriculiidites* sp., *Rugulatisporites caperatus*, *Tubistephano-colporites cylindricus*, *Distaverrusporites simplex*, *Retibrevitricolpites triangulatus*, *Triporites* sp. and *Retimonocolpites* sp. The spores recorded include: *Cyathidites minor*, *Zlivisporis blanensis*, *Rugulatisporites caperatus*, *Cyathidites australis*, *Cingulatisporites ornatus*, *Cyathidites* sp., *Laevigatosporites* sp., and Trilete spore.

The marine dinoflagellate cysts recorded include *Senegalinium* sp., *Batiacasphaera* sp., *Dinogymnium* cf *auclaense*, *Hystrichodinium* sp., *Paleocystodinium* sp., *Leiosphaeridia* sp. Polysphaeridium sp., *Exochosphaeridium* sp., *Spiniferites* sp., *Florentinia* sp., *Cleistosphaeridium* sp.,

Dinogymnium accuminatum, *Multispinura quantata* and *Subtilispaera* sp.

DISCUSSION

The recovered palynomorph species were used for biostratigraphic zonation, age dating and the paleoenvironmental interpretation of the stratigraphic interval studied in the Amansiodo-1 well.

Biostratigraphic zonation and age dating *Echitriporites trianguliformis* Zone (assemblage zone)

Interval: 1284.73–1496.57 m.

An assemblage zone is characterized by an assemblage of three or more fossil taxa. The palynomorphs taxa that characterize this zone include: *Echitriporites trianguliformis*, *Longapertites* sp., *Monocolpites* sp., *Monocolpites marginatus*,

Retidiporites magdalenensis *Zlivisporites blanensis*, *Senegalinium* sp. and *Baltiacosphaera* sp. The upper boundary of this zone is placed at the depth of 1284.73 m (the first sample analyzed) with the uppermost documented occurrence or first down-hole occurrence of *Zlivisporites blanensis*, *Monocolpites* sp., *Hystrichodinium* sp., *Leiosphaeridia* sp., while the lower boundary is placed at the depth of 1496.57 m (last sample analyzed) with the lowermost occurrence or last downhole occurrence of *Longaperites* sp., *Cyathidites* sp., Gemmate pollen, *Zlivisporites blanensis*, *Cyathidites australis*, *Senegalinium* sp., *Subtilisphaera* sp. The age of this zone is therefore inferred to be the upper Maastrichtian.

Echitriporites trianguliformis has a stratigraphic range of Campanian-Maastrichtian to Eocene in Sudan (Eisawi 2015) and the Campanian-Maastrichtian in Nigeria (Edet 1992). *Zlivisporites blanensis* has a stratigraphic range of Coniacian-Paleocene. It has also been reported from the Maastrichtian in Somalia, Late Cretaceous in Nigeria and from the Turonian to Early Maastrichtian in Sudan (Eisawi 2015). *Monocolpites marginatus* has a stratigraphic range of Campanian-Paleocene. Previous records of *Monocolpites marginatus* in Africa range from the Campanian-Maastrichtian in Nigeria and Sudan and to the Paleocene to Eocene in Nigeria (Eisawi 2015). The marker species *Proteacidites sigalii* was originally described from the Senonian (Coniacian to Maastrichtian) in Gabon and later reported from the Coniacian to Maastrichtian of a number of West African basins (Campanian-Maastrichtian of Egypt, the Maastrichtian of Nigeria and Sudan) (Eisawi 2015). *Retidiporites magdalenensis* which is Coniacian to Maastrichtian in age has been recorded from the Maastrichtian of Nigeria, Egypt and Somalia (Eisawi 2015).

The studied section is further confirmed to be upper Maastrichtian because of the high occurrence of the species reported to be restricted to the Maastrichtian such as *Echitricolporites trianguliformis*, *Cingulatisporites ornatus*, *Distaverrusporites simplex*, *Proteacidites sigalii*, *Dinogymnium* sp., *Dinogymnium* sp. cf. *auclaense* and *Retidiporites magdalenensis* (Soronnadi-Ononiwu et al. 2012). The *Dinogymnium* lineage became extinct in the Maastrichtian (Stover et al. 1999). However, the abundant record of the diagnostic marker species, especially *Echitricolporites trianguliformis*,

Monocolpites marginatus, *Proteacidites sigalii*, *Leiosphaeridia* sp. and *Senegalinium* sp. suggest an upper Maastrichtian age. The established zone of this study falls within the *Longaperites* sp. 3 Zone (assemblage zone) of Lawal & Moullade (1987) and the P100 zone of Evamy et al. (1978). This is because most of the recovered miospores in this study occurred within the established zones of the above authors.

Paleoenvironment of deposition

Inference regarding the paleodepositional environment of the studied well was made based on the biofacies information interpreted from the qualitative and quantitative evaluation of the palynomorph assemblages and the integration of the lithologic description of the section. The parameters considered in the interpretation of the paleoenvironment are: the palynological marine index, presence/absence of environmental diagnostic marker species.

