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Palynology, depositional environments, and paleoclimatic analysis of OGU-7 well, Niger Delta, Nigeria

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ABSTRACT

Palynological analysis of 100 ditch samples from a section of OGU-7 well, Niger Delta, was carried out to determine the age of the sediment, palynostratigraphic zones, depositional environments, and paleoclimate conditions using data sets from palynology, which well penetrated the paralic Agbada formation. The analyzed samples were from stratigraphic depth intervals of 1,792–9,140 m. Palynological slides were prepared following the standard palynological preparation technique involving hydrochloric (HCl) and hydrofluoric (HF) acids. The palynomorphs yielded 80 species. The section was dated Oligocene–early Miocene due to the occurrence of the diagnostic marker species such as *Cicatricosisporites dorogensis*, *Arecipites exilimuratus*, and *Echiperiporites estelae*. The interval zone of *Retitricolporites irregulari* and *Leiosphaeridia* sp.; the taxon range zone of *C. dorogensis*; and the concurrent range zone of *E. estelae* and *Echiperporites icacinoides* were established in line with the International Stratigraphic Guide which could contribute to the harmonization of the biozonation scheme in the Niger Delta Basin. The depositional environment was deduced from the Palynomorph Marine Index values (0% freshwater, 1%–50% brackish, and 51%–100% marine), indicating freshwater to brackish (coastal) environments of deposition for the studied sediment. The paleoecological groupings of the palynomorphs were used to delineate the paleoclimatic signals ranging (wetter to drier phases) from the distribution patterns of *Zonocostites ramonae* (Rhizophora) and *Monoporites annulatus* (Poaceae).

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1. Introduction

The discovery of commercial oil in 1956 has intensified more exploration and production activities in the Niger Delta, which has led petroleum explorationists to shift exploration and production activities from the continent into shallow water offshore and now into deep waters (Moshood and Marion, 2016). Because of the increase in search of hydrocarbon in the Niger Delta, much palynological work has been carried out in the basin, which has helped researchers to reveal the stratigraphy, sedimentology, structural styles, and petroleum potential of the basin.

Palynology is the study of the entire acid-resistant microscopic organic matter recovered from sediment or sedimentary rock. This organic matter is usually fossilized. They include pollen, spores, dinoflagellate, algal cysts, as well as plant debris, and other miscellaneous material. This organic matter when recovered

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from sediment undergoes several chemical alterations. Palynology finds its use in petroleum exploration essentially in terrestrial and marine environments. When integrated with other tools, including well logs and seismic stratigraphy, palynology is useful for chronostratigraphic correlation, paleoenvironmental studies, and evaluation of potential source reservoirs and sealing rocks (Copestake, 1993).

Some of the palynological investigations in the Niger Delta include the following: Adebayo et al. (2014), on the Miocene–Pliocene vegetation and climate dynamics of the Niger Delta, stated that the depositional paleoenvironment ranges from marginal marine to slightly brackish water, with a warm and humid climate and mangrove species dominating. Ajaegwu et al. (2012) subjected 50 ditch-cutting samples from ANE-1 well, Eastern Niger Delta, which penetrated the Agbada formation. This section belongs to the *Echitricolporites spinosus* zone. The result shows that the overall environment ranges from coastal to marginal marine. The applied palynological studies in the basin include that of Morley and Richards (1993) who used Gramineae cuticle as a tool for climatic change monitoring in the Late Cenozoic Niger Delta. Similarly, Olajide (2013) studied the sediments from CHEV-2 well Niger Delta and proposed five informal palynological zones for the studied sections of the wells due to the presence of some important marker species, such as *Retitricolporites irregularies*, *Psilatricolporites crassus*, and *E. spinosus*. Also, Oloto (2014) carried out a palynological study of Igbomoturu-1 well in the Niger Delta and recorded some dinoflagellate cysts, pollen and spores, foraminifera test linings, and fungal spores. He erected four zones for the palynostratigraphic subdivision: *Spiniferites pseudofurcatus* (zone 1) at the base, *Mutispinula quanta* (zone 2), *Chytrocisphaeridium* sp. (zone 3), and zone 4 was dominated by *Sumatradinium hispidium* at the top. These zones correspond with the *Verrucatosporites usmensis* zone described by Germeraad et al. (1968). Adebayo et al. (2012) studied the miospores from sediments of Bog-1 well in the Niger Delta. A late Oligocene–mid-Miocene age was assigned based on the co-occurrence of important pantropical stratigraphic markers such as *Zonocostites ramonae*, *Retimonocolpites pluribaculatus*, *Retibrevitricolporites protrudens*, *P. crassus*, *R. irregularies*, *Recamonocolpites hians*, *Pachydermites diederixi*, and *Bravicolporites guinetic*. These researches did not assign biozones properly using the international stratigraphic guidelines. Therefore, the aim of this work is to carry out the palynological studies of the strata penetrated by OGU-7 well in order to establish the palynostratigraphic zonation in line with the international stratigraphic guidelines.

1.1. Location and geology of the study area

The Niger Delta is situated in the Gulf of Guinea and extends to the southwest of the Benue Trough. The Niger Delta sedimentary basin evolved following the Early Cretaceous breakup between the South American and the African plates. The delta represents the regressive phase of the third cycle of deposition in the southern Nigerian sedimentary basins, which began during the Paleocene and has continued to the present day (Short and Stauble, 1967). The studied well is located in the onshore part of the Eastern Niger Delta, Greater Ughelli depobelts. OGU-7 well is located around latitude 5°28′07″N and longitude 7°61′07″E (Fig. 1).

1.1.1. Stratigraphy of the Niger Delta

The sequences of the Niger Delta have been subdivided into three stratigraphic units, namely Akata, Agbada, and Benin formations (Fig. 2).

Akata formation: The oldest of these formations is the Paleocene to recent Akata formation (Bankole et al., 2016). The Akata formation is characterized by continuous, uniform shale, and is laid down in a marine environment. The formation is characteristically composed of dark gray shale and occasionally sandy or silt of prodelta origin (Bankole et al., 2016). The shales of this formation are usually undercompacted (Chukwuma-Orji et al., 2017).

Agbada formation: On top of the marine sequence is the Eocene to recent Agbada formation. The Agbada formation is considered to be accumulated in deltaic front, delta-topset, and fluvio deltaic environments (Corredor et al., 2005). The Agbada formation, which this study penetrated, is subjected to palynological investigation and is composed of sandstone/sand bodies with mudstone. According to Ujoh et al. (2021), the formation is composed of cyclic sequences of marine and fluvile deposits. The ditch-cutting sample from this research indicates fine- to medium-grained sand/sandstone or mudstone. Also, fairly clean coarse-grained sands have also been encountered. They are locally calcareous, shelly, and contain pyrite. The formation, as observed in the present study, yields abundant and diverse palynomorphs. The formation grades vertically into the continental deposits of the Benin formation.

