

Palyno-Stratigraphy and Kerogen Assessment of OMA Well Sediments, Offshore Dahomey Basin, Southwestern Nigeria

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Abstract

Biostratigraphy has remained a tool for basin and environmental reconstruction in sedimentology. This study aims to further delineate and classify the lithology, environment of deposition, and the biozonation of microorganisms found in the studied well. Thirty-four (34) ditch cutting samples from OMA well, offshore Dahomey Basin, were considered for their textural and palynomorphs/palynofacies characterization. The samples were observed and processed according to the standard palynological procedure for geologic samples using hydrochloric and hydrofluoric acid digestion. The stratigraphic sequence of the well ranges from shale to sandstone to argillaceous sandstone. The shales appear highly fissile and laminated in all shades of grey and black while the sandstone colour ranges from light-grey/brown to brown and very deep brown. The sandstone contains some mica flakes and likely pyrites in fine-medium, sub-angular to rounded grains. A total of 28 diverse palynomorphs were reported from the palynological analysis with low abundance. The low recovery of pollens was likely due to limited terrestrial influence and the reasonable amount of dinoflagellate cysts and microforaminifera wall present indicated a marginal marine to a distal offshore environment. Two zones correlated for this study are *Danea mutabilis* (Early Paleocene) and *Dinogymnium euclaense* (Upper Maastrichtian) zones. Palynomaceral classifications through visual, microscopic kerogen assessment resulted in high preservation of organic matter which suggests a reducing environment of deposition. The dominances of 48% amorphous (I), and 36% exinite (II), with a considerable amount of the 5% vitrinite (III), and 11% inertinite (IV) kerogen types, indicate that the organic matter is mainly sapropelic and mixed humic-sapropelic types which are favorable for hydrocarbon generation and pri-

marily of marine origin. The spores/pollen colour ranges from light yellow/brown, brown transitioning into darker brown on a scale of 4/5 transitioning to 5/6. Medium degree of maturation (4/5) to late degree (6/7) of maturation was inferred. The studied interval of the OMA well sediments agrees with the established stratigraphic interval of the offshore, Dahomey basin, within the Upper Maastrichtian to Late Paleocene age range and supports high preservation of organic matter sufficient and mature enough to generate hydrocarbon.

Keywords

Palynomorphs, Kerogen, Depositional Environment, Spore Coloration Index

1. Introduction

The detailed study of the Dahomey Basin has increased in recent times due to the availability of more offshore data and its exploration opportunities. The potentials of the Dahomey Basin are next in exploitation to the prolific Niger delta basin which has remained a huge source of revenue for the Nigerian economy. Hence, the update and further understanding of these new data are essential for the basin stratigraphy, potentials, and other geological interpretations.

Biostratigraphy is one of the successful tools for environmental reconstruction, chronology, and age correlation in which Palynology, the study of pollens and spores, dinoflagellates, etc., is quite significant as discussed in the works of [Batten \(1982, 1996\)](#). Palynomorphs are plant and animal structures that are highly resistant to decay and acid treatments and as such are well preserved as microfossils suitable for environmental studies. Also, visual kerogen assessment has been a measuring tool for thermal alteration, maturation, and spore coloration deductions for source rock potential. Palynomacerals and assigned kerogen types are indicators of the source of organic matter.

Several studies on biostratigraphy in the Dahomey basin have been well reported through many centuries by various authors ([Adegoke, 1969](#); [Fayose, 1970](#); [Billman, 1976](#); [Omatsola & Adegoke, 1981](#); [Okosun, 1990](#); [Salami, 1987](#); [Jan du Chene, 1998](#); [Adeigbe et al., 2013](#); [Adeigbe & Amodu, 2015](#)). Recently, [Asadu and Nkem \(2020\)](#) assessed the palynological content of Well Z in the OPL 310 block in the offshore Dahomey basin. They reported the studied interval (1620 ft - 3500 ft) to be late Eocene to late Miocene in age and were mainly basal sandstone with intercalation of shale (Oshosun), which is overlain by shale (non-fissile) intercalating with Afowo sandstone. The well as a reference to the works of [Brownfield and Charpentier \(2006\)](#), penetrated the Oshosun and Afowo formations. There are still many nomenclature problems as the dating of younger sediments in the offshore part of the basin with the same name as the older sediments in the onshore part of the basin might not be stratigraphically appropriate. The objectives of this study include lithology classification, recovery, and identification of palynomorphs, application of the palynomorphs in understand-

ing the deposition environment and period of the deposition as well as the kerogen assessment, typing, and coloration deduced from them for possible hydrocarbon indication.

