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Graphic correlation and paleoenvironmental investigation of the upper Eocene–lower Oligocene sediments in the Dahomey Basin, southwestern Nigeria: insights from palynomorphs

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ABSTRACT. This study presents the results of a comprehensive qualitative and quantitative palynological analysis of four shallow boreholes (Epe-1, Olokonla-1, Ikoyi-1 and Badore-1) in the lower Eocene–upper Oligocene periods of the Dahomey Basin, southwestern Nigeria. The lithostratigraphic analysis revealed three lithologies (sandy-shales, shaly-sands and sandstones). Two most important palynological zones, the *Verrucatosporites usmensis*, as well as the *Magnastriatites howardi* Pan-tropical zones, are delineated. First Appearance Datum (FAD) of *Achomosphaera alcicornu* marked the late Eocene–early Oligocene boundaries (E/O) within the four boreholes, while FAD of *Adnatosphaeridium multispinosum* defined the late Eocene–early Oligocene boundary (E/O) in Ikoy-1. Two informal palynological assemblage zones were revealed in the four boreholes. Common occurrences of palms, mangrove, fresh water and brackish water pollen, and pteridophyte spores with spots records of marine elements and algae species during marine invasion suggested fluctuation from fluvio-deltaic/nearshore to marginal marine paleoenvironments. Graphic correlation discloses that for every meter of sedimentary rock accretion within Epe-1, equally amounted to merely 0.31 m, 0.56 m, as well as 0.47 m of sediments, which were put down in Olokonla-1, Ikoyi-1, as well as Badore-1, respectively. These comparative rates of sedimentary rock accretion show with the purpose of either there is fewer attrition occurrence and/or extra accommodation gap within Epe-1 than Olokonla-1, Ikoyi-1, as well as Badore-1. The assessment of the slopes, intercept and correlation equations through graphic correlation procedures enable the identification of four biostratigraphic events in Epe-1, Olokonla-1, Ikoyi-1, as well as Badore-1. The findings in this investigation are necessary for depositional succession and paleoenvironmental understandings, as well as basin investigation, and above all, to show a relationship of broadly separated boreholes.

KEYWORDS: palynology, stratigraphy, graphic correlation, depositional environment, Eocene–Oligocene boundary, Dahomey Basin

INTRODUCTION

The Eocene–Oligocene transition is marked by large-scale extinction of organisms, and floral and faunal turnover and changes (Frederiksen, 1988; Haasl and Hansen, 1996; Oboh et al., 1996; Ivany et al., 2000). This phenomenon can be recognized using palynological methods. Palynostratigraphy is a tool that is useful in characterizing the chronostratigraphic horizons and paleoenvironments of sedimentary rocks in various depositional

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settings such as continental, coastal and marginal marine (Rull, 2002). Graphic correlation is a fundamental method that offers improved stratigraphic resolution and enhanced accuracy and precision end results (Mann and Lane, 1995; Krebs et al., 1997; Krebs, 2011).

Cenozoic paleoenvironments, as well as the reconstruction of past vegetation have been deduced using a range of palynological and sedimentary proxies (Willumsen, 2004; Singh et al., 2015; Zarei, 2017; El Atfy et al., 2017, 2021, 2022; El Beialy et al., 2019). These proxies proffer a way by which paleoecology and paleogeography can be reconstructed. However, marine organisms are most affected by this phenomenon (Dockery, 1986). According to Burroughs (2001, 2007) and Cronin (2010), Eocene–Oligocene was a time of major climatic changes, especially cooling, that were probably caused by significant impacts such as volcanic events and meteorite impacts (Berggren and Prothero, 1992). Hence, the paleoforal events around the Eocene–Oligocene boundary in Nigeria's inland basins such as the Dahomey Basin are worth researching to understand the phenomenon of climatic changes.

Most previous biostratigraphic and paleoenvironmental studies in Nigerian basins are concentrated within the Niger Delta Basin owing to intense hydrocarbon explorations and exploitation activities in the region (e.g. Fajemila, 2012; Fadiya et al., 2014; Ikegwuonu and Umeji, 2016; Bankole et al., 2016; Chukwuma-Orji et al., 2017; Olayiwola and Bamford, 2019; Olayiwola, 2021; Fajemila et al., 2022). In the Dahomey Basin, a small number of studies have employed palynological investigation in biostratigraphic and paleoenvironmental analyses (e.g. Bankole et al., 2006; Adeigbe et al., 2013; Adeniran, 2015; Bolaji et al., 2020; Asadu and Nkem, 2020). This work is an appendage of the study by Olayiwola et al. (2021) where palynological and palynofacies data were utilized to analyze the sequence stratigraphic framework of the upper Eocene–lower Oligocene Dahomey Basin. This present study will correlate biostratigraphic events, determining the rate of sedimentation and reconstruction of paleoenvironment. The findings of this work will give valuable ideas in delineating the depositional succession, paleoenvironmental understandings, basin analysis and correlation of widely separated boreholes in the Dahomey Basin region.