Benin formation: Capping the sequence is the continental Benin formation, deposited during the Oligocene to recent (Bankole et al., 2016). The

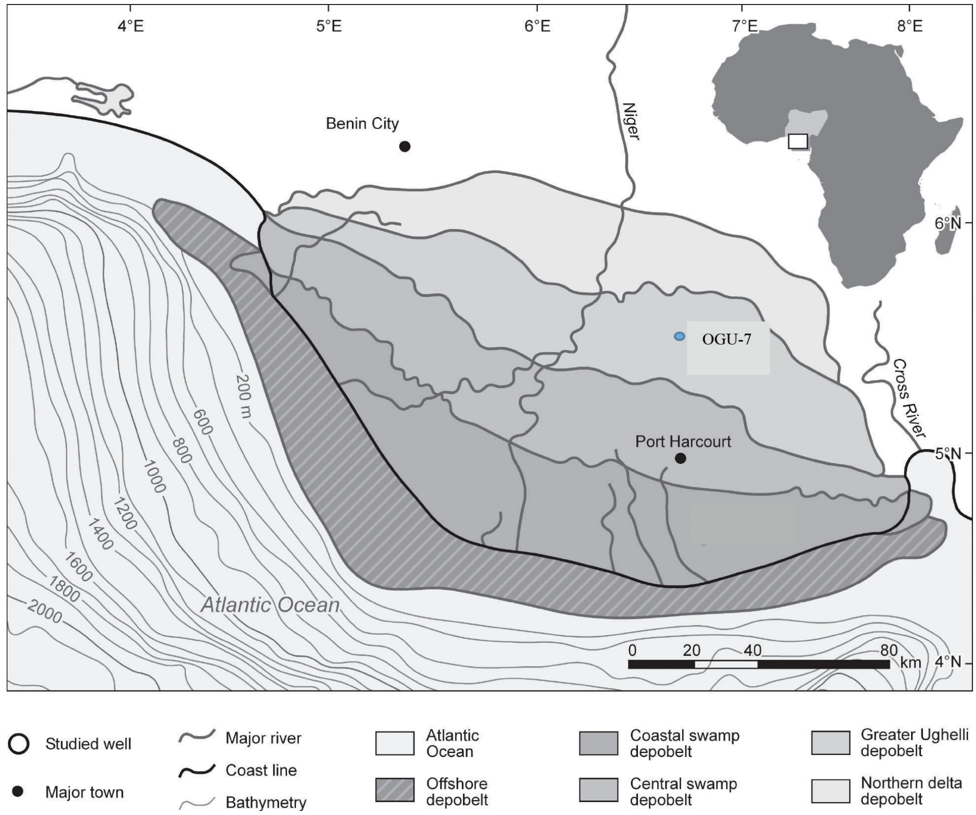


Figure 1. Location of OLA well, in Greater Ughelli Depobelt, Eastern Niger Delta, Nigeria. (Modified after Doust and Omatsola, 1990).

formation represents continuous continental deposits ranging from coarse- to medium-grained sand/sandstones (Bankole et al., 2016). Some of the few samples that penetrated the Benin formation in this study indicate medium- to coarse-grained sand/sandstones.

1.1.2. Structural styles

Growth faults, rollover anticlines, and antithetic faults are the commonest structures in the Niger Delta (Fig. 3). Other structures include crestal faults, flank faults, and shale diapirs (Doust and Omatsola, 1990).

Growth faulting dominates the structural style in the Niger Delta basin. They are syn-depositional or syn-sedimentary faults. They are triggered by the movement of deep-seated, overpressured, ductile marine shales and aided by slope instability (Doust and Omatsola, 1990). Growth faults offset an active surface of deposition. They are commonly referred to as structure building faults. Growth fault defines the updip limit of the depobelts and tends to flatten at depth. The growth fault in the Niger Delta basin exhibits a seaward or southerly dip. The angle of dip along the plane of these fault changes down to the particular depth where the plane almost flattens out. The down dip or distal end of a depobelt is defined by counter-regional faults. The dips (landward dips) of counter-regional faults are usually opposite to that of structure-building growth faults. They have been suggested to be generated usually at a lithology change (sand to shale) (Doust and Omatsola, 1990). Immediately at the back of a counter-regional fault exists another structure-building growth fault which delineates the proximal end of a new depobelt. Such a combination of growth fault and counter-regional fault to the south of the basin is referred to as "back to back faulting." In the tertiary sediments of the Niger Delta, growth faults play a major role in the migration and entrapment of oil and gas (Fig. 4).

The antithetic fault displays a similar dip direction like the counter-regional fault but is not associated with the delineation of depobelt boundaries (Doust and Omatsola, 1990). The antithetic fault can be considered as a bisector of growth faults (Fig. 2). The antithetic fault displays no growth.

Rollover anticlines are another important structure in the Niger Delta as they play an important role in hydrocarbon trapping. Weber and Daukoru (1975) associated the development of these rollover anticlines with bed rotation along the growth fault as a

