Journal of Mining and Geology Vol. 57(1) 2021. pp. 193 - 202 0022-2763

Palynostratigraphy and Paleobathymetric Studies of XAD-1 Well Niger Delta Basin, Nigeria

Chukwuma-Orji, J.N., Okosun, E.A. and Onoruoiza, A.L.
Department of Geology, Federal University of Technology, Minna, Nigeria.
Corresponding E-mail: **jacinta@futminna.edu.ng**

Abstract
Palynological analysis was carried out on one hunderd and sixty-two (162) ditch cutting samples of XAD-1 well within the depth interval of 1373 – 4300 m with the aim of interpreting the palynostratigaphy and paleobathmetry. The well is located in Offshore depobelt of Niger Delta Basin, on Latitude 4°47′ N and Longitude 5°50′ E. Lithologic description of the samples shows that the lithologies of the studied section consist majorly of thick shale/mudstone, sandy mudstone and thin sandstone lithologic units, indicating lower part of the Agbada Formation. Standard procedures of acid method for recovery of palynomorph from samples were followed. The ditch cuttings samples yielded one hundred and twenty-three palynomorph species which occurred abundantly throughout the studied section of the well. These included diagnostic marker species like *Zonocostites ramonae, Praedapolis africanus, Cicatricosisporites dorogensis, Retibrevitricolporites protrudens/obodoensis.* Middle Eocene to Early Miocene was assigned to the studied section using age diagnostic marker species. Five palynostratigraphic zones were established based on the stratigraphic range of palynormorphs present in the studied section. The biozones include *Monoporites annulatus – Margocolporites rauvolfii*, *Pachydermites diederixi – Doualaidites laevigatus*, *Racemonocolpites hians – Numulipollis neogenicus*, *Cicatricosisporites dorogensis – Praedapollis africanus* and *Grimsdalea polyonalis – Striatricolpites catatumbus* Zone. These are useful for correlation of middle Eocene to early Miocene stratigraphic succession. Paleobathymetic interpretation was done using palynomorphs such as algae, dinoflagellate cysts, bissacate pollen, spores and pollens. The paleobathymetric ranges inferred from the studied section are estuarine (littoral) – inner neritic (0 – 40 m) and inner neritic – outer neritic (40 – 200 m) in the marine environments. This is an indication of significant depth of burial of deposited micro fauna and flora in the sediments, necessary for hydrocarbon accumulation and generation.

Keywords: *Palynostratigraphy, paleobathymetry, palynomorphs, biozones.*

Introduction

This study discusses the use of palynomorphs as signals to geologic age and ancient water depths/environments. Paleobathymetry is the determination of ancient water depth (paleodepth). It is the paleoenvironmental interpretation most widely used in petroleum exploration because of its value in determining the depositional history of a basin. Fine-grained pelagic marine sediments that were deposited in low-energy environments are most suitable for palaeobathymetry reconstructions. These sediments generally contain faunal and floral populations that are least affected by downslope transport.

The Niger Delta is ranked among the major prolific deltaic hydrocarbon provinces in the world and most significant in West African continental margin (Aizebeokhai and Olayinka, 2010). Some authors (Chukwu *et al.,* 2012; Olajide *et al*., 2012; Oloto 2014; Ola and Adewale, 2014; Chukwuma-Orji, *et al.,* 2017; Chukwuma-Orji *et al*., 2019) have carried out thorough and extensive biostratigraphic works in the Niger Delta Basin but not have related it to paleobathymetry. This scarcity of available paleobathymetry information serve as necessity to carry out the present research aimed at reconstructing the paleodepth of the studied section of the XAD-1, Niger Delta Basin, Nigeria. This will also add to the existing information/knowledge of palynomorphs diversities in the Niger Delta Basin.

Location of Studied well and Geology of the Niger Delta Basin

The XAD-1 well is located in Offshore depobelt of Niger Delta Basin, with Latitude 4°47′ N and Longitude 5°50′ E (Figure 1). Niger Delta is located in the Gulf of Guinea on the margin of West Africa at the southern culmination of the Benue Trough (Corredor *et al.,* 2005); and extends from about latitudes 4º to 6º North and longitudes 3º to 9º East (Opara, 2010). Niger delta is a vast sedimentary basin constructed over time through successive thick layers of sediments dating back 40-50 million years to the Eocene Epoch. It is a large arcuate delta of the typical wave and tidal dominated type (Doust and Omatsola, 1990).

The geology of the Niger Delta Basin comprises of Akata agbada and Benin Formations (Bankole, 2010). The Akata Formation consists of open marine and prodelta dark grey shale with lenses of siltstone and sandstone. The age of the Akata Formation ranges from Paleocene in the proximal onshore parts of the delta to Recent in the distal offshore. The Agbada Formation consists of cyclic coarsening-upward regressive sequences composed of shales, siltstones and

sandstones which include delta front and lower delta plain deposits ((Reijers *et al*., 1996)). The Agbada Formation ranges in age from Eocene to Holocene. The Benin Formation is the uppermost unit in Niger Delta Basin. It comprises a succession of Eocene to Holocene massive poorly indurated sandstones, thin shales, coals and gravels of continental to upper delta plain origin. The Niger Delta Basin is gifted with very substantial hydrocarbon deposits and is one of the world's largest basins, with the subaerial portion covering about 75,000 km^2. The regressive wedge of clastic sediments which it comprises is thought to reach a maximum thickness of about 12 km (Doust and Omatsola, 1990). According to Muraat (1972), the Niger Delta Basin is bounded to the west by the Benin flank, the subsurface extension of the West Africa shield; to the east by Calabar flank, the subsurface extension of the Oban massif; to the North by the post Abakaliki Anambra basin; and the Atlantic Ocean to the south. It ranks amongst the world's most prolific petroleum producing Tertiary deltas that together account for about 5% of the world's oil and gas reserves (Opara *et al.,* 2011). It is also considered a classical shale tectonic province (Wu and Bally, 2000). Accumulation of marine sediments in the basin probably commenced in Albian time after the opening of the South Atlantic Ocean between the African and South American continents (Doust and Omatsola, 1990).