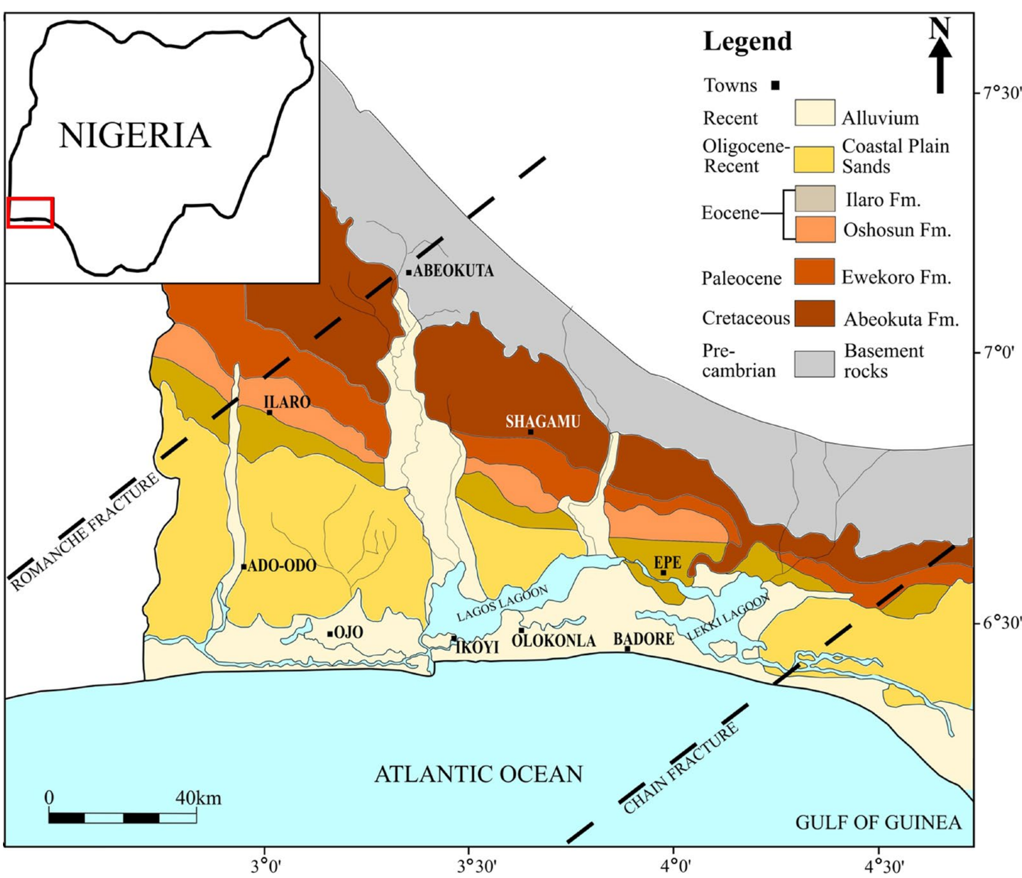

Figure 1. Geological map of the Eastern part of the Dahomey Basin, Nigeria

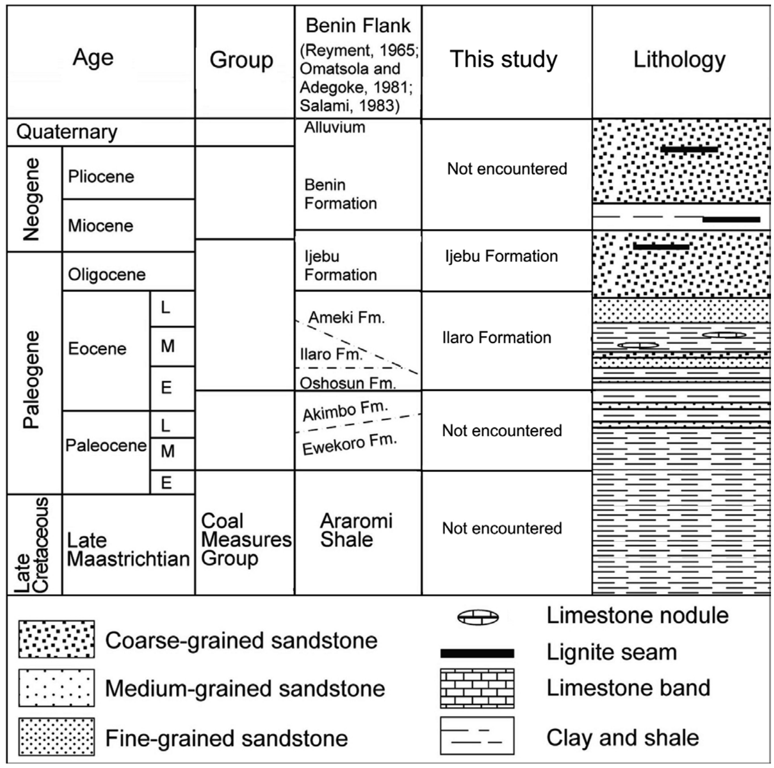

Figure 2. Stratigraphic column of Benin Flank in Nigeria (Modified from Reyment, 1965; Omatsola and Adegoke, 1981; Salami, 1983). E = early; M = middle; L = late

LOCATION, GEOLOGY AND STRATIGRAPHY OF THE STUDY AREA

The study area is located within the Ijebu/Ilaro Formations in the eastern portion of Benin (Dahomey) Basin, southwestern Nigeria. Geographically, it is bounded by longitudes 3°00′E and 5°00′E and latitudes 6°00′N and 7°30′N, and occupies the continental margin of the Gulf of Guinea of West Africa (Fig. 1). It is a merger of inland/coastal/offshore sections, which extends from southeastern Ghana all the way throughout Togo and the Republic of Benin to southwestern Nigeria (Brownfield and Charpentier, 2006).