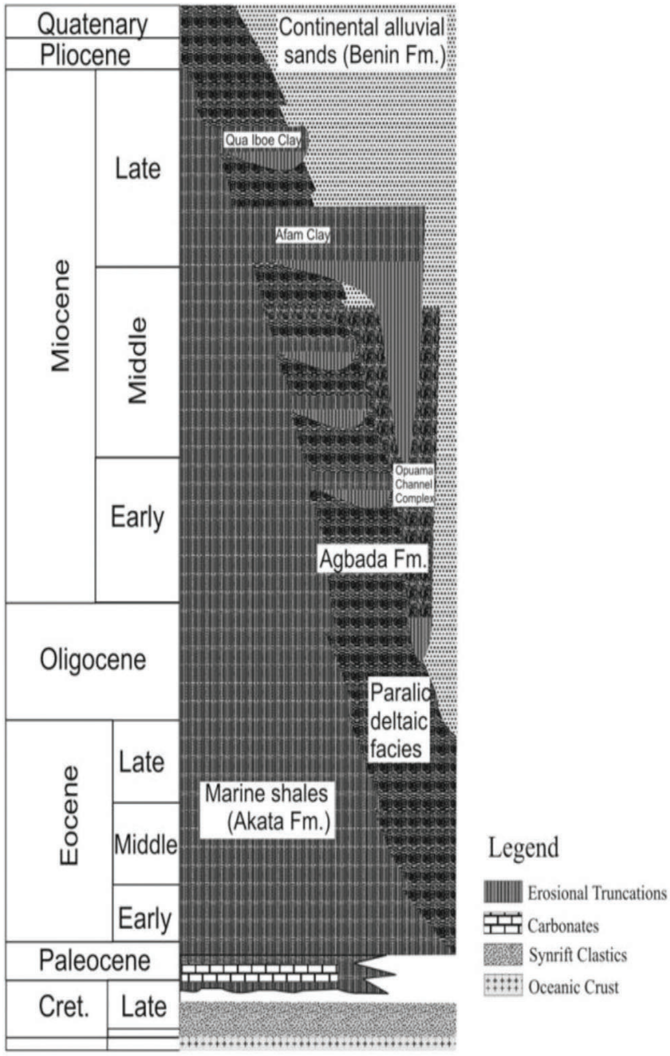


Figure 2. Stratigraphy of the formations of the Niger Delta (Bankole et al., 2016).

result of rapid deposition. They also suggested that oil fields in the Niger Delta are anticlines rollover structures.

2. Materials and Methods

A total of 100 ditch-cutting samples within the intervals of 1,792–9,140 m from the OGU-7 well were provided by Addax Nigerian Petroleum Limited, Lagos, Nigeria, for palynological analysis. The sample preparation and analysis were carried out in Mosunmolu Laboratory Nigeria Limited, Lagos. The geological formations penetrated by the well are the Agbada formation and the lowest part of the Benin formation, which was not palynologically investigated because of the lack of organic content in the sample. The ditch-cutting samples were analyzed following the standard palynological preparation method (acid method) which included sample treatment with 10% hydrochloric acid and 40% hydrofluoric acid for carbonates and silicates removal, respectively. HNO_3 was used as the oxidizing agent to enhance the visibility of the palynomorphs. Staining of the slide was done using safranin O to enhance the appearance of any dinoflagellate cysts under the microscope, most of which are fairly transparent in routine (unstained) preparations.

Microscopic studies of the slides were carried out using the palynological microscope (Leitz Diaplan Microscope). Palynomorphs viewed were identified and named using palynological albums and also different systematic publications of palynomorphs. The identified species were counted using

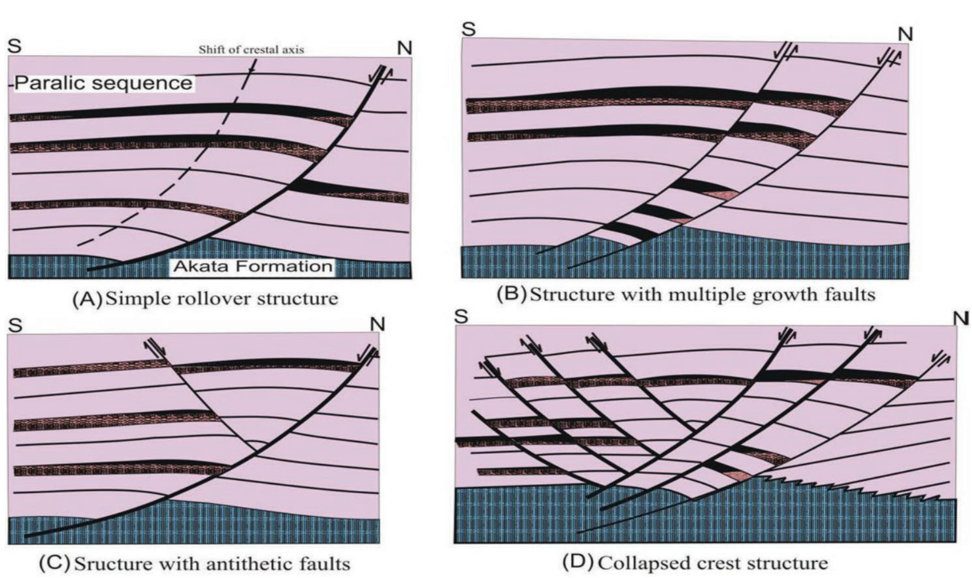


Figure 3. Principal type of oil field structure in the Niger Delta (after Doust and Omatsola, 1990)

the tally system and recorded on the analysis sheet. The process was repeated for all the slides and the result were inputted into the StrataBugs software to prepare the palynomorphs chart. This method has been discussed extensively by the work of Ujoh et al. (2022).

3. Results and Discussion

3.1. Palynomorph abundance and distribution pattern of OGU-7 well

The ditch cuttings analyzed from OGU-7 well yielded a large number of palynomorphs with variations in

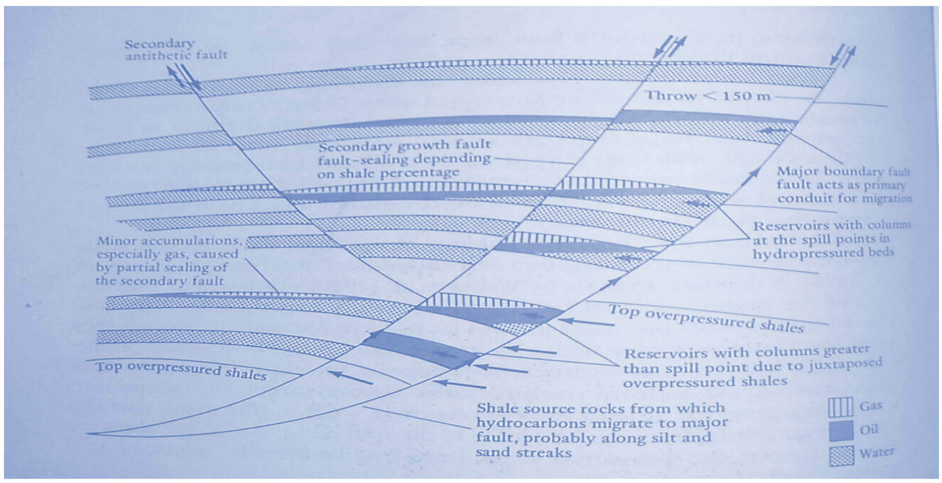


Figure 4. Mode of accumulation of oil and gas in the Niger Delta's growth fault traps (after Weber et al., 1980).