2. Geologic Setting

The Gulf of Guinea province harbors several basins that formed as a result of the tectonic activities that separated the African and South American continental plates including the opening of the South Atlantic Ocean (**Figure 1**). This started during the late Jurassic era and several geologic events such as rifting and uplifts have evolved into the now basin stratigraphic systems. The tectonic events resulted in the formation and categorisation of sediments before, during, and after the rifting. The Dahomey basin spans four countries and the eastern part of the basin is located in southwestern Nigeria (**Figure 2**).

Many authors ([Billman, 1976](#); [Petters, 1982](#); [Omatsola & Adegoke 1981](#); [Elvsborg & Dalode, 1985](#); [Okosun, 1990](#)) have attempted to classify the stratigraphy but several issues of nomenclature still occur even as the offshore part of the basin is unraveled. According to [Billman \(1992\)](#), the Dahomey Basin stratigraphy can be subdivided into three chronological units; pre-lower Cretaceous folded sediments, Cretaceous sediments, and Tertiary sediments. The Cretaceous sediments are the Abeokuta group comprising the Ise, Afowo, and Araromi formations. The Tertiary sediments consist of Ewekoro, Akinbo, Oshosun, Ilaro, and Benin (coastal plain sand) formations. [Brownfield and Charpentier \(2006\)](#) subdivided the offshore lithostratigraphy into 18 geological units from the Jurassic to the present and they comprise mainly shale, silt, and sandstone

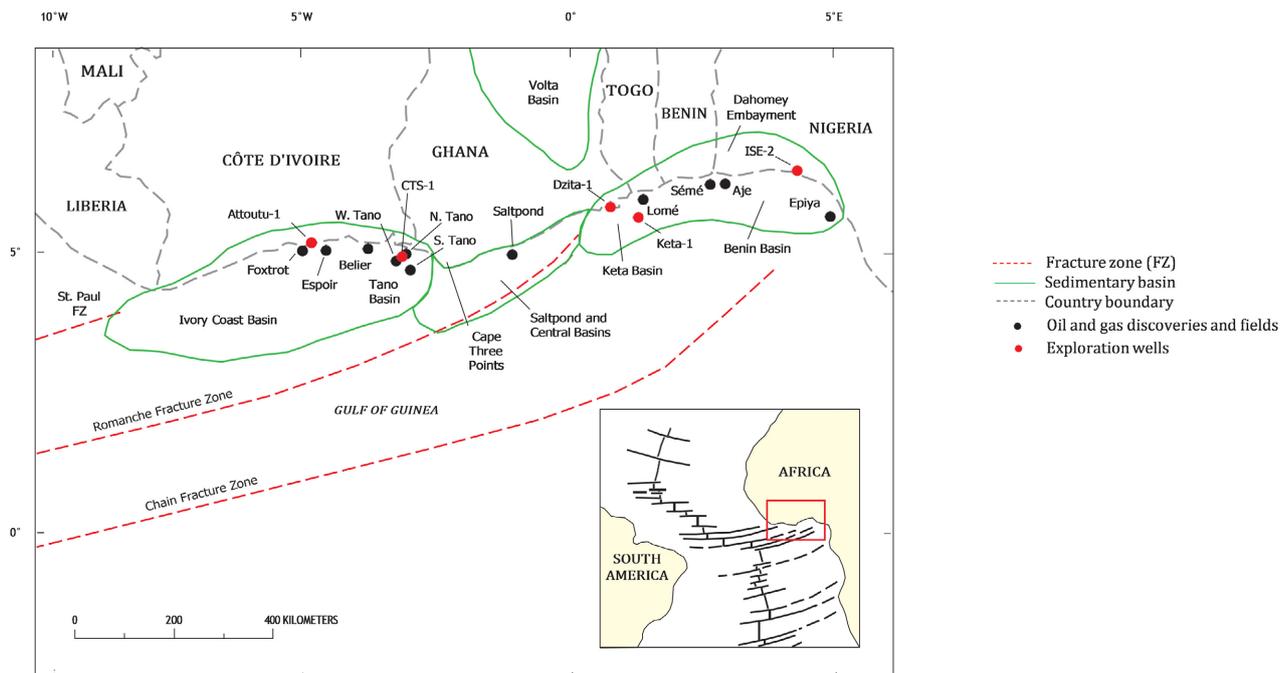


Figure 1. The gulf of Guinea province showing associated upper sedimentary basins ([Brownfield & Charpentier, 2006](#)).