Tectonically, the gap of the southern part of the Atlantic Ocean within the Gulf of Guinea throughout the end of Jurassic to Cretaceous periods resulted in the formation of the Dahomey Basin. The fractured zones that are evidenced next to the oceanic crust, for example the Charcot fracture zone, which manifested the same as trenches and ridges are related to the Dahomey Basin (Brownfield and Charpentier, 2006). In addition, the initiation of this basin is related to rift-caused basement subsidence that started in the early Cretaceous (i.e. Neocomian). Subsequently, there is a broad succession of sands and gravel, of continental origin, above the whole basin (Lehner and De Ruiter, 1977). Billman (1976) and Omatsola and Adegoke (1981) concluded that more than 1400 m of these deposits are conserved in the coastal regions of Nigeria, as well as in the adjacent offshore areas of the Benin Republic. Within the late Cretaceous, another episode of major tectonic activity was recorded that affected the Dahomey Basin and most likely resulted in the closure and folding of the basin (Fig. 1). According to Babalola (1988), there are three major oceanic fracture zones that intersected the basin and extended more distant inland as northeast-trending faults. This resulted in the formation of two major grabens, which are separated by a horst. These are the northwest-southeast graben and the northeast-southwest graben that are understood being underlain by continental crust and oceanic crust basements, respectively.

The basin was further affected by tectonic activities, which caused the tilting and dense faulting of the basement rocks, as well as the formation of a sequence of horsts and grabens in the overlying sediments (Omatsola and Adegoke, 1981).

Studies by Reyment (1965), Omatsola and Adegoke (1981), as well as Salami (1983) led to the establishment of the stratigraphic design of the eastern Dahomey Basin (Fig. 2). However, surface and subsurface information from these studies demonstrate that, in nearly all portions of the Dahomey Basin, the stratigraphy is dominated by a uniformity of shale and sand amid intercalations of small fractions of clay and limestone (Obaje, 2009).

Stratigraphically, the Dahomey Basin consists of Cretaceous and Paleogene sediments. The Cretaceous sediments, in ascending order of age, comprise the Araromi, Afowo and Ise Formations that were regarded as components of the Abeokuta Group. The sediments of the Ise Formation unconformably overlie the basement complex and are composed of coarse conglomerate sediments. Afowo Formation comprises transitional to marine sandstone with thick interbedded shales and siltstone. Araromi is the youngest Cretaceous formation and it comprises shales and siltstone with limestone and sand interbeddings. According to Omatsola and Adegoke (1981), this was the deepest distinct sedimentary component within this basin (Fig. 1). Paleogene sediments consisted of, in stratigraphically descending order, the Benin, Ilaro/Ijebu, Oshosun, Akinbo, as well as Ewekoro Formations. The Ewekoro Formation is composed of essentially shallow marine limestones that were accumulated due to the persistence of the oceanic transgression through the Paleocene epoch (Ogbe, 1972; Okosun, 1990). According to Ogbe (1972), the Ewekoro Formation underlies the Akinbo Formation non-conformably in a number of localities. Moreover, in areas where the Ewekoro Formation is absent the Akinbo Formation is straight and lies on the Afowo Formation unconformably. Adeigbe et al. (2013) allocated an early to middle Eocene age to this formation on the basis of fossil groups including for instance corals, mollusks and pelagic, as well as planktonic foraminifera. The Oshosun Formation comprises colored laminated glauconitic clay, as well as shale in association with sandstone intercalations above the Akinbo Formation. Adeigbe et al. (2013) allocated a mid-Eocene (Lutetium) age to the Oshosun Formation on the basis of foraminiferal groups. The Ilaro/Ijebu Formation lies conformably above the Oshosun Formation and comprises huge, feebly consolidated and cross-bedded sandstones. An Eocene–Oligocene age is allocated to this formation on the basis of the fossil assemblage of this formation. Jones and Hockey (1964) accounted that the Benin Formation was the youngest of the Paleogene sediments within the basin that was also known as the Coastal Plain Sandstone and comprised substantial ferruginized sandstones. Short and Stauble (1967) allocated an Oligocene–Recent age to this formation on the basis of its fossil assemblage.

METHODS

Ninety-nine ditch-cutting samples from Olokonla-1, Epe-1, Badore-1 as well as Ikoyi-1 holes bored within the onshore Dahomey Basin were examined in this investigation. The samples were acquired from Krust Venture, Lagos, Nigeria on 19th February 2019 and were stored in the palynological laboratory of AG. Leventis Museum of Natural History, Obafemi Awolowo University, Ile-Ife, Nigeria. All the boreholes were georeferenced (Epe-1 – 6°34′N and 3°58′E; Olokonla-1 – 6°28′N and 3°36′E; Ikoyi-1 – 6°27′N and 3°26′E; Badore-1 – 6°26′N and 3°51′E; Fig. 1). The ditch-cutting samples were taken at 1.50 m intervals for both lithostratigraphic and palynological analyses.