From the PMI plot (Fig. 4), intervals 1284.73–286.35 m, 1301.50 m, 1310.64 m and 1411.22 m respectively have high palynomorph marine index values of 75% and above. They are suggestive of deposits within a marine environment. These intervals also consist of moderate records of pollen and spores with an abundant dinoflagellate cyst. The dinoflagellate cysts recovered include *Subtilisphaera* sp., *Senegalinium* sp., *Leiosphaeridia* sp., *Baltiacosphaera* sp., *Florentinia* sp., *Dinogymnium* cf. *euclaense*, *Dinogymnium* sp. and *Dinogymnium acuminatum*. The presence of *Spiniferites* sp. and *Hystrichodinium* sp. indicate an open marine (inner neritic to outer neritic) environment (Stover et al. 1999). *Cyclonephelium* sp., *Polysphaeridium* sp. and *Cleistosphaeridium* sp. are indicative of slightly saline condition and near shore environment (Stover et al. 1999, Okeke & Umeji 2016). The above assemblages suggest that the sediments of these intervals were deposited within a marine environment.

Also the following intervals 1295.40 m, 1304.54–1307.59 m, 1341.12–1371.60 m, 1380.74–1383.79 m, 1405.13 m, and 1421.90–1496.57 m respectively were deposited in brackish water due to a low palynomorph marine index of less than 75% while other intervals such as 1377.70 m and 1402.08 m (Fig. 4) have zero palynomorph marine index values which suggest a fresh water environment.

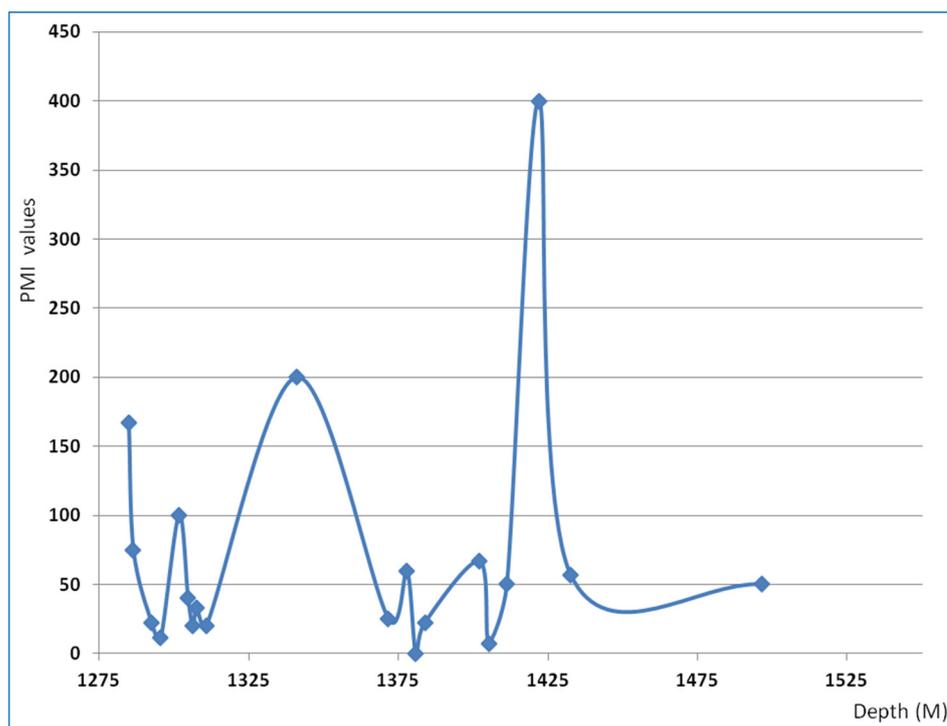


Fig. 4. Palynomorphs Marine Index Chart (PMI) for the Amansiodo-1 well

These intervals consist of moderate records of pollen and spores with diagnostic marker species such as: *Monocolpites marginatus*, *Longapertites marginatus*, *Echitriporites trianguliformis*, *Retidiporites magdalenensis*, and *Cyathidites minor*, also suggest a brackish to fresh water environment (Okeke & Umeji 2016).

CONCLUSIONS

The lithology of the studied ditch cutting samples of a section of the Amansiodo-1 well (1284.73–1496.57 m) is composed of black, hard and fissile shale. These samples were subjected to palynostratigraphic analysis to determine their age and depositional environment. The palynomorph assemblages recorded in the samples include spores, pollens and dinoflagellate cysts. An assemblage zone of *Echitriporites trianguliformis* Zone was established. The studied section is dated to the upper Maastrichtian based on the stratigraphical ranges of marker species. The PMI plot and the environmentally diagnostic marker species suggest that the sediments of the studied interval were deposited within marine to brackish water (coastal)

environments with minor fresh water incursions. Coastal environments are suitable environments for hydrocarbon accumulation and exploration. The palynological analysis has contributed to the biostratigraphic zonation, age dating and paleoenvironmental studies of the Anambra Basin where the studied well is located.

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