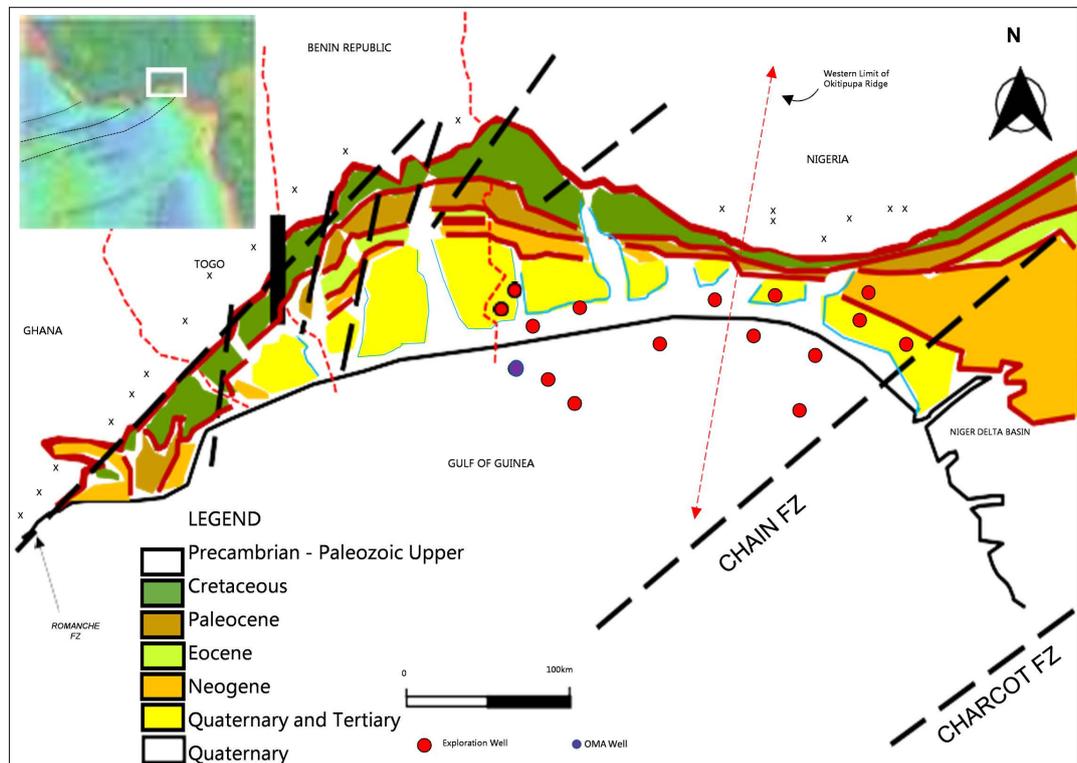


Figure 2. Geology of eastern Dahomey Basin (modified after Billman, 1992).

and he identified three unconformities within the offshore basin packages (**Figure 3**).

3. Methodology

3.1. Lithology

The lithological sequence of the well was established by feeling the samples and the textural characteristics such as shape, size, colour, laminations, etc. were noted. The hand lens was also used to further identify these parameters. The sample interval ranges from 2850 ft (868 m) to 6180 ft (1865 m), approximating a 1000 m interval.

3.2. Palynology

Careful palynological preparations and analyses were carried out for thirty-four (34) ditch cutting samples. The samples were well sorted for depth correlation and labeling. Standard laboratory procedures were followed to digest the samples and remove silicates and carbonates with the use of hydrofluoric acid and dilute hydrochloric acid respectively. The residue was bleached using nitric acid and washed with distilled water. The residue was then sieved through a 5 μ m sieve. Labeled coverslips were mounted on the hot plate for drying after pipetting each sample residue on them. The slides were attached using Norland adhesive and were mounted on the Olympus CX41 binocular microscope for observation and identification of the palynomorphs.