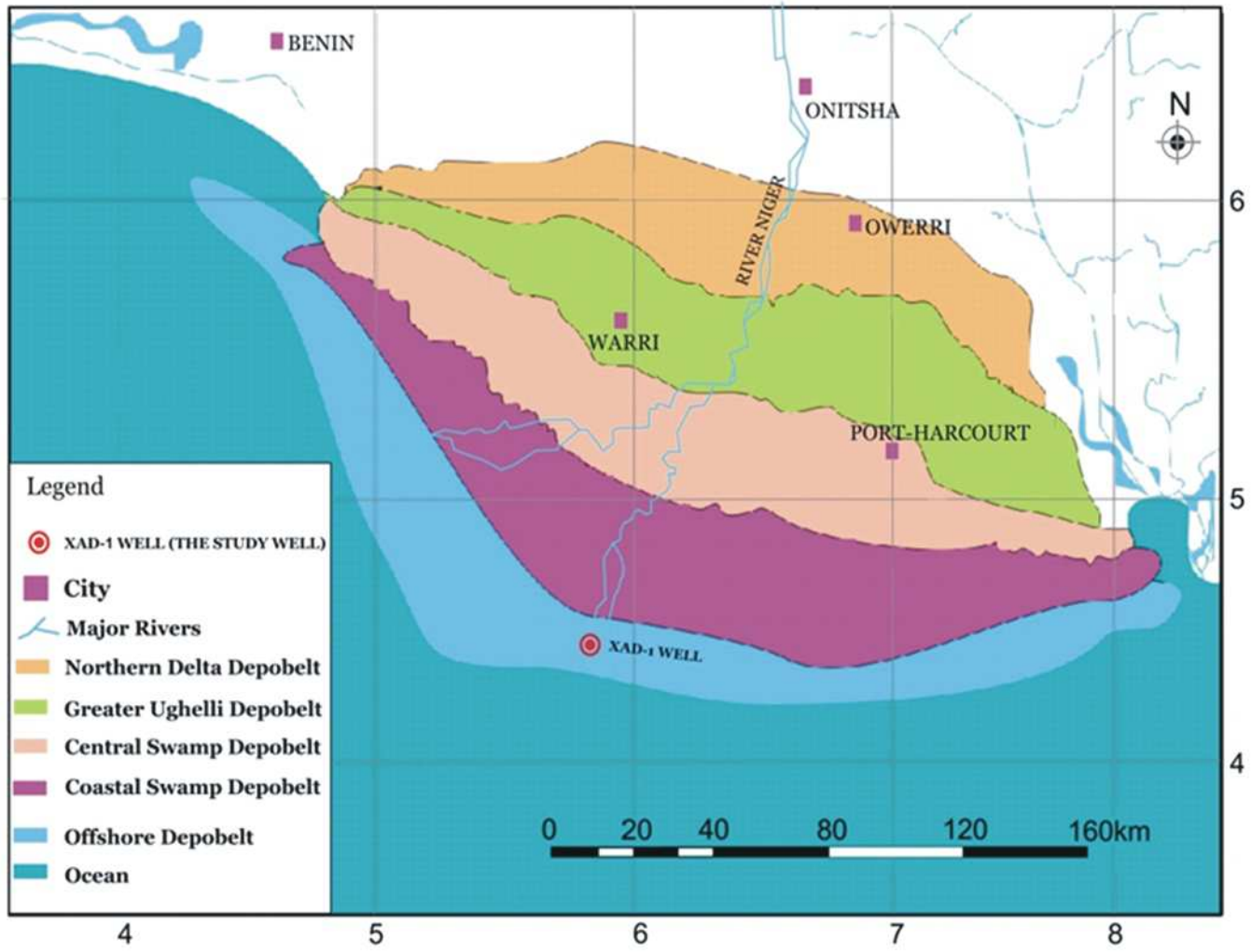

Fig. 1: Location map of the studied well in the Niger Delta (Modified after Ajayi and Okosun, 2014).

Materials and Methods

A total number of 162 ditch cutting samples from XAD-1well (interval 1373-4300 m) obtained from Nigerian Geological Survey Agency (NGSA) Kaduna were subjected to lithologic description and palynological analysis.

The lithologic description of the ditch cutting samples was based on physical inspection of the samples with the

aid of magnifying hand lens and chart for textural analysis of clastic sediments (Hallsworth and Knox. 1999).

The 162 ditch cutting were prepared for palynomorphs recovery using the standard palynological acid maceration technique in which hydrochloric (HCl) and hydrofluoric (HF) acids were used for carbonates and silicates removal respectively. Fifteen grams of each sample were put into well labelled 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 sonifer 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 (HNO_3). The residue was stained with Safranin O, before being mounted on glass slides and analyzed with the aid of an Olympus CX41 Binocular light transmitted microscope.

Results

Lithology: The lithology was observed to consists of thick shale/mudstone, sandy mudstone and thin sandstone units (Figure 2), indicating lower Agbada paralic units (Durugbo and Uzodimma, 2013).

Palynology*:* The result of the palynological analysis carried out on 162 ditch cutting samples from XAD-1 well (interval 1373 – 4100 m) yielded 123 diverse palynomorph species comprising of pollen, spores, dinocysts and algae specimens. The result of the analysis is presented in the palynomorph distribution chart of XAD-1 well (Figure 2).

The palynofloral assemblage was dominated by pollen and spores namely: *Laevigatosporites* spp, *Retimonocolpites obaensis*, *Psilatricolporites crassus*, *Zonocostatites ramonae, Pachydermites diederixi* a*crostichum aureum, Verrucatosporites* sp., *Verrucatosporites usmensis*. Three algae were identified: *botryococcus braunii*, *Concentricytes circulus, Pediastrum* sp. and other notable dinoflagellate include *Spiniferites* sp., *Selenopemphix* sp., *Lingulodinium machaerophorum*, *Leiosphaeridia* sp. Figure 3 shows the microphotograph of some of the recovered palynonmorphs.

Discussion

Palynozonation and Age: The zonal division is based on the first and last downhole occurrences of palynomorphs recorded within the interval. The following interval range zones *Monoporites annulatus – Margocolporites rauvolfii*, *Pachydermites diederixi – Doualaidites laevigatus*, *Racemonocolpites hians – Numulipollis neogenicus*, *Cicatricosisporites dorogensis – Praedapollis africanus* and *Grimsdalea polyonalis – Striatricolpites catatumbus* were recognized. The studied interval is dated middle Eocene (Bartonian age) – early Miocene (Burdigalian age) within the age boundaries of 42.1 – 18.3 Ma (Table 1). The Eocene – Oligocene boundary is marked by the first downhole occurrence of *Doualaidites laevigatus* and last downhole occurrence of *Racemonocolpites hians* at the depth of 3064 m, The Oligocene – Miocene boundary is equally marked by the first downhole occurrence of *Cicatricosisporites dorogensis* at the depth of 2409 m (Table 1).