LITHOSTRATIGRAPHIC DESCRIPTION

Standard procedures were employed in the preparation of the ditch-cutting samples (Selley, 1976) including laboratory preparation, as well as lithological descriptions like sphericity, roundedness, sorting and color of the sediment particles. Identification of accessory minerals, such as glauconite, ferruginous materials, pyrites and shell fragments, as well as carbonaceous detritus was carried out for each sample. These lithostratigraphic data were plotted with the help of Tilia™ software version 2.6.1. to generate graphic representations for each of the boreholes (Fig. 4a–d).

PALYNOLOGICAL ANALYSIS

Each sample was prepared for palynological analysis based on standard processes (e.g. Faegri et al., 1989). This comprises the adding up of hydrofluoric acid, hydrochloric acid, potassium hydroxide, as well as heavy liquid separation in a saturated zinc chloride ($ZnCl_2$; specific gravity = 2.6) solution. The palynological preparations were carried out at the palynological laboratory of the Biological Sciences Department, Redeemer's University, Nigeria. The detailed palynological preparations and procedures for the identification, counting and descriptions of palynomorphs were previously reported in Olayiwola et al. (2021). The prepared residues and the studied slides were stored at the palynological laboratory of AG. Leventis Museum of Natural History, Obafemi Awolowo University, Nigeria.

GRAPHIC CORRELATION ANALYSIS

Graphic correlation investigation started by choosing Epe-1 borehole as the composite standard section (CS). It is the deepest borehole in the study area, and it is well sampled, with a relatively high number of fossils the distribution of which into associations is moderate

Table 1. Biostratigraphic events (FADs and LADs) in Epe-1, Olokonla-1, Ikoyi-1 and Badore-1 boreholes (T – Tops, B – Bases)