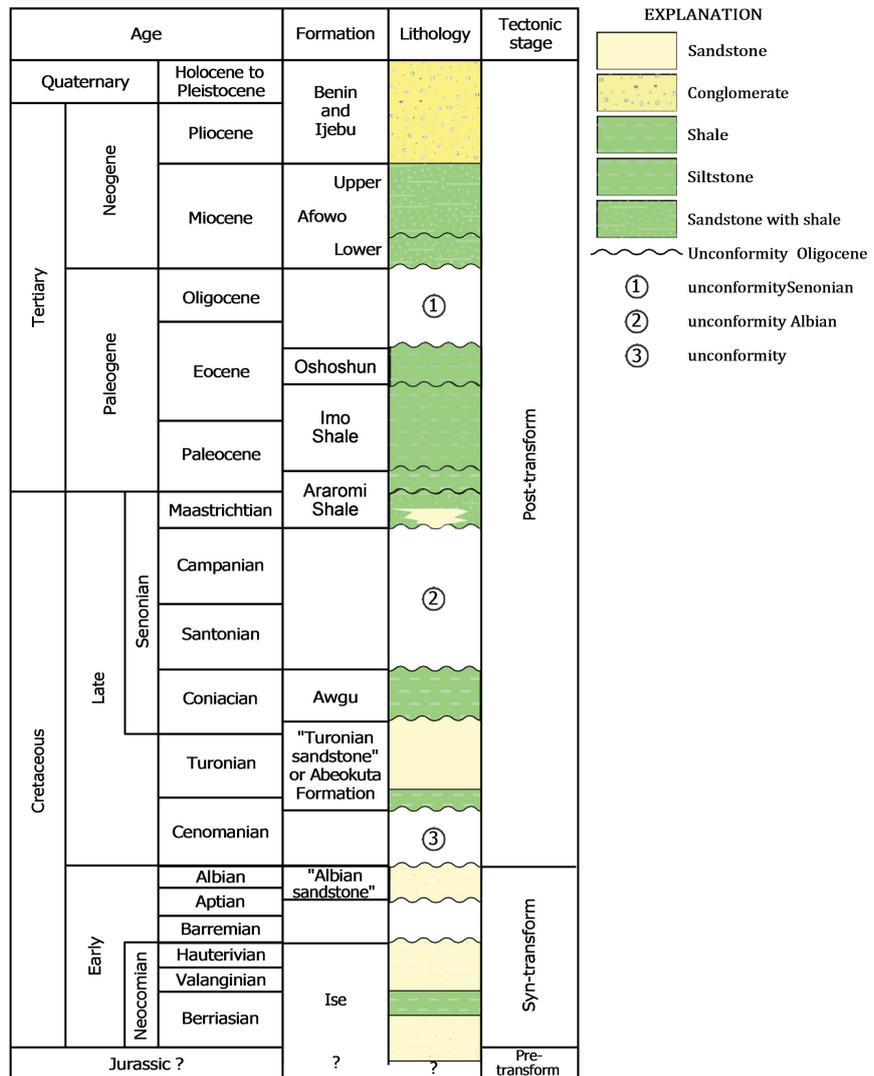


Figure 3. Stratigraphy of the offshore Dahomey Basin showing three unconformities (after Brownfield & Charpentier, 2006).

3.3. Kerogen Analysis

Kerogen, the insoluble part of the organic matter is left after the minerals and silicates contained in the samples have been dissolved with acids. This serves as a qualitative and quantitative method for organic petrology (Tyson, 1993). The kerogen and colour alterations were considered for some of the samples and no oxidant was added for proper preservation of the organic matter. 20 µm was used in sieving after preparation and dried on the coverslips, covered with slides which were then mounted on the microscope for the palynomaceral identification.

4. Results and Discussions

4.1. Lithology Description

The representative samples of the OMA well were sampled at 30 ft intervals

each. The total sampled depth ranges from 2850 ft to 6180 ft, with approximately 3330 ft depth interval. The stratigraphic column of the sampled interval consists of mainly shale, shale with intercalation of sandstone, sandstone, and argillaceous sandstone/silt (Figure 4). The sample sizes were fined-medium grained. The shales exhibited different shades of grey and black. The shales were highly laminated, fissile, and sheety in texture. The sandstone colour ranges from light grey to light brown, brown, and very deep brown. The shapes were sub-angular to rounded and few microfossils were observed including minerals such as mica flakes and pyrites. The depths perceived to be rich in organic matter have deeper grey/black colour of shale.

4.2. Palynomorphs Distribution

The samples are moderately preserved with few records of pollens, spores, and dinoflagellate cysts. A total of 28 diverse palynomorph species were recovered with low abundance (Figure 5 and Figure 6). The palynomorphs recorded include *Monocolpites marginatus*, *Longapertites marginatus*, *Longapertites* sp.,

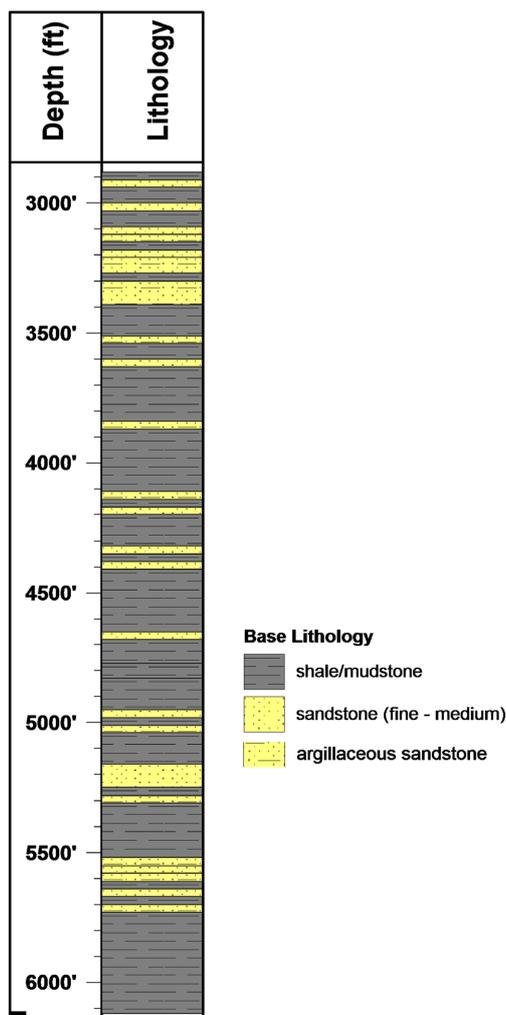


Figure 4. Litholog of OMA well.