The age assignment is based on stratigraphic ranges of marker species in contemporaneous basins in Africa and other parts of the world (Figure 4). The record of the stratigraphic range of some of the recovered pollen and spores in this study is presented in Figure 4. From Figure 3, species numbers 3, 5, 10, 11, 17, 18, 19, 21, 23 and 25 have been documented in the work of Bankole *et al*. (2014). Species numbers 1, 2, 3, 5, 7, 10, 15, 16, 18, 20, 23 and 24 were recorded by Germeraad *et al*. (1968). Morley (1997) recorded the occurrences of species numbers 1, 5, 10, 12, 14, 16, 17, 21, 22 and 23. Species numbers 8, 9, 13, 19 and 25 were documented by Lawal (1975). Oloto (1994) recorded the occurrences of species numbers 3, 4, 5, 6, 10, 15, 18, 23 and 24. Legoux (1978) also recorded species numbers 11, 14, 16, 17, 19, 25, 26, 27, 28 and 29 for age determination.

Zone 1: *Grimsdalea polyonalis – Striatricolpites catatumbus* Zone

Stratigraphic Interval: 1373 - 1755 m

Definition: The top is marked by the first downhole occurrence (FDO) of *Striatricolpites catatumbus* while the base of the zone was defined by the first downhole occurrence (FDO) of *Grimsdalea polyonalis* and *Praedapolis africanus*. This zone is an interval range zone.

Characteristics: It is characterized by *Acrostichum aureum, Verrucatosporites* sp*, Zonocostites ramonae, Laevigatosporites* sp*, Psilatricolporites crassus* etc. This zone was characterized by the first appearance of