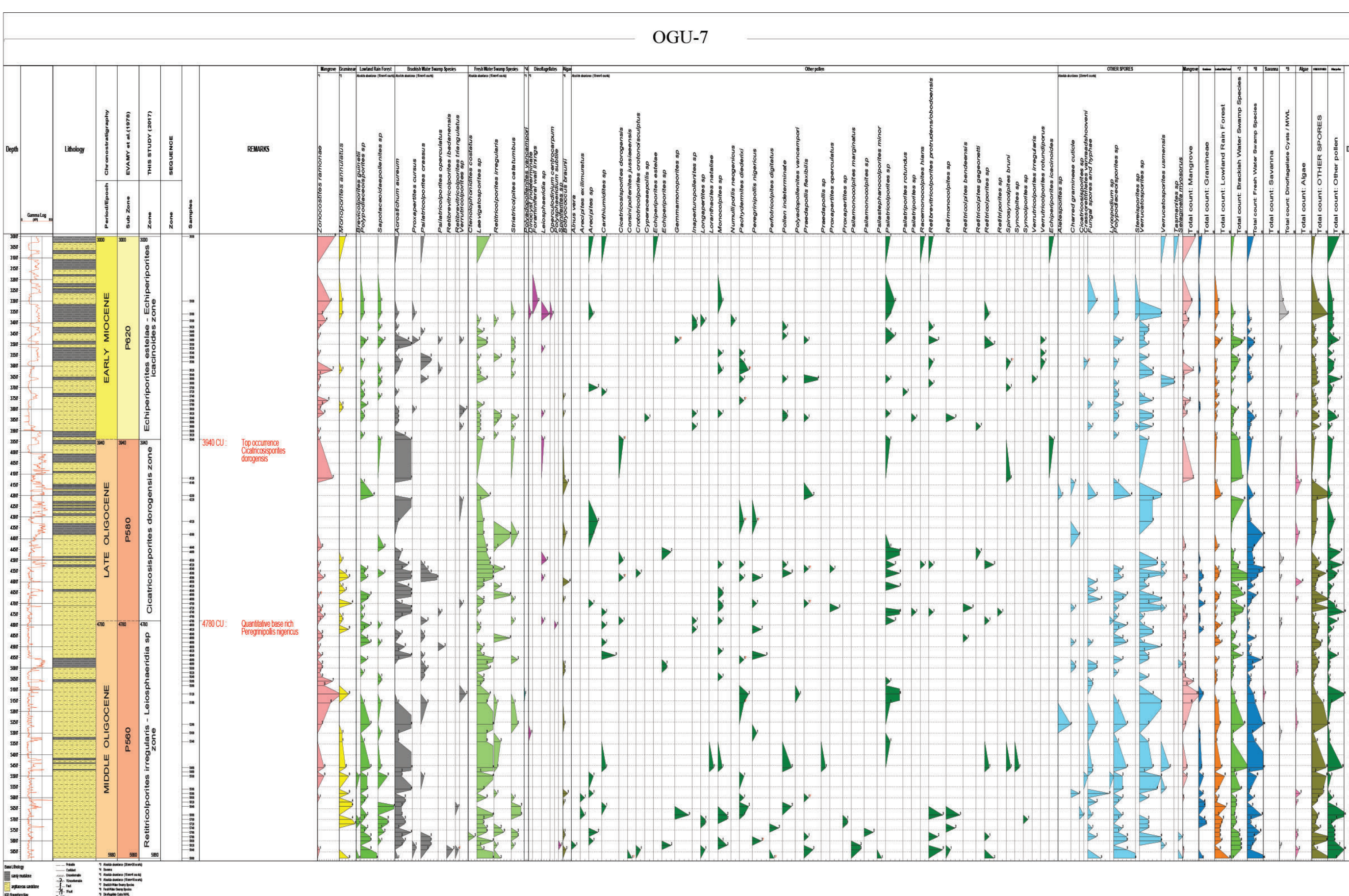
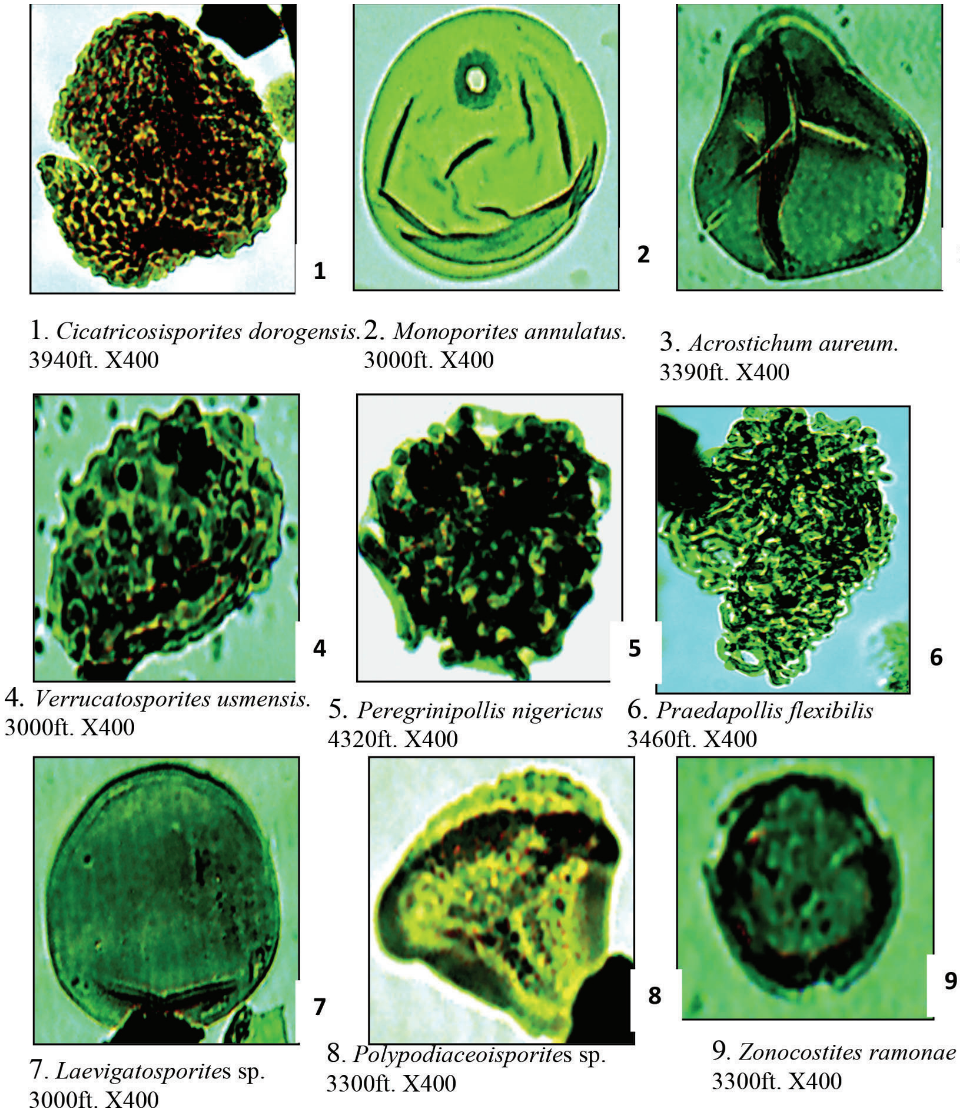


Figure 5. Palynomorph distribution chart for OGU-7 well.