Retimonocolpites obaensis, *Retimonocolpites* sp., *Monoporites annulatus*, *Milfordia* sp., *Foveotriletes margaritae*, *Ephedripites ambiguus*, *Ephedripites* sp., *Cingulatisporites ornatus*, *Distaverrusporites simplex*, *Cyathidites minor*, *Cyathides* sp., *Laevigatosporites* sp., and *Verrucatosporites* sp. Few dinoflagellate cysts including *Cleistorphaeridium* sp., *Senegalinium* sp., *Subtilisphaera* sp., *Dinogymnium* sp., *Selenopemphix* sp., and *Palaeocystodinium* sp.

The marine indicator, microforaminifera wall lining, was also recovered in appreciable quantities. The above assemblages are suggestive of a marine environment of deposition. The low records of pollens suggest limited plant microfossils and terrestrial influence and hence, the assemblages tend towards marine species.

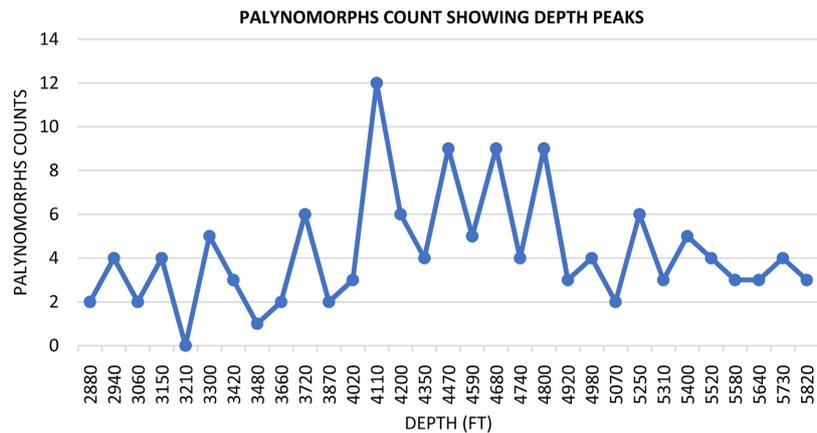


Figure 5. Palynomorphs counts from OMA sediments.