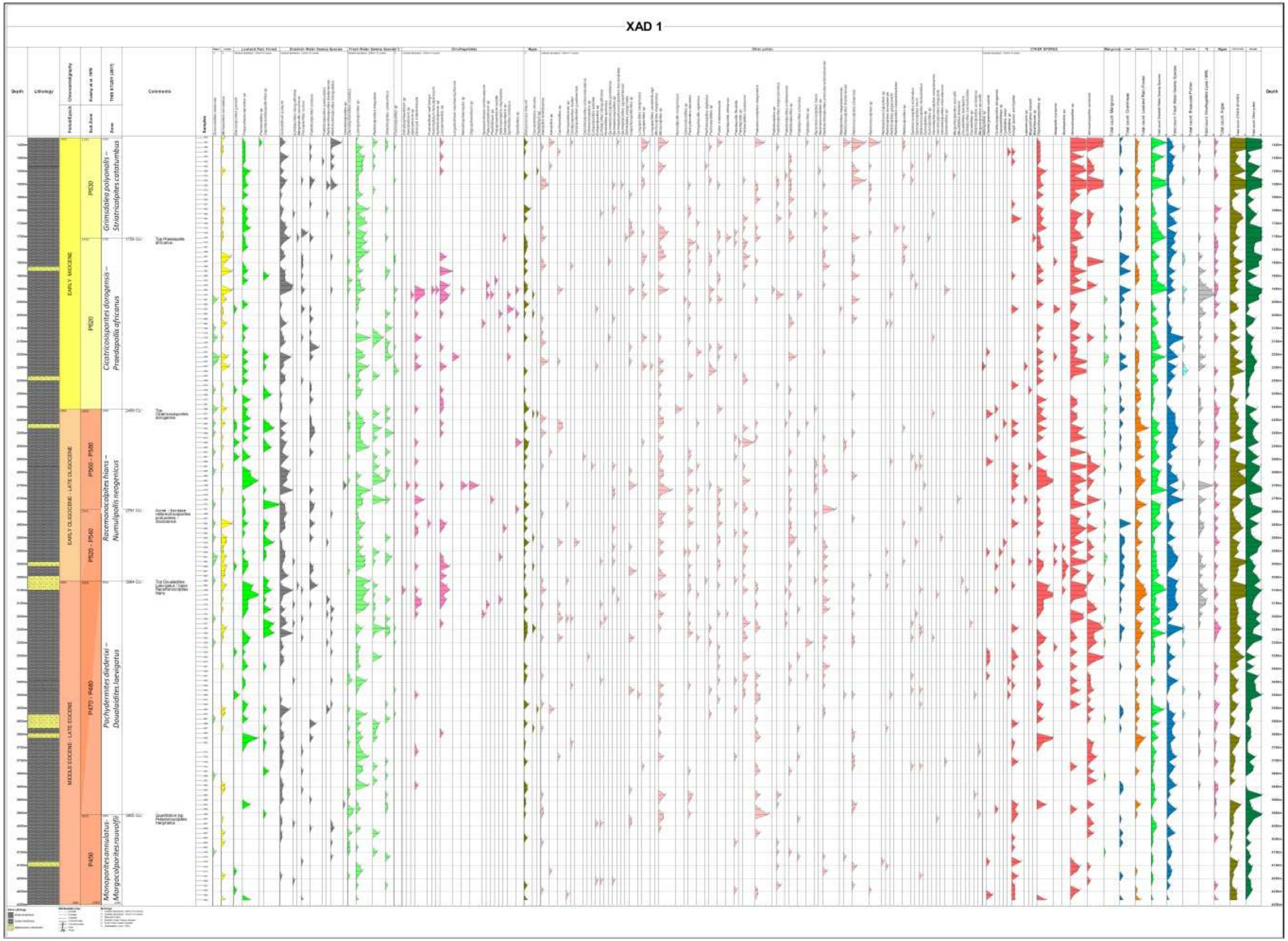

Fig. 2: Palynomorphs distribution chart of XAD-1 well

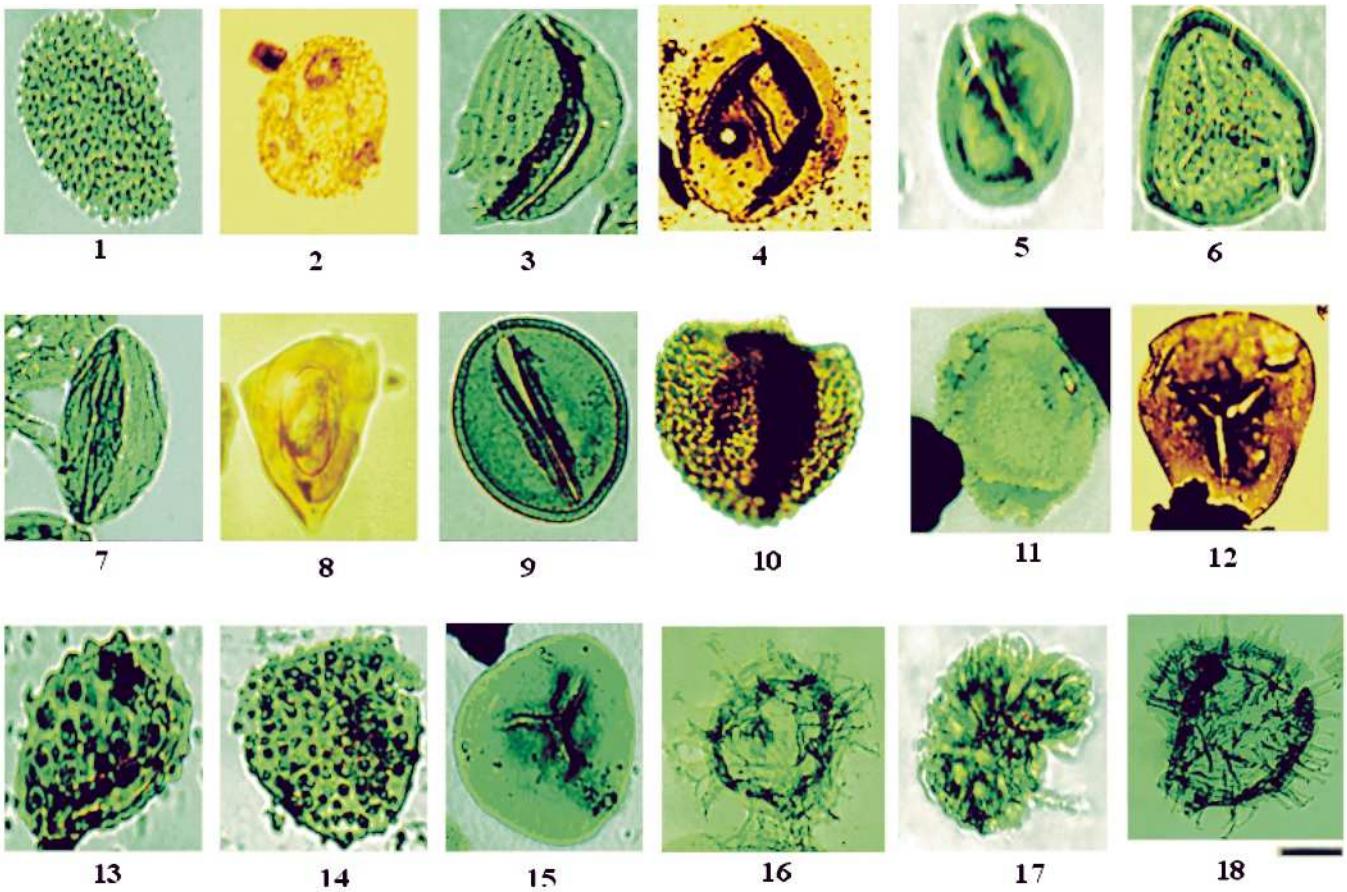

Fig. 3: Recovered palynomorphs form XAD-1 well: 1 *Racemonocolpites hians* Legoux, 1978, 2 *Retibrevitricolporites obodoensis,* Legoux, 1978 3 *Striamonocolpites rectostriatus* Legoux, 1978 4 *Monoporites annulatus Van Der Hammen 1954*, 5 *Zonocostites ramonae*, 6 *Polypodiaceoisporites* sp., 7 *Striatricolporites (Striatopollis) catatumbus,* 8 *Doualaidites laevigatus* , 9 *Psilamonocolpites marginatus,* 10 *Cicatricosisporites dorogensis* Potonie' and Gelletich,1933*, 11 Retibrevitricolporites obodoensis* Legoux, 1978, 12 *Acrostichum aureum* Oloto, 1994, *13 Verrucatosporites usmensis Germeraad et al. 1968, 14 Echitriporites trianguliformis* Van Hoeken-Klinkerberg 1964 15 *Acrostichum aureum,* Oloto, 1994, 16 *Spiniferites ramosus,* Mantell 1854 17 *Botryococcus braunii, Kutzing 1849* 18 *Polysphaeridium subtile* Deflandre and Cookson, 1955. Scale bar = 30μm

Pediastrum sp at a depth of 1500 m and also records the highest occurrence of *Verrucatosporites usmensis* at a depth of 1391 m.

Age: The zone is dated early Miocene (Burdigalian age, 21.5 – 16.3 Ma) (Table 1). The FDO of *Praedapolis africanus* is diagnostic of early Miocene (Palynological Consortium Biostratigraphic Sub-Committee, 2000). This zone is equivalent to P630 of Evamy et al. (1978).

Zone 2: *Cicatricosisporites dorogensis – Praedapollis africanus* Zone

Stratigraphic Interval: 1755 - 2409 m

Definition: The top is marked by the first downhole occurrence (FDO) of *Praedapollis africanus* while the base of the zone is defined by the first downhole occurrence (FDO) of *Cicatricosisporites dorogensis*. This zone is an interval range zone.

Characteristics: High abundant and diverse palynomorphs species were recovered within this zone which includes *Zonocostites ramonae, Laevigatosporites* sp, *Selenopemphix* sp, *Psilatricolporites crassus, Retimonocolporites obaensis, Leiosphaeridia* sp, *Verrucatosporites usmensis*. This abundant diversity at the upper part (1645 – 2573 m) may have been due to the availability of light, oxygen for photosynthesis of the taxa. This zone records the FDO of *Zonocostites ramonae* at depth of 1991 m. The only (first and last) occurrence of *Apteodinium* sp at a depth of 1973 m was recorded within this zone. This zone was characterized by FDO of *Cinctiperiporites mulleri*, suggestive of Miocene (Palynological Consortium Biostratigraphic Sub-Committee, 2000).