1. *Cicatricosisporites dorogensis.* 3940ft. X400
2. *Monoporites annulatus.* 3000ft. X400
3. *Acrostichum aureum.* 3390ft. X400
4. *Verrucatosporites usmensis.* 3000ft. X400
5. *Peregrinipollis nigericus* 4320ft. X400
6. *Praedapollis flexibilis* 3460ft. X400
7. *Laevigatosporites* sp. 3000ft. X400
8. *Polypodiaceoisporites* sp. 3300ft. X400
9. *Zonocostites ramonae* 3300ft. X400

Figure 6. Photomicrographs (×400) of some important palynomorphs retrieved from OGU-7 well.

abundance, diversity, and preservation from the depth sampled. Figure 5 shows the palynomorphs recovered, with a total number of 80 species. Pollen and spores were good with a total species count of 74. Dinoflagellates were fairly represented with six species found in the well. Algae were poorly recovered with one species found in OGU-7 well. The photomicrographs of some selected species of palynomorphs are shown in Figure 6.

The palynomorphs were statistically represented on a distribution chart to show their abundance and distribution pattern using Microsoft Office Excel. From the palynomorph distribution chart, it can be deduced that the most abundant miospore was of the pollen taxonomy, which reflects about 49% of the total palynomorphs population. Spores were the next, with 48% of sporomorph recovery, followed by dinocyst with 1% and algae with 2% recovery (Table 1 and Fig. 7).

Table 1. Percentage palynomorph distribution in OGU-7 well.

Palynomorph type	Percentage distribution
Pollen	49
Spores	48
Dinoflagellate	1
Algae	2

However, individual palynomorphs were statistically analyzed to show their abundance pattern in the two wells. Also, of all the palynomorphs assemblages analyzed statistically, the most abundant palynomorph species was *Laevigatosporite* sp., with about 13% of the total palynomorph count, followed by *A.*

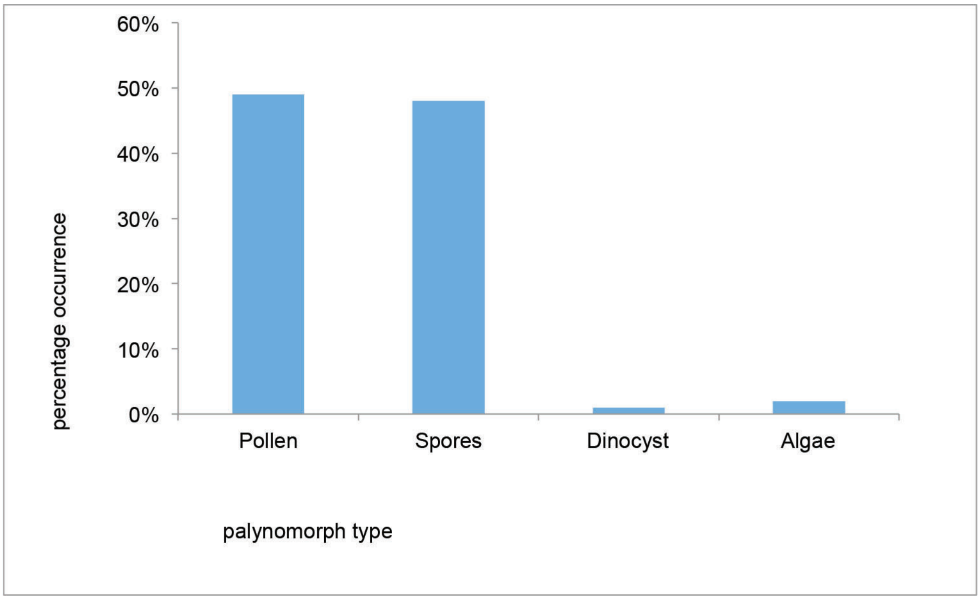


Figure 7. Percentage abundance of the palynomorph in OGU-7 well.

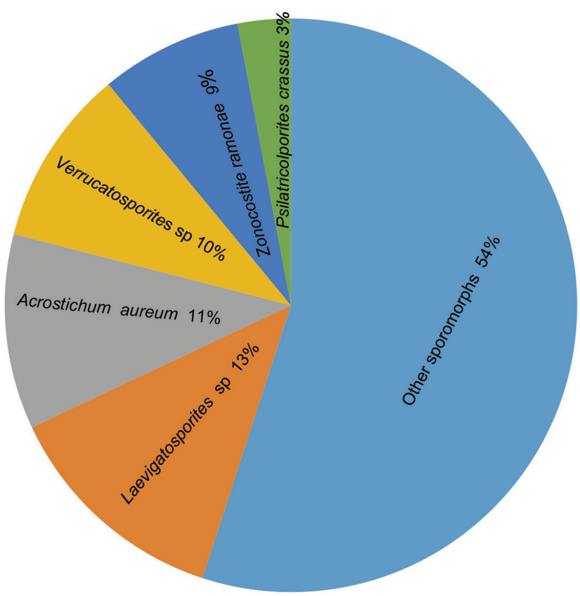


Figure 8. Percentage abundance of the palynomorph species in OGU-7 well.

aureum (11%), *Verrucatosporite* sp. (10%), *Z. ramonae* (8%), and *P. crassus* (3%), while other sporomorphs assemblages accounted for 54% of the abundance in the well (Fig. 8).