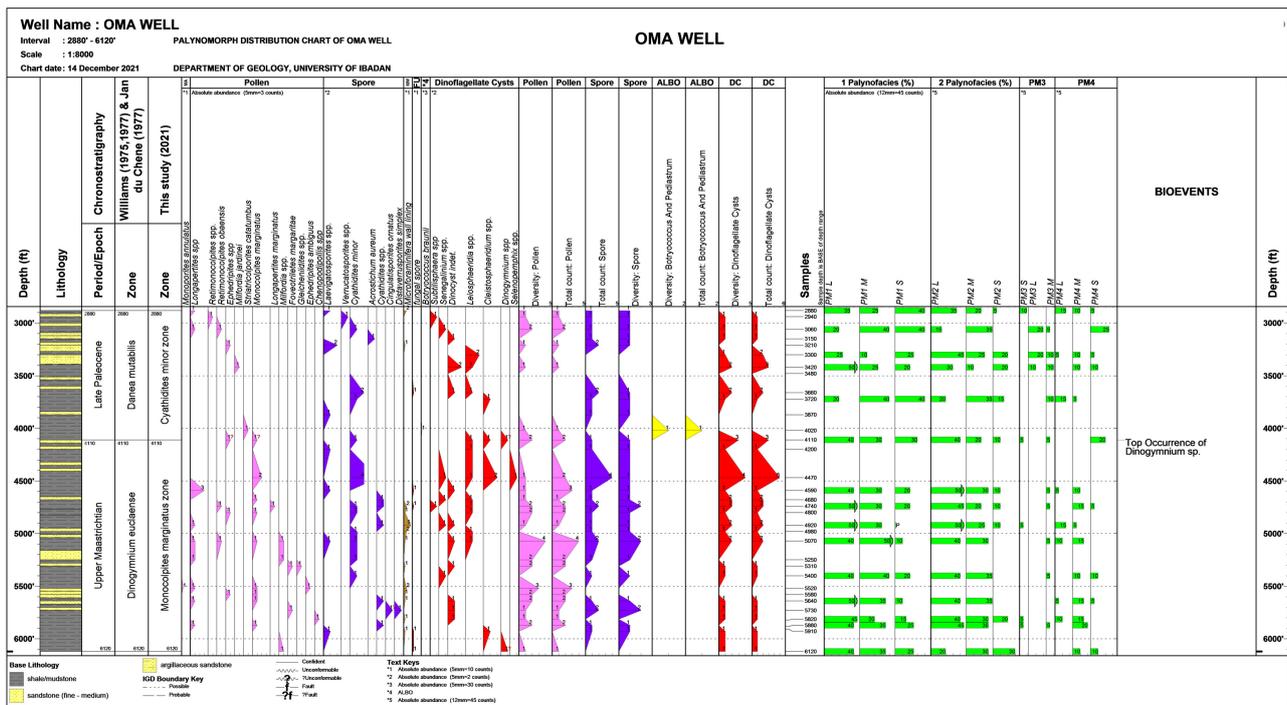


Figure 6. Palynomorph and palynofacies chart of OMA well.

4.2.1. Zonation/Age Dating

The thirty-four (34) samples of the OMA well fall within two palynological zones of Williams (1975), Williams and Bujak (1977a, 1977b) and Jan du Chene et al. (1978). The first younger zone is *Danea mutabilis* zone while the next (older) zone is *Dinogymnium euclaense* zone. The boundary between the first and the second zone at 4110 meters was delineated by the top occurrence of a *Dinogymnium* sp. The presence of *Monocolpites marginatus*, *Longapertites marginatus*, *Longapertites* sp., *Foveotriletes margaritae*, *Cingulatisporites simplex*, *Milfordia* sp., and *Cyathidites minor* characterizes these two zones. The age of the first and second zones is dated Early Paleocene – Upper Maastrichtian respectively. This study established the biomarkers; *Cyathidites minor* (late paleocene) as Zone I and the *Monocolpites marginatus* (Upper Maastrichtian) as Zone II. Details of the zones recognized are discussed in Table 1.

4.2.2. Environment of Deposition

The moderate records of pollen and spores including *Monocolpites marginatus*, *Longapertites marginatus*, *Longaoertites* sp., *Retimonocolpites obaensis*, *Foveotriletes margaritae*, *Cingulatisporites ornatus*, *Laevigatosporites* sp., with few dinoflagellate cysts show that the selected sediments of OMA well samples were deposited within the marine environment.

The marine indicator, microforaminiferal wall linings was also recorded in an appreciable amount which supports the marine nature of the sediments (Figure 7). According to El Diasty et al. (2014), the rare/low quantity of pollens recovered suggests a distal offshore environment. Some of the dinoflagellate cysts recovered include *Cleistophaeridium* sp., *Senegalinium* sp., *Subtilisphaera* sp., *Selenopemphix* sp., and *Palaeocystodinium* sp.

Table 1. Palynological zones recognized within OMA well.

Depth (ft)/Lithology	Series	Sub series	Williams (1975); Williams & Bujak (1977a, 1977b); Jan du Chene et al. (1978)	This Study (2021)	Bio Events
3000'	Paleocene	Late paleocene	<i>Danea mutabilis</i> zone	Cyathidites minor zone i	
3500'					
4000'	Maastrichtian	Upper maastrichtian	<i>Dinogymnium euclaense</i> zone	<i>Monocolpites marginatus</i> zone ii	
4500'					
5000'					
5500'					
6000'					

 Top occurrence of *Dinogymnium*

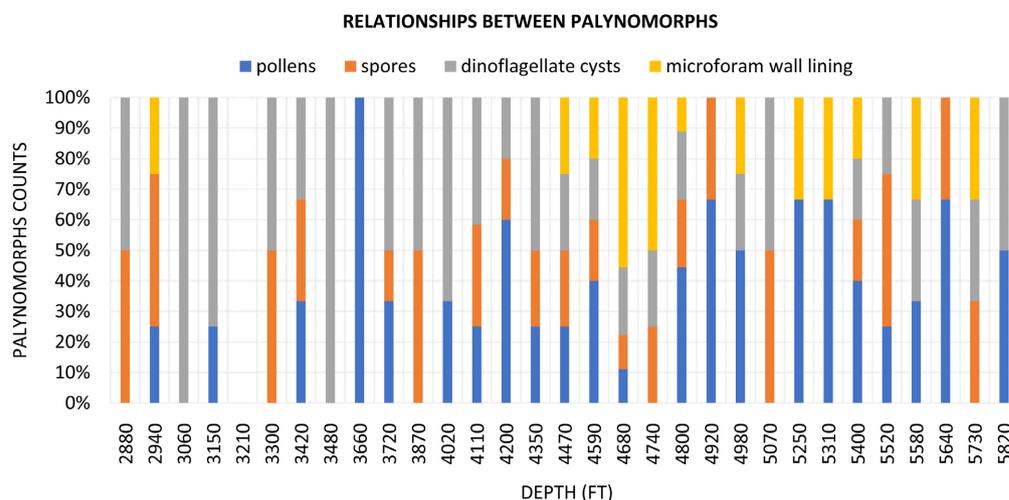


Figure 7. Percentage relationship between the palynomorphs.