No.	Taxa	Epe-1		Olokonla-1		Ikoyi-1		Badore-1	
		LAD (T) (m)	FAD (B) (m)	LAD (T) (m)	FAD (B) (m)	LAD (T) (m)	FAD (B) (m)	LAD (T) (m)	FAD (B) (m)
1	*Arecipites* sp. Nichols et al., 1973	17.25	24.75	5.95	23.25	0.00	0.00	0.00	0.00
2	*Echitriporites trianguliformis* Van Hoeken-Klinkenberg, 1964	17.25	26.25	8.25	25.50	21.8	30.00	0.75	30.00
3	*Longapertites marginatus* Van Hoeken-Klinkenberg, 1964	5.2	26.25	8.25	30.00	0.25	30.00	6.75	14.75
4	*Proxapertites cursus* Van Hoeken-Klinkenberg, 1966	0.25	18.00	5.95	25.50	14.30	29.30	20.85	0.00
5	*Psilamonocolpites marginatus* Puri, 1963	24.75	0.00	5.95	29.25	0.00	0.00	0.00	0.00
6	*Psilamonocolpites* spp. Puri, 1963	0.25	24.75	0.00	0.00	4.50	17.25	0.75	30.00
7	*Racemonocolpite hians* Legoux, 1978	8.25	17.25	4.50	26.25	0.00	0.00	6.75	11.25
8	*Retimonocolpites obaensis* Jan Du Chêne, Onyike et Sowunmi, 1978	2.25	28.50	5.25	29.25	0.25	30.00	0.75	30.00
9	*R. asabaensis* Jan Du Chêne, Onyike et Sowunmi, 1978	6.00	26.25	0.00	0.00	0.00	0.00	4.50	24.75
10	*Retimonocolpites* sp. Pierce, 1961	0.75	26.25	0.00	0.00	0.00	0.00	6.75	0.00
11	*Spinizonocolpites echinatus* Muller, 1968	18.00	0.00	11.25	21.00	29.30	30.00	0.00	0.00
12	*Canthium* spp. Khan, 1976	9.75	19.50	0.00	0.00	0.00	0.00	4.50	30.00
13	*Ctenolophonidites costatus* Van Hoeken-Klinkenberg, 1966	13.50	0.00	8.25	13.50	0.00	0.00	0.00	0.00
14	*Pachydermites diederixi* Germeraad et al., 1968	0.25	16.50	0.00	0.00	0.00	0.00	6.75	21.00
15	*Proteacidites cooksonni* Cookson, 1950	3.75	16.50	0.00	0.00	0.00	0.00	0.00	0.00
16	*Psilatricolporites crassus* Van der Hammen, 1954	0.25	24.75	4.5	26.25	0.25	24.80	4.50	26.25
17	*Psilatricolporites* spp. Van der Hammen, 1954	5.25	26.25	0.00	0.00	5.95	28.50	4.50	30.00
18	*Retibrevitricolporites protrudens/ibadanensis* Van der Hammen, 1954; Legoux, 1978	17.25	21.75	14.25	21.00	0.00	0.00	0.00	0.00
19	*R. protrudens* Van der Hammen, 1954	13.50	17.25	0.00	0.00	4.50	8.25	10.50	19.50
20	*R. triangulatus* Van Hoeken-Klinkenberg, 1964	14.25	28.5	5.95	25.5	10.50	17.25	4.50	30.00
21	*Retitricolporites irregularis* (Van der Hammen) Pierce, 1961	6.00	26.25	8.25	26.25	7.75	19.50	4.50	30.00
22	*Spirosyncolpites bruni* Legoux, 1978	3.75	24.75	3.75	28.50	4.5	30.00	2.25	0.00
23	*Striatopollis bellus* Sah, 1967	14.25	26.25	0.00	0.00	0.00	0.00	14.75	0.00
24	*Striamonocolpites rectostriatus* Legoux, 1978	3.75	16.50	8.25	10.50	2.25	10.50	0.00	0.00
25	*Verrutricolporites rotundiporus* Legoux, 1978	17.25	26.25	0.00	0.00	0.00	0.00	4.50	30.00
26	*Zonocostites ramonae* Germeraad et al., 1968	18.75	0.00	8.25	15.25	5.25	10.50	2.25	24.75
27	*Cyathidites minor* Sah, 1967	0.25	28.50	2.25	27.75	2.25	28.50	0.75	22.50
28	*Deltoidospora adriennis* Pflug, 1952 and Potonie, 1956	0.75	21.75	5.95	29.25	0.25	30.00	0.60	30.00
29	*Laevigatosporites* spp. Ibrahim, 1933	0.25	24.75	4.50	30.00	2.25	30.00	0.60	30.00
30	*Verrucatosporites* spp. Van der Hammen, 1954	0.25	28.5	2.25	30.00	2.25	29.30	0.60	30.00
31	*Verrucatosporites usmensis* Van der Hammen, 1954	0.25	28.5	2.25	30.0	0.25	30.00	4.50	30.00
32	*Polypodiaceoisporites* spp. Sah, 1967	1.5	18.00	9.00	24.75	0.00	0.00	2.25	30.00
33	*Achomosphaera* spp. Eisenack, 1954	6.00	26.25	2.25	21.75	2.25	23.25	10.50	0.00
34	*Adnatosphaeridium multispinosum* Williams et Downie, 1966	0.25	11.25	9.00	24.75	0.00	0.00	0.00	0.00
35	*Andalusiella* sp. Riegel, 1974	14.25	0.00	7.75	18.75	0.00	0.00	0.00	0.00
36	*Areoligera* spp. Lejeune-Carpentier, 1938	6.00	0.00	5.25	29.25	0.00	0.00	12.75	14.75
37	*Batiacasphaera* spp. Drugg, 1970	12.75	17.25	0.00	0.00	28.50	29.30	0.00	0.00
38	*Cometodinium* sp. Stove et Evitt, 1978	0.25	19.50	0.00	0.00	0.00	0.00	0.00	0.00
39	*Cerodinium* sp. Vozzhennikova, 1963	0.00	0.00	0.00	0.00	9.00	18.80	0.00	0.00
40	*Diphyes colligerum* Deflandre et Cookson, 1955	6.00	9.75	0.00	0.00	0.00	0.00	0.00	0.00
41	*Cordosphaeridium inodes* Davey et Williams, 1966	0.00	0.00	16.5	23.25	0.00	0.00	0.00	0.00
42	*C. exilimurum* Davey et Williams, 1966	0.75	14.25	0.00	0.00	0.00	0.00	0.00	0.00
43	*Glaphyrocysta* spp. Stover et Evitt, 1978	6.00	14.25	0.00	0.00	0.00	0.00	12.75	0.00
44	*Hafniasphaera septata* Cookson et Eisenack, 1967	12.75	16.5	0.00	0.00	0.00	0.00	0.00	0.00
45	*Hystrichokolpoma rigaudiae* Deflandre et Cookson, 1955	14.25	17.25	0.00	0.00	0.00	0.00	0.00	0.00
46	*Operculodinium centrocarpum* Cookson Wall, 1967	12.75	13.50	0.00	0.00	0.00	0.00	14.75	0.00
47	*Operculodinium* sp. Cookson Wall, 1967	6.00	18.00	0.00	0.00	18.80	0.00	0.00	0.00
48	*Paleocystodinium* sp. Alberti, 1961	3.75	12.75	0.00	0.00	9.00	29.30	0.00	0.00
49	*Phelodinium africanum* Biffi et Grignani, 1983	0.25	6.00	0.00	0.00	0.00	0.00	0.00	0.00
50	*Selenopemphix* sp. Benedek, 1972	6.00	0.00	21.00	23.25	0.00	0.00	2.25	10.50
51	*Selenopemphix* cf. *nephroides* Benedek, 1972	6.00	14.25	4.50	16.50	3.75	23.25	4.50	0.00
52	*Spiniferites ramosus* Ehrenberg, 1838	0.75	0.00	4.50	10.50	23.25	0.00	0.00	0.00
53	*Spiniferites* sp. Ehrenberg, 1838	0.75	0.00	25.50	29.25	0.00	0.00	15.75	19.75
54	*Leiosphaeridia* spp. Eisenack, 1958	6.00	14.25	2.50	18.75	0.00	0.00	0.75	14.75
55	*Botryococcus braunii* Kützing, 1849	0.25	12.75	8.25	30.00	23.25	28.50	0.60	27.75
56	*Pediastrum* sp. Knight et Martin, 1989	0.25	28.50	2.50	26.25	2.25	29.3	0.00	0.00