Age: Early Miocene (Aquitanian age, 23.3 – 21.5 Ma) is assigned to this zone. The FDO of *Cicatricosisporites dorogensis and Praedapollis africanus* are diagnostic of

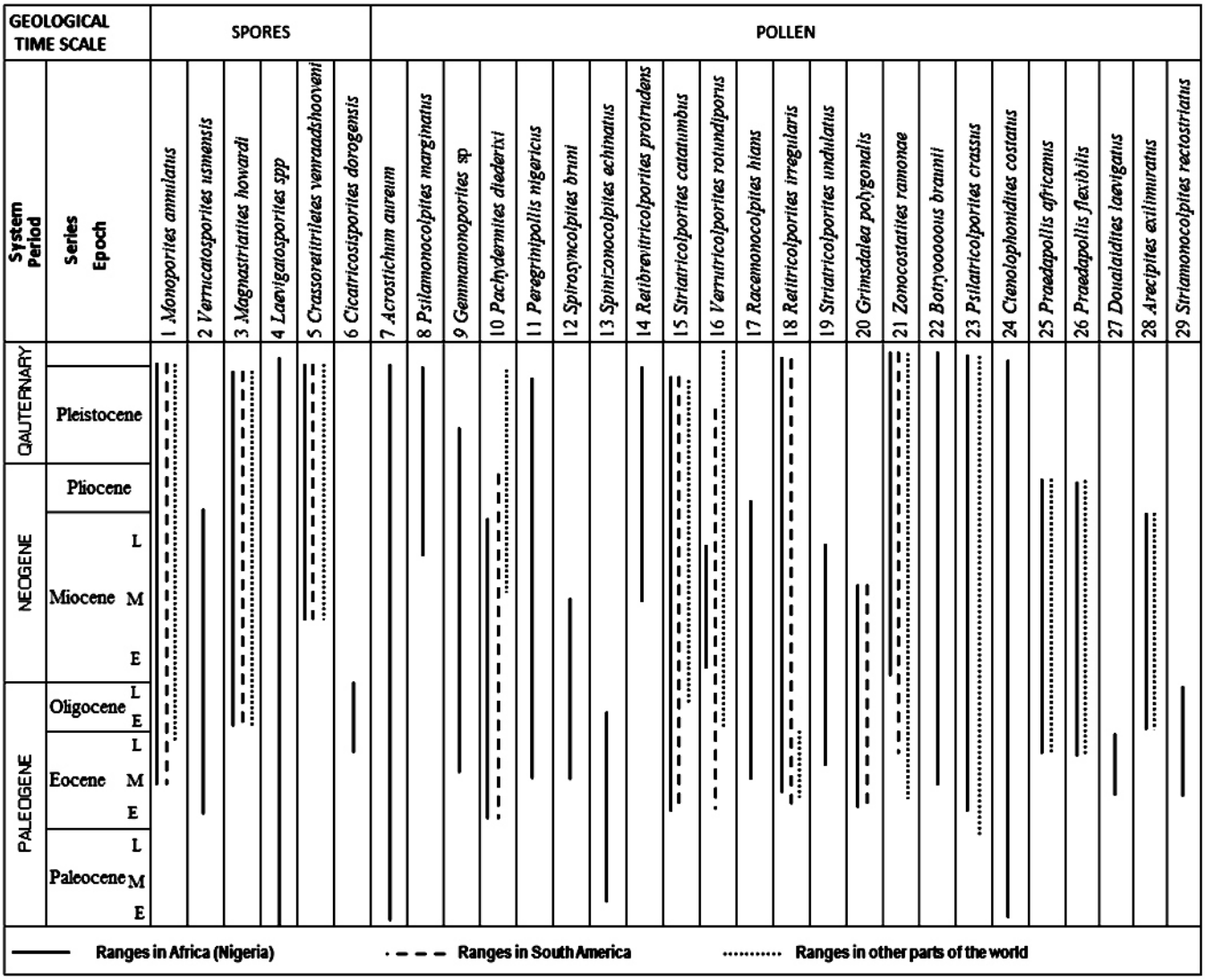

Fig. 4: Stratigraphic range of selected palynomorphs from the studied wells (Germeraad *et al*., 1968; Lawal, 1975; Legoux, 1978; Morley, 1997; Oloto, 1994 and Bankole *et al*., 2014).

Table 1: Established palynozones and age of the studied section of XAD-1 well

Period		Epoch		Age	Age (Ma)	Palynozones (This Study)	Depth (m)
Tertiary	Paleogene	Miocene	Early Miocene	Burdigalian	16.3	*Grimsdalea polyonalis – Striatricolpites catatumbus*	1373
			Early Miocene	Aquitanian	21.5	*Cicatricosisporites dorogensis – Praedapollis africanus*	1755
		Oligocene	Early – Late Oligocene	Rupelian - Chattian	23.3	*Racemonocolpites hians – Numulipollis neogenicus*	2409
		Eocene	Late Eocene	Priabonian	35.4	*Pachydermites diederixi – Doualaidites laevigatus*	3064
			Middle Eocene	Bartonian	38.6	*Monoporites annulatus – Margocolporites rauvolfii*	3955
					42.1		4300

early Miocene (Palynological Consortium Biostratigraphic Sub-Committee, 2000). This zone is equivalent to P620 of Evamy *et al.* (1978). *Praedapollis africanus* has been reported from the Upper Eocene to Lower Miocene of Cameroon and Nigeria and Oligocene/Miocene of Sudan (Mohammed et al., 2017).

Zone 3: *Racemonocolpites hians – Numulipollis neogenicus* Zone

Stratigraphic Interval: 2409 - 3064 m

Definition: The top is marked by the first downhole occurrence (FDO) of *Numulipollis neogenicus* while the base of the zone is defined by the last downhole occurrence (LDO) of *Racemonocolpites hians* and *Perfotricolpites digitatus*. This zone is an interval range zone.

Characteristics: It is characterized by increase abundance of *Spiniferites* sp. *Retibrevitricolporites protrudens/obodoensis*, *Psilatricolporite crassus*, *Pachydemites diederixi*. The lone occurrence of *Apectodinium* sp. and *Chenopodiaceae* sp. at a depth of 2700 m and 2773 m respectively was recorded within this zone.

Age: The zone is dated early Oligocene –late Oligocene (Rupelian – Chattian age, 35.4 – 23.3 Ma). Increased abundance of *Doualaidites laevigatus*, *Spiniferites* sp., *Retibrevitricolporites protrudens/obodoensis* and *Perfotricolpites digitatus* are diagnostic of Oligocene age. This zone is equivalent to P520 – P580 of Evamy *et al*. (1978). Legoux (1978) recorded abundant occurrence of *Perfotricolpites digitatus* from Oligocene strata of Nigeria.