4.3. Kerogen Analysis

Palynological materials in the sampled depth contain palynodebrics and Amorphous Organic Matter (AOM). As shown in **Table 2**, large to medium-sized PalynoMaceral (PM) types I&II dominate the recoveries of the organic matter. Moderate records of small to medium-sized palynomaceral types III & IV were also noted. This indicates that the selected sediments of OMA well samples are dominated by the large-medium sized Amorphous cortex, structureless material (PMI), and the platy-like structured plant material (PMII) which are marine in origin (**Plate 1**). Moderate quantities of medium-small-sized stomata-bearing aqueous plant materials (PMIII) and black lath/needle-shaped plant material (PMIV) were also recorded within the studied section.

The dominance of 48% amorphous (I), and 36% exinite (II), with a considerable amount of the 5% vitrinite (III), and 11% inertinite (IV) kerogen types, indicate that the organic matter is mainly sapropelic and mixed humic-sapropelic types (**Figure 8**). The above occurrence indicates a marine environment of deposition (Tissot & Welte, 1978) with mixed kerogen types and affirms a favorable hydrocarbon generation potential for the selected samples of OMA well. Also, the high level of organic matter preservation suggests a reducing environment during deposition (Tyson, 1993).

Thermal Maturation of Pollen and Spores

Spore Coloration Index (1 - 10): The macerals exhibit yellow, orange-brown to pale-dark brown colour under the transmitted light and show a medium level of degradation. The spore colour (**Table 3**) ranges from light brown to brown transitioning into darker brown/black. The spore coloration scale as deduced from the palynomorphs colour is 4/5 transitioning to 7/8, equivalent to the Thermal Alteration Index (TAI) of 2 to 3+ and vitrinite reflectance (% R_0) greater than 0.5. The degree of thermal maturation is inferred to be a medium degree of maturation (4/5) to a late degree (5/6) of maturation.

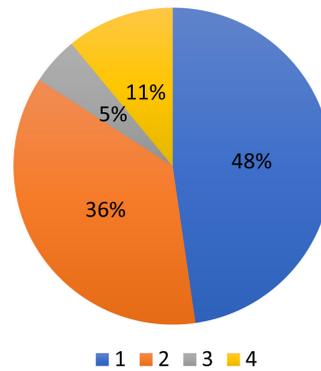


Figure 8. Percentage distribution of the kerogen types (1 - 4) within OMA well sediments.