3.2. Palynostratigraphic zonations and biochronology of OGU-7 well

Zone I: *R. irregularis* and *Leiosphaeridia* sp. zone

Zone type: Interval zone

Depth: 1,792–1,457 m (5,880–4,780 ft)

Age: Middle Oligocene

Diagnosis: The top is marked by the Last Downhole Occurrence (LDO) of *Leiosphaeridia* sp. and the bottom is marked by the LDO of *R. irregularis*. Only a lone species, *Cicatricosisporites dorogensis*, has its LDO at the top of the zone. Other species within this zone marking their LDO at the base include *Brevicolporites guinetii*, *Corsinipollenites jussiaeensis*, *Perfotricolpites digitatus*, and *Psilastephanocolpites minor.* Species marking their only appearance within this zone include *Retibrevitricolporites ibadanensis*, *Retibrevitricolporites triangulates*, *Polyadopollenites vancampori*, *Polysphaeridium subtle*, *Spiniferites* sp., *Alnus vera*, *Arecipites exilimuratus*, *B. guinetic*, *C. jussiaeensis*, *Loranthacites nataliae*, *P. digitatus*, *P. vancampori*, *Praedopollis* sp., *Proxapertites* sp., *Psilamonocolpites marginatus*, *Psilamonocolpite* sp., *P. minor*, *Syncolpites* sp., *Syncolporites* sp., *Cicatricosisporites* sp., *Lycopodium* sp., and *Selaginella myosorus.* This zone is bounded at the top by quantitative base *Peregrinipollis nigericus* at 1,457 m (4,780 ft) and this correlates with the P560 subzone described by Evamy et al. (1978).

Zone II: *C. dorogensis* zone

Zone type: Taxon range zone

Depth: 1,457–1,201 m (4,780–3,940 ft)

Age: Late Oligocene

1

Diagnosis: The top and base of this zone are marked by the First Downhole Occurrence (FDO) and LDO of *C. dorogensis*. No associated species occurred within this zone, but other long- and short-ranging species running through this zone include *Retibrevitricolporites triangulatus*, *P. vancampori*, Dinocyst indeterminate, *Operculodinium centrocarpum*, *P. subtle*, *Spiniferite* sp., *A. vera*, *A. exilimuratus*, *C. jussiaeensis*, *Crototricolporites crotonoisculptus*, *Cyperaceaepollis* sp., *Echiperiporites estelae*, *Inaperturopollenites* sp., *Longapertites* sp., *L. nataliae*, *Numullipolis neogenicus*, *P. vancampori*, *Preadapollis* sp., *Proxapertites* sp., *P. minor*, *Psilatriporites rotundus*, *Psilatricoporites* sp., *Retitricolpites gageonetti*, *Retitriporites* sp., *Spirosyncolpites bruni*, *Syncolpites* sp., *Syncolporites* sp., *Verrutricolporites irregularis*, *Verrutricolporites rotundiporus*, *Echiperiporites icacinoides*, *Cicatricosisporites*sp., *Crassoretitriletes vanraadshooveni*, *Lycopodium* sp., *Stereisporites* sp., and *S. myosorus*. This zone correlates with the P580 subzone described by Evamy et al. (1987) as is bounded at the top by *C. dorogensi*s and at the base by *P. nigericus.*

Zone III: *E. estelae* and *E. icacinoides* zone

Zone type: Concurrent range zone

Depth: 1,201–9,140 m (3,940–3,000 ft)

Age: Early Miocene

Diagnosis: This zone is a concurrent zone, marked at the top with the FDO of *Echiperiporites estalae* and at the base with the LDO of *E. icacinoides*. Species marking their FDO in this zone include *Monoporite annulatus*, *Z. ramonae*, *A. aureum*, *P. crassus*, *Laevgatosporites* sp., *Arecipites* sp., *Canthiumidites* sp., *Psilatricolporite* sp., *R. hians*, *R. protrudens/obodoensis*, *V. usmensis*, and *Tasmanite* sp. Species marking their FDO and LDO within this zone include *Tasmanites* sp., *Verrutricoporites rotundus*, *N. neogenicus*, *Cyperaceaepollis* sp., *O. centrocarpum*, and foraminiferal wall linings. This zone corresponds to the P620 subzone described by Evamy et al. (1978) as it is bounded at the base by *C. dorogensis.*

Table 2. Summary of biozonation for OGU-7 well.

Zone name	Depth interval	Zone type
Retitricolporite irregularis and *Leiosphaeridia* sp Zone	1,792–1,457 m	Interval zone
Cicatricosisporites dorogensis Zone	1,457–1,201 m	Taxon range zone
Echiperiporites estelae and *E. icacinoides* Zone	1,201–914 m	Concurrent range zone

3.3. Depositional environments' interpretation

In this study, the terrestrial groups are represented by pollen and spores and the marine group is represented by dinocyst (the two major groups used in the interpretation of the depositional environments).

3.3.1. Palynomorph Marine Index (PMI) of OGU-7 well

Helenes et al. (1998) formulated the PMI to support the interpretation of depositional environments. PMI is calculated using the following formula:

$$\text{PMI}= (Rm/Rt+1)100$$

where R_m is the richness of marine palynomorphs (dinoflagellate, acritarchs, and foraminifera test linings) and R_t is the richness of terrestrial palynomorphs (pollen and spores) counted per sample. In this study, R_m and R_t were expressed as the number of species per sample. In relation to the classification by Helenes et al. (1998), this study denotes 0% or nil PMI values, indicating freshwater, 1%–50% as PMI values, indicating brackish environment, and 51%–100% as PMI values, indicating marine environment.

Based on the formula, most depths from OGU-7 well generally recorded 0% PMI values, indicating a freshwater environment (Table 4 and Fig. 4), while few depths recorded 1%–50% PMI values 1,005 m (3,300 ft) (11.8%), 1,024 m (3,360 ft) (22.7%), 1,072 m (3520 ft) (33.3%), 1,164 m (3,820 ft) (5.6%), 1,200 m (3,940 ft) (6.3%), 1,371 m (4,500 ft) (16.7%), 1,395 m (4,580 ft) (2.4%), 1,456 m (4,780 ft) (7.7%), 1,463 m (4,800 ft) (9.1%), 1,627 m (5,340 ft) (11.1%), 1,737 m (5,700 ft) (4.3%), and 1,773 m (5,820 ft) (5.6%) denoting a brackish environment. No depth was recorded above 50% (marine). It can be deduced from the PMI values that the depositional environments observed in this study range from freshwater to brackish environments.

3.4. Paleoecological groupings of the palynomorphs

Based on the different taxa encountered in the investigated sediments (OGU-7 well), different ecological groups have been identified from the palynomorph distribution charts. Following the approaches of Sowunmi (1981), Poumot (1989), Ige (2009), and Adojoh et al. (2015), the different ecological groups identified include mangrove taxa, savannah taxa, rainforest taxa, freshwater swamp taxa, and marine group (Table 4). The mangrove taxa (littoral) species identified include *Z. ramonae*, *Acrostichum aurum*, and *P. crassus*, which are sensitive to sea level oscillation.

Mangroves are well established during phases of sea level rise. The periods of relative sea level rise when the

Table 3. PMI values for OGU-7 well.