Zone 4: *Pachydermites diederixi – Doualaidites laevigatus* Zone

Stratigraphic Interval: 3064 - 3955 m

Definition: The top of the interval is defined by the first downhole occurrence (FDO) of *Doualaidites laevigatus*, while the base is marked by the last downhole occurrence (LDO) of *Pachydermites diederixi.*

Characteristics: The zone is characterized by the LOD of *Retibrevitricolporites ibadanensis, Podocarpidites* sp., *Praedapollis africanus* and *Praedapollis flexibilis*. The base of this interval has the highest occurrence of *Psilamonocolpites marginatus*. *Psilatricolporites operculatus, Retibrevitricolporites ibadanensis* and *Retibrevitricolporites triangulates*.

Age: The zone is dated late Eocene (Praibonian age, 38.6 – 35.4 Ma). The LOD of *Retibrevitricolporites ibadanensis, Praedapollis africanus* and *Praedapollis flexibilis* are indications of late Eocene (Legoux, 1978).

Zone 5: *Monoporites annulatus – Margocolporites rauvolfii* Zone

Stratigraphic interval: 3955 - 4300 m

Definition: The top of the interval is defined by the last downhole occurrence (LDO) of *Margocolporites rauvolfii*, while the base is marked by the last downhole occurrence (LDO) of *Monoporites annulatus*.

Characteristics: The base of this zone has the highest occurrence of *Polypodiaceoisporites* sp. and the top of the interval has the highest occurrence of *Psilamonocolpites marginatus*. Other species that characterize this zone include *Polypodiaceoisporites* sp., *Verrucatosporites* sp. *Verrucatosporites usmensis, Sapotaceoidaepollenites* sp. *acrostichum aureum Brevicolporites guinetii, Polypodiaceoisporites* sp., *Ctenolphonidites costatus*, *Laevigatosporites* sp., *Retitricolporites irregularis* and *Striatricolpites catatumbus*.

Age: It is dated middle Eocene (Bartonian age, 42.1 – 38.6 Ma) because of the occurrence of *Psilatricolporites crassus*, *Cinctiperiporites mulleri, Ctenolphonidites costatus* and *Monoporites annulatus* which are indicators of Bartonian age in the Niger Delta Basin (Palynological Consortium Biostratigraphic Sub-Committee, 2000).

Paleobathymetric Interpretation

Paleobathymetry of XAD-1 well has been determined using the occurrences, co-occurrences and relative abundances of microfloral elements that are indicative of paleo-water depth. Marine indicators or dwellers such as dinoflagellates are ideal for paleobathymetric/paleoenvironmental interpretations (Stover and Williams, 1982). They tend to be most abundant in rocks deposited in middle neritic to upper bathyal environments and abundance decreases both landward and seaward. Dinoflagellates used in paleobathymetric interpretation include *Operculodium* sp, *Spiniferites* sp, *Selenopemphix* sp, *Nematosphaeropsis* sp, *Homotryblium* sp. Other

palynomorphs include pores, pollens, bissacate pollen and algae (Figure 5). Stover *et al.* (1996) gave ranges of marine environments in which some palynomorphs thrives. It is summarized in the table 2.

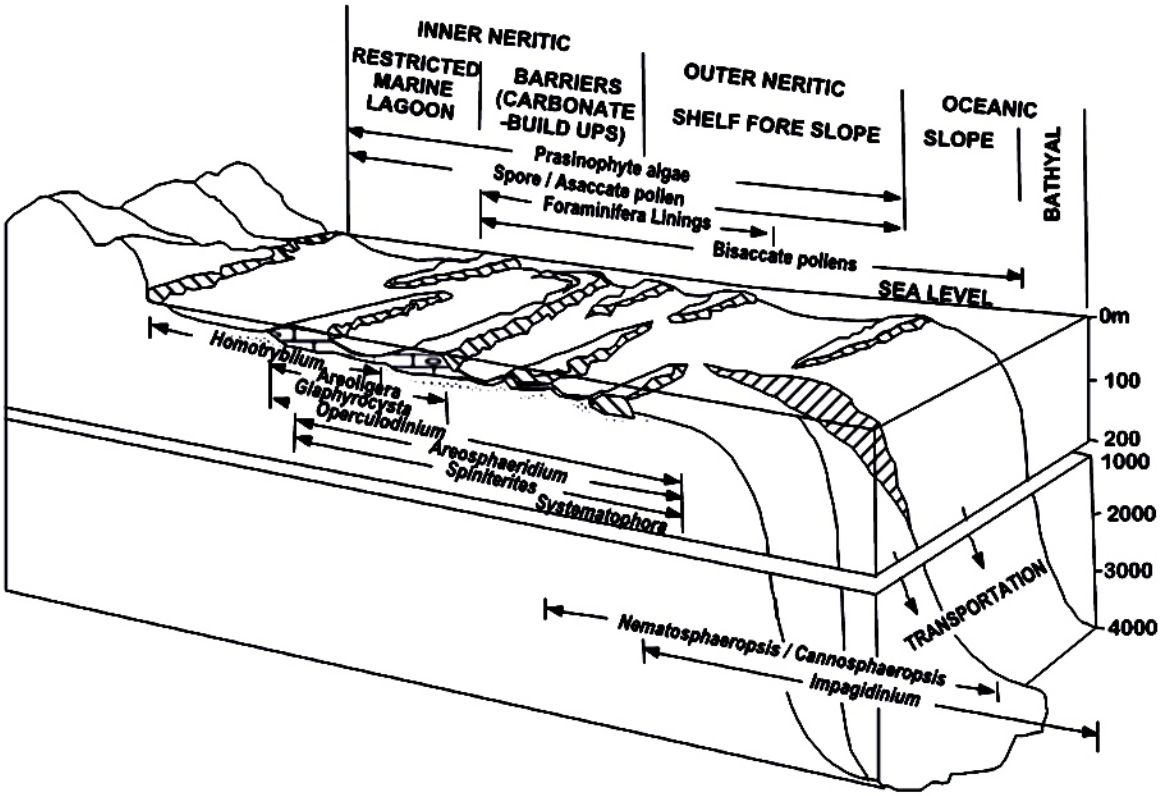

Fig. 5: Dinoflagellate cyst and other palynomorph distribution patterns for a continental shelf – slope, upper Eocene – lower Oligocene (Stover et al. 1996).