and there is no sign of any main facies break throughout the borehole (Mann and Lane, 1995; Gouwy and Bultynck, 2000; Jaramillo et al., 2009). Palynostratigraphical information was evaluated utilizing graphic correlation with PAST™ software (Shaw, 1964; Edwards, 1984, 1989; Dowsett, 1989). This technique does not pursue the common trending that every extinction or evolution event signifies a timeframe. Conversely, it considers the entire assemblage to discover the precise stratigraphic range for each taxon (Edwards, 1989; Dowsett, 1989; Table 1). The design for a graphic correlation is an x-y cross plot on which palynostratigraphic records, i.e. last (extinction) and first (evolution) appearances, chosen as bases "o" and tops "+", respectively, of all taxa documented in the four wells (Table 1) were lain open to linear modelling employing the computer package PAST™ version 1.89 (Paleontological Statistics software ©) of Hammer et al. (2007). Epe-1 borehole (CS) was plotted on the X-axis versus Olokonla-1, Ikoyi-1 and Badore-1 boreholes on the Y-axis and lines of greatest fit known as "line of correlation" (LOCs) were drawn (Shaw, 1964; Miller, 1977; Fig. 5a–c). The correlation equations were obtained from the slope and intercept, and LOCs values. The slope values suggested comparative rate of sediment accretion (Shaw, 1964).

RESULT AND DISCUSSION

In the recent times, situations such as dry wells or unbalanced record of oil reserves have persisted in the discovery and development of petroleum within the Niger Delta (Odeyemi and Ogunseitan, 1985; Kadafa, 2012; Kadafa et al., 2012; Aniefiok et al., 2016). Moreover, till date about twenty-three oil fields have been shut or abandoned because of the problems mentioned earlier (Descalzi, 2015). However, apart from the Paleogene Niger Delta Basin, the Cretaceous Anambra Basin is presently the only inland basin within Nigeria that has been proved to contain the commercial quantities of hydrocarbons (Onuoha and Dim, 2016). Hence, it is important to intensify research in other Nigerian inland basins such as the Dahomey Basin, in order to have better understanding of its petroleum system.

LITHOSTRATIGRAPHIC ANALYSIS

Lithostratigraphic study of the Badore-1, Ikoyi-1, Epe-1 and Olokonla-1 samples showed the deposition of three types of lithology, shaly-sands, sandy-shales and sandstones. Fluctuations of sandy-shales and sandstones at depths of 0.25–8.25 m, 8.25–18.00 m and 18.00–28.50 m, respectively, characterized Epe-1 (Fig. 4a). The upper portion of Olokonla-1 is composed of sequences of sandy-shales at the depths of 17.25–18.00 m, 15.75–16.50 m, 11.25–13.50 m, 9.75–10.50 m, 0.00–3.75 m and shaly-sands, at the depths of 18.00–18.75 m, 16.50–17.25 m, 13.50–15.75 m, 10.50–11.25 m, 3.75–9.75 m (Fig. 4b). On the contrary, the lower portion is made up of alternations of sandy-shales at the depths of 19.50–21.00 m and 21.75–27.75 m, shaly-sands at the depths of 18.75–19.50 m and 21.00–21.75 m, and sandstones at the depths of, 28.75–30.00 m and 27.75–28.75 m (Fig. 4b). Fluctuation of sandstones at depth intervals of 24.80–30.00 m, 14.25–18.80 m, 0.00–5.25 m and shaly-sands at intervals of 18.80–24.80 m and 5.25–14.25 m characterized Ikoyi-1 (Fig. 4c). There was fluctuation of sandstones at depth intervals of 24.00–26.65 m and 6.75–10.65 m, and sandy-shales at 30.00–26.25 m, 24.00–10.65 m and 6.75–0.25 m in Badore-1 (Fig. 4d).

The sandy-shale lithology is regarded as an upward deepening succession that is made up of fine deposits, as well as shaly-sand; otherwise sand lithologies are inferred as an upward shallowing succession, which is composed of coarser-grained deposits (e.g. Krapez, 1996, 1997). Shaly sands and sandstones defined in this investigation could possibly form reservoir rocks (e.g. Fozao et al., 2019; Mkinga et al., 2020). In contrast, the sandy-shales delineated here might probably form source and cap rocks (Dim et al., 2018; Al-Areeq and Albaroo, 2019).

PALYNOSTRATIGRAPHICAL ZONATION

The palynostratigraphical zonation of Olokonla-1, Epe-1, Ikoyi-1 and Badore-1 boreholes was based on recovered floral occurrences and age diagnostic forms as defined by Germeraad et al. (1968) and Evamy et al. (1978) (Fig. 3). Two broad palynological zones were delineated on the basis of characteristic floral composition in the four boreholes (see Olayiwola et al., 2021). Thus, the sediments in the boreholes vary in age from late Eocene to early Oligocene. The P470-P480 subzones were the oldest subzone, while P520-P540 subzones represented the youngest subzones. The first appearance datum of *Achomosphaera alcicornu* in Olokonla-1, *Homotryblium plectilum* in Epe-1, *Adnatosphaeridium multispinosum* in Ikoyi-1, *Adnatosphaeridium multispinosum* and *Homotryblium plectilum* in Badore-1 along with the last appearance datum of *Homotryblium tenuispinosum* in Epe-1 defined the boundary between P470-P480 and P520-P540 subzones (Figs 3 and 4a–d).