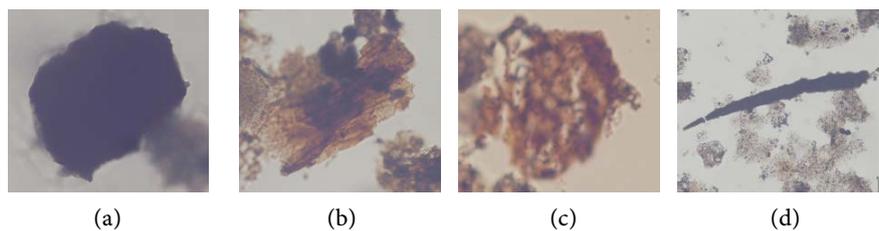


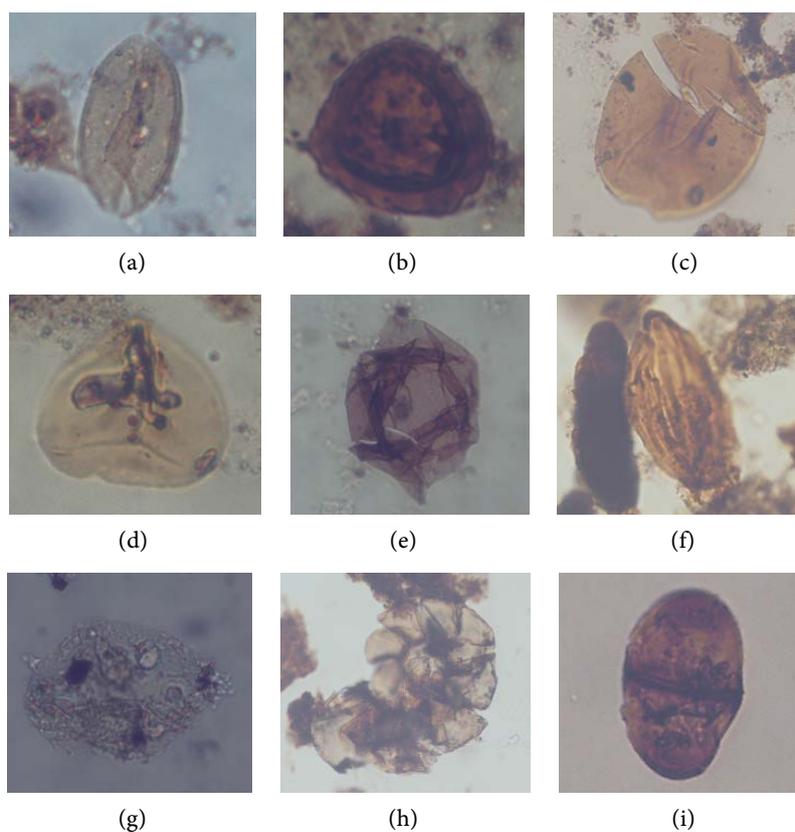
Plate 1. Large Palynomacerals (PM), kerogen types (I, II, III & IV). 20× magnification. (a) PM I; (b) PM II; (c) PM III; (d) PM IV.

Table 2. Statistical representation of the different types of Palynomacerals (PM) abundance. S-small, M-medium, L-large.

DEPTH (FT)	PM1			PM2			PM3			PM4		
	S	M	L	S	M	L	S	M	L	S	M	L
2880	40	25	35	5	20	7	10			5	10	15
3060	40	40	20		35	15		5	20	25		
3300	25	10	25	20	25	45		10	20	5	10	5
3420	20	30	50	20	10	30		10	10	10	10	
3720	40	40	20	15	35	20		10			5	15
4110	30	30	40	10	20	40	5	5		20		
4590	20	30	40	10	30	50		5			10	5
4740	20	30	50	10	20	45		5		5	15	
4920	10	30	50	10	25	50	5				5	15
5400	20	40	40		35	40		5		10	10	
5640	10	35	50		35	40				5	15	5
5070	10	50	40		30	40		5			15	10
5820	15	20	45	20	30	40	5				15	10
5880	25	35	40		30	40	5	5			20	
6120	25	35	40	30	30	20				10	10	
	350	480	585	150	410	522	30	65	50	95	150	80

Table 3. Spore Colour index with correlation with other scales (Waples, 1985).

Organic Thermal Maturity	Spores/pollen coloration	Palynomorphs in OMA well	Thermal Alteration Index (TAI)	Vitrinite Reflectance (% R ₀)
Immature			1	0.2%
			1+	0.3%
			2-	
Mature phase; onset generation of oil			2	0.5%
			2+	
			3-	0.9%
			3	
			3+	
Dry gas to Barren		 	4-	1.3%
			4	2.0%
			5	2.5%
	Deformed			

**Plate 2.** Few Pictural Representations of Palynomorphs Recovered (40× magnification). (a) *Retimonocolpites obaensis*; (b) *Cingulatisporites ornatus*; (c) *Monocolpites marginatus*; (d) *Cyathidites minor*; (e) *Subtilisphaera* sp.; (f) *Ephedripites* sp.; (g) *Dinogymnium* sp.; (h) Microforaminiferal wall lining; (i) Fungal spore.

5. Conclusion

The OMA well sediments appear to be deposited in a quiet, reducing environment as seen with the fissile nature of the shale, the averagely well-sorted and sub-angular to rounded grain sizes of the sandstone, and the abundance preservation of organic matter observed. Two zones were established for this study and assigned the Late Maastrichtian to late Paleocene age based on palynomorphs recovered as shown in **Plate 2**. The recorded low pollen and spores and a significant amount of the dinoflagellate cysts and microforaminifera lining indicated a marine setting of deposition. The palynofacies were counted and categorized based on visual assessment of the palynomaceral types, sizes, shapes, and colours, and the Type I and II kerogen types dominated the studied interval with considerable mixed type, Type II & III.

Furthermore, the thermal maturity of the organic matter was deduced based on the coloration of the palynomorphs which ranged from yellow to brown to deep brown on the Spore Coloration Index and Thermal Alteration scale which inferred middle maturation to a late degree of maturation.

The palynological and virtual kerogen assessments of the sediments of the OMA well have further proven that the offshore Dahomey Basin is viable for hydrocarbon. This study has also established the age and depositional environment of the studied lithology intervals for further basin stratigraphic analyses.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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