Depth (m)	Marine richness R_m	Terrestrial richness R_t	PMI $(R_m/R_t + 1)$ 100
9,140	0	26	0
1,006	2	17	11.8
1,024	5	22	22.7
1,033	0	10	0
1,042	0	9	0
1,049	0	7	0
3,460	0	7	0
1,055	0	27	0
1,067	0	18	0
1,072	1	3	33.3
1,079	0	5	0
1,085	0	10	0
1,091	0	14	0
1,103	0	19	0
1,109	0	7	0
1,116	0	19	0
1,122	0	8	0
1,128	0	5	0
1,139	0	6	0
1,146	0	5	0
1,149	0	10	0
1,152	0	11	0
1,320	0	7	0
1,164	1	18	5.6
1,170	0	18	0
1,176	0	4	0
1,182	0	11	0
1,189	0	3	0
1,194	0	7	0
1,201	1	16	6.3
1,256	0	16	0
1,262	0	4	0
1,280	0	24	0
1,286	0	13	0
1,317	0	11	0
1,335	0	14	0
1,353	0	10	0
1,359	0	14	0
1,372	2	12	16.7
1,378	0	25	0
1,384	0	25	0
1,390	0	38	0
1,396	1	41	2.4
1,402	0	4	0
1,408	0	15	0

Depth (m)	Marine richness R_m	Terrestrial richness R_t	PMI $(R_m/R_t + 1)\ 100$
1,414	0	12	0
1,420	0	26	0
1,426	0	17	0
1,433	0	16	0
1,438	0	28	0
1,445	0	20	0
1,451	0	9	0
1,457	1	13	7.7
1,463	1	11	9.1
1,469	0	13	0
1,475	0	9	0
1,481	0	15	0
1,487	0	12	0
1,494	0	14	0
1,499	0	5	0
1,506	0	20	0
1,511	0	18	0
1,517	0	12	0
1,524	0	13	0
1,530	0	5	0
1,536	0	7	0
1,542	0	10	0
1,548	0	13	0
1,561	0	6	0
1,573	0	35	0
1,603	0	5	0
1,615	0	34	0
1,627	1	9	11.1
1,664	0	13	0
1,670	0	56	0
1,676	0	6	0
1,695	0	33	0
1,700	0	18	0
1,706	0	13	0
1,712	0	18	0
1,719	0	23	0
1,731	0	31	0
1,737	1	23	4.3
1,743	0	19	0
1,750	0	19	0
1,756	0	22	0
1,761	0	28	0
1,768	0	29	0
1,773	1	18	5.6
1,780	0	26	0
1,792	0	46	0

Table 4. Paleoecological groupings of some selected environmental marker species recovered from OGU-7 well.

		Mangrove taxa				Savanna taxa				Freshwater taxa						Rainforest taxa					Marine taxa				
Zonocostites ramonae	Depth (m)	*Zonocostites ramonae*	*Acrostichum aurum*	*Psilatricolporites crassus*	Total mangrove taxa	*Monoporite annulatus*	Charred gramineae cuticle	Fungal spore	Total savanna taxa	*Botryococcus braunii*	*Laevigatosporites sp*	Stria. catatumbus	*Arecipites exilimuratus*	*Echiperiporites estelae*	Total freshwater taxa	*Verrucatosporites sp.*	*Peregrinopollis nigericus*	*Sapotaceoidaepollenites sp*	*Polypodiaceoisporites sp*	Total rainforest taxa	Dinocyst indeterminate	Foraminiferal wall linings	*Leiosphaeridia sp 3*	*Operculodinium centrocarpum*	Total marine (dinocyst) taxa
	9,140–1,042	22	3	1	26	4	0	2	6	0	2	1	0	1	4	10	0	3	2	14	1	2	3	1	7
	1,047–1,072	1	12	1	14	0	0	0	0	0	8	3	0	0	11	6	0	3	3	12	0	0	1	0	1
	1,077–1,109	9	4	6	19	1	0	0	1	0	3	2	0	0	5	8	0	1	1	2	0	0	0	0	0
	1,103–1,128	2	1	2	5	0	0	0	0	0	3	0	0	0	3	4	0	3	3	10	0	0	0	0	0
	1,139–1,320	11	3	0	14	2	0	1	3	2	5	2	0	0	7	6	0	2	4	12	0	0	1	0	1
	1,164–1,189	2	9	0	11	0	0	1	1	4	4	2	0	0	6	5	0	1	1	7	0	0	1	0	1
	1,194–1,280	7	15	0	22	0	1	2	3	0	9	2	0	0	11	12	1	0	5	18	0	0	0	0	0
	1,286–1,359	3	7	1	11	1	2	0	3	2	25	0	0	0	25	8	0	2	0	10	0	0	2	0	2
	1,372–1,396	4	20	16	40	6	0	2	8	4	17	0	0	0	17	12	2	2	5	21	0	0	1	0	1
	1,402–1,426	3	26	0	29	6	0	5	11	1	4	1	0	0	5	20	1	0	6	27	0	0	0	0	0
	1,433–1,457	5	10	2	17	5	1	0	5	0	3	1	0	0	4	7	5	1	4	12	0	0	1	0	1
	1,463–1,487	5	7	2	14	0	1	1	2	0	5	2	0	0	2	11	0	1	5	17	0	0	0	0	0
	1,494–1,517	7	7	5	19	0	2	4	6	3	14	0	0	0	0	2	0	0	3	5	0	0	0	0	0
	1,524–1,548	29	1	3	33	3	0	2	5	0	9	3	0	0	3	11	0	3	4	18	0	0	0	0	0
	1,561–1,627	5	23	0	28	4	0	0	4	1	34	0	0	0	0	16	1	2	6	25	0	0	0	0	0
	1,664–1,700	4	10	1	15	10	0	7	17	4	12	4	1	0	17	6	0	3	5	14	0	0	0	0	0
	1,706–1,737	0	11	0	11	13	0	2	15	0	10	3	1	0	14	6	0	14	6	26	0	0	0	0	0
	1,743–1,792	0	1	5	6	3	0	3	6	3	4	5	0	0	12	15	2	3	7	27	1	0	0	0	1

mangroves are well established at the coast are related to wet climate phases (Bankole et al., 2016). The savannah floras (*M. annulatus*) are another important hinterland group. These plants quickly colonize the space abandoned by the mangrove and are left dry during the fall of the sea level. They are related to dry climate phases (Chukwuma-Orji et al., 2017). The rainforest floras are represented by a large number of botanical families. Their abundance is not directly linked to sea level fluctuation, but to climate change.

The dominance of this floral group (mangrove) is linked to wet climates (Adojoh et al., 2015). The freshwater floras live landward from the mangrove floras and they are established during periods of cool climates. Paleoecological groupings of the palynomorphs were used to delineate the paleoclimate signals that prevailed during the deposition of the sediment.