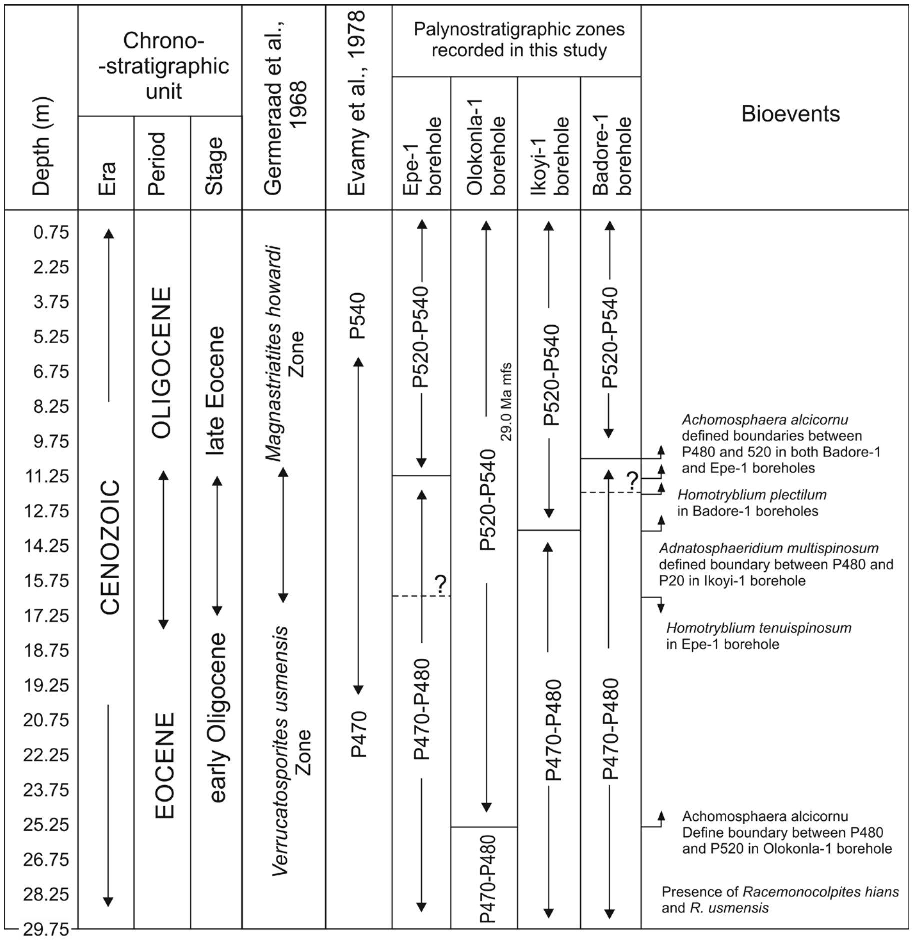

Figure 3. Chart of palynomorph subzones recognized in Epe-1, Olokonla-1, Ikoyi-1 and Badore-1 boreholes based on the frameworks of Evamy et al. (1978)

PALYNOLOGICAL ASSEMBLAGE ZONE (PAZ) AND PALEOENVIRONMENTAL DEDUCTIONS

Two informal palynological assemblage zones (PAZ A and PAZ B) are recognized in the four boreholes. The PAZ zones are subdivided into A1, B1, B2 and B3 in Epe-1; A1, A2, A3, B1, B2 and B3 in Olokonla-1; A1, A2, A3, B1, B2 and B3 in Ikoyi-1; and A1, B1, B2 and B3 in Badore-1 (Fig. 4a–d). The PAZs are correlated with the P400 and P500 zones of Evamy et al. (1978; see Fig. 3) and B2-A and G3-G2 zones of Legoux (1978). The P400-P500 are part of the Microfloral zonal Scheme established by Evamy et al. (1978) for sedimentary rocks in Nigeria that correspond to upper Eocene–early Oligocene age (see Fig. 3). These are documented on the basis of the relative abundance of diagnostic marker species (Ikegwuonu et al., 2020; Olayiwola et al., 2022; see Fig. 3).

PAZ in Epe-1 borehole

Palynological assemblage zone (PAZ) in Epe-1 revealed four palynozones A1 (28.5–25.5 m), B1 (25.5–20.0 m), B2 (20.0–10.0 m) and B3 (10.0–0.5 m) (Fig. 4a). The bottom of the PAZ is marked with the presence of *Zonocostites ramonae* (*Rhizophora* spp.) that belong to mangrove swamps, *Retibrevitricolporites triangulatus* and *Retimonocolpites obaensis* while the top is defined by the occurrence of *Psilamonocolpites* sp., *Retitricolporites irregularis* (*Alchornea cordifolia*; mangrove swamp), *Striatricolpites bellus* and *Polypodiaceoisporites* sp (Adojoh et al., 2017, 2019; Sciumbata et al., 2021; Table 2). This assemblage zone is further characterized by the occurrence of *Verrucatosporites* sp. (Polypodium; ~45%), *Cyathides minor* (*Cyathea* spp.; ~10%) and *Laevigatosporites* sp. (~5%) representing fresh water swamps, *Deltoidospora adriennis* (Pteridaceae; ~30%) representing brackish water swamps, *Polypodiaceoisporites* sp. (~10%) and *Sapotaceoidaepollenites* sp. (*Chrysophyllum africanum*; ~20%) representing lowland rainforests, *Retibrevitricolporites* sp. (~10%), *Retimonocolpites obaensis* (~10%), *Psilatricolpites crassus* (~5%) and *Psilamonocolpites* sp. (~10%)