Table 2: Palynomorphs Distribution in Marine Environments

PALYNOMORPHS	MARINE ENVIRONMENTS
Algae (*Botryococus braunii, Concentricytes circus, Pediastrum* sp)	Inner neritic – outer neritic
Spores/Asaccate pollen (*Zonocostites ramonae, Praedapollis* sp, *Verrucatosporites*)	Inner neritic – outer neritic
Bisaccate pollen (*Podocarpidites* sp)	Inner neritic (Barriers) – slope
Dinoflagellate cysts	
Homotryblium	Estuarine to inner neritic (restricted marine – lagoonal)
Leisphaeridia; Nematosphaeropsis	Outer neritic – oceanic (slope)
Spiniferites; Operculodinium	Inner neritic – outer neritic

Relating the palynomorph distribution chart (Figure 2) to the table 2 and figure 4, the paleobathymetric interpretation of the studied section of XAD-1 well is inferred as follows:

Inner Neritic - Outer Neritic (40 – 200 m in marine environment)

The stratigraphic interval of 1373 – 3645 m is inferred to have been deposited in within inner neritic to outer neritic in the marine environment because of the occurrence of *Operculodium centrocarpum, Spiniferites* sp, *Spiniferites ramosus* (inner – outer neritic species), *Selenopemphix nephoide, Selenopemphix* sp., few records of *Homotryblium tenuispinosum, Lingulodinium machaerophorum* (inner neritic), *Polysphaeridium subtile apectodinium* sp. and *Adnatosphaeridium* sp. (Stover *et al.*1996). Head *et al.* (1989) considered *Operculodium* sp. to be outer neritic and species of *Selenopemphix* to be estuarine to inner neritic. From the recovered palynomorph chart (Figure 2), species of *Podocarpidites* (bisaccate pollen) occurs

at 1409 – 3573 m; *Spiniferites* and *Operculodium* sp. occur abundantly from 1954 – 3191 m within the studied section. Algae species such as *Botryococus braunii, Concentricytes circus a*nd *Pediastrum* sp. occurs abundantly within the interval. They are suggestive of inner – outer neritic (40 – 200 m in marine environment). However, there are occurrences of *Leisphaeridia* sp. and *Nematosphaeropsis* sp. (outer neritic – slope species) within the interval (Stover et al., 1996; Chekar et al 2018). Pollen and spores like *Zonocostites ramonae, Verrucatosporites usmensis, Monoporites annulatus, Polypodiaceoisporites* sp. and *Praedapollis* sp. occur abundantly right from the top to the bottom of the studied section. They are also suggestive of inner neritic – outer neritic.

Estuarine (Littoral) – Inner Neritic (0 – 40 m in marine environment)

The stratigraphic interval of 3645 – 4300 m is inferred to have been deposited within estuarine – inner neritic environment owing to non-recovery of dinocysts within the interval except the recovery of specimens of dinocysts indeterminate at 3645 m. Palynomorphs recoveries within this interval are pollen, spores and algae. Pollen and spores like *Zonocostites ramonae, Verrucatosporites usmensis, Monoporites annulatus, Polypodiaceoisporites* sp., *Praedapollis* sp. occurred abundantly right from the top to the bottom of the studied section. Algae species of *Botryococus braunii* occurs abundantly from the top to the bottom of the studied section. They are also suggestive of estuarine – inner neritic.

Conclusion and Recommendation

Palynological analysis of ditch cutting samples from XAD-1 well within the depth interval of 1373 - 4300 m yielded abundant dinoflagellate cysts algae, pollens and spores. These include species like *Praedapolis africanus, Cicatricosporites dorogensis, Monoporites annulatus, Margocolporites rauvolfii*, *Pachydermites diederixi, Doualaidites laevigatus*, *Racemonocolpites hians, Numulipollis neogenicus*, *Cicatricosisporites dorogensis, Praedapollis africanus*, *Grimsdalea polyonalis, Striatricolpites catatumbus Retibrevitricolporites protrudens/obodoensis*, *Zonocostatites ramonae* and *Verrucatosporites* sp. Middle Eocene to early Miocene age was assigned to the studied portion using the occurrences of age diagnostic marker species that occurred throughout the studied portion of the well. Five palynostratigraphic zones were established based on the stratigraphic range of palynormorphs present in the studied section. The biozones include *Monoporites annulatus – Margocolporites rauvolfii*, *Pachydermites diederixi – Doualaidites laevigatus*, *Racemonocolpites hians – Numulipollis neogenicus*, *Cicatricosisporites dorogensis – Praedapollis africanus* and *Grimsdalea polyonalis – Striatricolpites catatumbus* Zone. The established palynostratigraphic zones in this study are in line with the international stratigraphic guide and could contribute to the standardisation and harmonisation of biozonation scheme in the Niger Delta Basin. This will also be useful in correlation of middle Eocene to early Miocene stratigraphic succession. The paleobathymetric interpretation of the studied portion suggests a bathymetric range between estuarine to outer neritic. This is an indication that the depth of burial of deposited micro fauna and flora in the sediments was significant enough for hydrocarbon generation. Palynofacies and sedimentological studies are recommended for better understanding of the paleodepth penetratred by the well.

Acknowledgements

The authors are grateful to the Geological Survey Agency of Nigeria, Kaduna for the provision of the ditch cuttings used for this work. We are also grateful to the Crystal Age Limited, Lagos for providing the needed facilities necessary for the analysis.

References

Aizebeokhai a.P. and Olayinka, I. (2010). Structural and stratigraphic mapping of Emi field, offshore Niger Delta. *Journal of Geology and Mining Research*, 3, 25-38

Ajayi, E.O. and Okosun, E.A. (2014). Calcareous Nannofossil Biostratigraphy of A, B, C, D Wells, Offshore Niger Delta, Nigeria, 3. 108-123.

American Association of Petroleum Geologists Wiki, (2017). Paleobathymetry. Retrieved from http://www.wiki.aapg.org/Paleobathymetry.

Chekar, M., Slimani, H., Jbari, H., Guédé, K.E., Mahboub, I., Asebriy, L. and Aassoumi, H. (2018). Eocene to Oligocene dinoflagellate cysts from the Tattofte section, western External Rif, northwestern Morocco: Biostratigraphy, paleoenvironments and paleoclimate. *Palaeogeography, Palaeoclimatology, Palaeoecology* 507, 97–114.

Chukwu, J.N., Okosun, E.A. and Alkali, Y.B. (2012). Foraminiferal Biostratigraphy and Depositional Environment of Oloibiri-1 Well, Eastern Niger Delta, Nigeria. *Journal of Geography and Geology*, 4, 114-122.