3.4.1. Paleoclimatic studies for OGU-7 well

They intervals (1,792–1,627) showed reduced representation of wet climate indicators: mangrove floras and the brackish water algae *Botryococcus*. The dry climate indicator such as Poaceae (*M. annulatus*), Gramineae, and fungi spores prevailed during this interval, indicating the prevalence of savannah ecosystem and dry period during this interval. Brenac (1988) reported that increase in grass pollen (Gramineae) is an indication of a dry and cool climate. The reduced occurrence of mangrove swamp species in this zone is an indication of a lowered sea level, thereby allowing only a few establishments of mangrove species near the coast during this interval (Table 4 and Fig. 9).

These intervals (1,627–1,457 m and 1,201–9,140 m) recorded high peaks of mangrove floras (although with local fluctuations) with the savanna vegetation

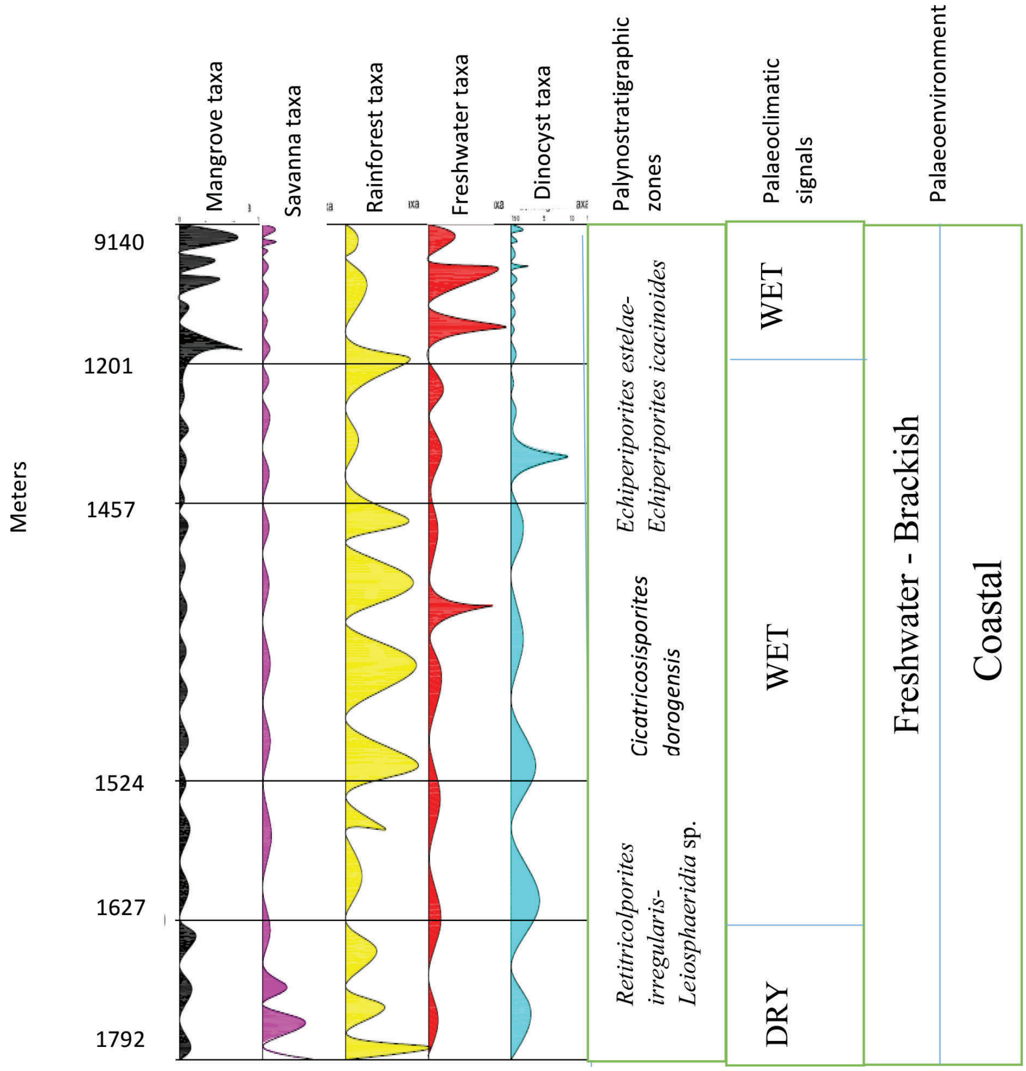


Figure 9. Graphical representation of the paleoecological groups and inferred palynostratigraphic zones, paleoclimatic signals, and paleoenvironment.

showing spotty occurrences throughout these intervals, thus indicating a wet climate condition and subsequently a rise in sea level. During these intervals, the mangrove floras throve around the coast. Also, the prevalence of rainforest vegetation and freshwater floras further confirmed a wetter climate for these intervals (Table 4 and Fig. 9).

4. Conclusion

Palynomorphs including pollen, spores, algae, and dinoflagellates were identified within the studied section and their distribution varied from one depth to another in terms of diversity and abundance. The section penetrated the geological Agbada formation. Palynostratigraphic zonation of the studied section was carried out based on the stratigraphic ranges of the diagnostic marker palynomorph species assemblages in the wells. Three zones were established for the well: *R. irregularis* and *Leiosphaeridia* sp. zone; *C. dorogensis* zone; and *E. estelae* and *E. icacinoides* zone (1,792–9,140 m) in accordance with the International Stratigraphic Guide (Biostratigraphic Units) which correlates with the P560, P580, and P620 subzones described by Evamy et al. (1978) and the *Magnastriatites howardi–E. spinosus* combined zones described by Germeraad et al. (1968); these zones will help in harmonizing the zonation scheme in the Niger Delta. The studied stratigraphic interval was dated to Oligocene–early Miocene due to the discovery of Oligocene to early Miocene age diagnostic marker species such as *C. dorogensis*, *A. exilimuratus*, and *E. estelae*. Freshwater to brackish environments of deposition have been inferred for the studied sections based on the PMI values and the presence of important marker species such as *Laevigatosporites* sp., *A. exilimuratus*, *E. estelae*, *Z. ramonae*, *A. aureum*, *P. crassus*, *Leiosphaeridia* sp., *Spiniferites* sp., and *Selenopemphix* *nephroides*. Therefore, the intervals studied were deposited within coastal/littoral environment which could be suitable for hydrocarbon accumulation. The paleoclimatic conditions shows alteration between wet and dry climates from paleoecological groupings.

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