Chukwuma-Orji, J.N., Okosun, E.A., Alkali, Y.B., Fadiya, L.S. and Taiwo, O.M. (2017). Palynofacies Analysis of Ida 5 -well, Niger Delta Basin, Nigeria *Nigeria Journal of Engineering and Applied Sciences (NJEAS)* 4, 95 - 112

Chukwuma-Orji, J.N., Okosun, E.A. and Gana F.D. (2019). Palynofacies analysis of Ida-4 well, Niger Delta Basin, Nigeria. Geology, Geophysics and Environment, 45, 219 – 230.

Corredor, F., Shaw, J.H. and Billoti, F. (2005). Structural styles in the deep-water fold and thrust belts of the Niger Delta: *American Association of Petroleum Geologists Bulletin*, 89, 753– 780.

Bankole, S.I. (2010). Palynology and stratigraphy of three deep wells in the Neogene Agbada Formation, Niger Delta, Nigeria. Implications for petroleum exploration and paleoecology, PhD thesis, der Technischen Universität Berlin, 1-190.

Bankole, S.I., Schrank, E. and Osterloff, P.L. (2014). Palynostratigraphy, palaeoclimates and palaeodepositional environments of the Miocene aged Agbada Formation in the Niger Delta, Nigeria. *Journal of African Earth Sciences*, 95, 41–62.

Doust, H. and Omatsola, E. (1990). Niger Delta divergent/passive margin basins *american Association of Petroleum Geologists Memoir*, 48, 201-238.

Durugbo, E.U. and Uzodimma, E. (2013). Effects of lithology on palynomorph abundance in wells X1 and X2 from the Western Niger Delta, Nigeria. *International Journal of Geology, Earth and Environmental Sciences,* 3, 170 – 179.

Evamy, B.P., Haremboure, J., Kamerling, P., Knaap, W.A., Molly, F.A. and Rowlands, P.H. (1978). Hydrocarbon habitat of Tertiary Niger Delta. American association of Petroleum Geologists bulletin, U.S.A 62: 1-39.

Germeraad, J.J., Hopping, G.A. and Muller, J. (1968). Palynology of Tertiary sediments from tropical areas. *Review of Paleobotany and Palynology,* 6, 189-348. doi: 10.1016/0034-6667(68)90051-1

Lawal, J. (1975). A review of microfloral zonation in the Tertiary of Nigeria. Unpublished, 2 – 21.

Legoux, O. (1978). Quelques espéeces de pollen caractéristiques du Néogène du Nigéria. Bullletin des Centres de Recherche Exploration-Production ElfAquitaine 2: 265-317.

Hallsworth, C.R. and Knox, R.W. O'B. (1999). British Geological Survey rock classification scheme. Volume 3 classification of sediments and sedimentary rocks. British Geological Survey Research Report, 99-03.

Head, M.J., Norris, G. and Mudie, P.J. (1989). Palynology and Dinocyst Stratigraphy of the Upper Miocene and Lowermost Pliocene, ODP Leg 105, Site 646, Labrador Sea, in Srivastava, S. P. arthur, M. and Clement, B., Ocean Drilling Program, Proceedings, Scientific Results, 105: 423-451, pl. 1-7.

Mohammed, Z., Awad, M.Z. and Eisawi, A. (2017). Upper Cretaceous to Neogene Palynology of the Rawat Basin, White Nile State, Sudan, *Journal of Earth Science and Climatic Change*, 8:397, DOI: 10.4172/2157-7617.1000397

Morley, R.J. (1997). Offshore Niger Delta palynological zonation, prepared for the Niger Delta Stratigraphic Commission, *Palynova*, 1, 1 – 6.

Muraat, R.C. (1972).Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiaiy of Southern Nigeria. In: T. F. J. Dassauvagie and Whiteman (Eds) African Geology, IbadanUniversity Press, Nigeria.251-266.

Ola, P.S. and Adewale, B.K. (2014) Palynostratigraphy and Paleoclimate of the Sequences Penetrated by Meren 31 Side Tract-2 Well, Offshore Niger Delta. *International Journal of Geosciences,* 5, 1206-1218.

Olajide, F.A., Akpo, E.O. and Adeyinka, O.A. (2012). Palynology of Bog-1 Well, Southeastern Niger Delta Basin, Nigeria. *International Journal of Science and Technology*, 2, 214 - 222.

Oloto, I.N. (1994). Nigerian Maastrichtian to Miocene dinoflagellate and miospore biozones – A summary, *Journal of Mining and Geology*, 30, 61 – 73.

Oloto, I.N. (2014). Palynological Study of Igbomotoru - 1 Well, Central Coastal Niger Delta, Nigeria. *International Journal of Scientific and Technology Research*, 3, 287-292.

Opara, A.I. (2010). Prospectivity evaluation of "Usso" Field, Onshore Niger Delta Basin, using 3-D seismic and well log data: *Petroleum and Coal*, 52, 307-315.

Opara, A.I., Anyiam, U.O. and Nduka, V. (2011). 3-D seismic interpretation and structural analysis of Ossu oil field, Northern depobelt, onshore Niger delta, Nigeria: *Pacific Journal of Science and Technology*, 12, 502-509.

Palynological Consortium Biostratigraphic Sub-Committee (2000). Palynological distribution chart of the Niger Delta, Unpublished report.

Reijers, T.J.A., Petters, S.W. and Nwajide, C.S. (1996). The Niger Delta basin, sedimentary geology and sequence stratigraphy. In T.J.A. Reijers (*Ed.*), *Selected chapters on geology* (pp. 100 - 117). Warri: SPDC Corporate Reprographic Services.

Stover, L.E. and Williams, G.L. (1982). Dinoflagellates, Third North American Paleontological Convection, Proceedings, 2: pp. 525-533

Stover, L.E., Brinkhuis, H., Damassa, S.P., De Verteuil, L., Herby, R.J., Monteil, E., Partridge, A.D., Powell, A.J., Riding, J.B., Smelror, M. and Williams, G.L. (1996). Mesozoic-Tertiary Dinoflagellates acritarchs and Prasinophytes in Jannsonius, J. and McGregor. D. C. (ed.), Palinology: Principles and Applications: American Association Stratigraphic Palynologists Foundationn, 2, 641-750.

Wu, S. and Bally A.W. (2000). Slope tectonics—Comparisons and contrasts of structural styles of salt and shale tectonics of the northern Gulf of Mexico with shale tectonics of offshore Nigeria in Gulf of Guinea p.151– 172.