Table 2. Distribution of recovered palynomorphs into ecological groups and botanical affinities

No.	Ecological group	Pollen/Spore species	Family (Stuchlik, 2001; Adojoh et al., 2017, 2019; Sciumbata et al., 2021)	Botanical affinities (NLR) (Rull, 2002; Adojoh, 2017; Stuchlik, 2001; Sciumbata et al., 2021)
1	Mangrove	*Zonocostites ramonae*	Rhizophoraceae	*Rhizophora mangle*
		Psilatricolporites crassus	Euphorbiaceae	*Tabernaemontana*
2	Freshwater swamp	*Retitricolporites irregularis*	Euphorbiaceae	*Amanoa*
		Laevigatosporites sp., *Verrucatosporites* sp., *Verrucatosporites usmensis*	Pteridophyta Polypodiaceae Polypodiaceae	Fern spore *Polypodium* *Polypodium*
		Cyathides minor	Cyatheaceae-Dicksoniaceae	–
3	Brackishwater swamp	*Deltoidospora adriennis*	Pteridaceae	*Deltoidospora* sp.
		Pachydermites diederixi	Guttiferae	*Symphonia globulifera*
4	Lowland	*Stereisporites* sp.	Sphagnaceae, Bryophyta	Moss spores sp.
5	Palms/tropical trees	*Psilamonocolpites* sp.	Arecaceae	*Ancistrophyllum*
		Retimonocolpites hains, *Retimonocolpites asabaensis*, *Retimonocolpites obaensis*, *Echitricolporites trianguliformis*, *Longapertites marginatus*		Palm trees
6	Savanna	*Monoporites annulatus*	Poaceae	*Graminidites* sp.
		Cyperaceaepollis sp.	Cyperaceae	*Cyperus* sp.
7	Freshwater algae	*Botryococcus braunii*	Algae	–
8	Lowland rainforest (tropical trees)	*Canthium* spp., *Canthiumpollenites* sp.	Rubiaceae	*Rubia tinctorum*, *Randia* sp.
		Polypodiaceoisporites sp.	Adiantiaceae-Pteridaceae/ Pteridophyta	Fern spores
		Sapotaceoidaepollenites sp.	Sapotaceae	*Chrysophyllum africanum*
9	Montane trees	*Pinus* pollen	Pinaceae	*Pinus palustris*, *Pinus balfouriana*

representing palms (Fig. 4a; Table 2). Others are fungal spores (~60%) and fresh water algae *Botryococcus braunii* (~20%). In addition, there is spot-like occurrence of dinocysts *Impagidinium* sp. (~5%) and *Operculodinium* sp. (~5%), and *Spiniferites ramosus* (~5%), *Paleocystodinium* sp. (~6%) and *Cordosphaeridium inodes* (~3%) (Fig. 4a; Table 2). Reasonable to rich occurrences of the mangrove swamp *Z. ramonae* (*Rhizophora* spp.; ~10%) co-occurring with common fresh water swamp, brackish water swamp, lowland rainforest and palms suggest fluvio-deltaic/nearshore paleoenvironment and high frequency of fungal spores, moderate to spot-like occurrence of fresh water algae and dinocysts, respectively, indicate marginal marine paleoenvironment (Guerstein et al., 2014; Mathews et al., 2018). Gough and Hall (2017) reported fluvio-deltaic/nearshore environments for the deposition of Oligocene sediments from Salin Sub-Basin, Central Myanmar. In addition, Durugbo and Olayiwola (2017) earlier reported similar assemblage of palynomorphs, in the middle Miocene Niger Delta, as above and concluded the paleoenvironment to be fluctuated between fluvio-deltaic/nearshore to marginal marine. Presence of *Verrucatosporites usmensis*, *Racemonocolpites hians* and last appearance datum of *Homotryblium tenuispinosum* dated the lower part of this PAZ, i.e. palynozones A, B1 and B2 to be late Eocene while the upper part palynozone B3 was dated early Oligocene due to the presence of *Arecipites exilimuratus*, *Selenopemphix nephroides* and the first appearance datum of *Achomosphaera alcicornu* (Olayiwola et al., 2021; Figs 3 and 4a).

PAZ in Olokonla-1 borehole

The palynological assemblage in Olokonla-1 belongs to six informal palynozones A1(30.0–28.5 m), A2 (28.5–23.5 m), A3 (23.5–18.0 m), B1 (18.0–11.5 m), B2 (11.5–7.5 m) and B3 (7.5–0.5 m) (Fig. 4b). The base of PAZ is marked by *Longapertites marginatus*, brackish water swamp *Deltoidospora adriennis* (Pteridaceae i.e., *Deltoidospora*?) and *Leiosphaeridia* sp. and the top of the zone is defined by the presence of lowland rainforest *Polypodiaceoisporites* sp. (fern spores) and mangrove swamp *Zonocostites ramonae* (*Rhizophora* spp.). This palynological assemblage comprise brackish water swamp *Deltoidospora adriennis* (~30%), lowland rainforest trees of *Sapotaceoidaepollenites* sp.

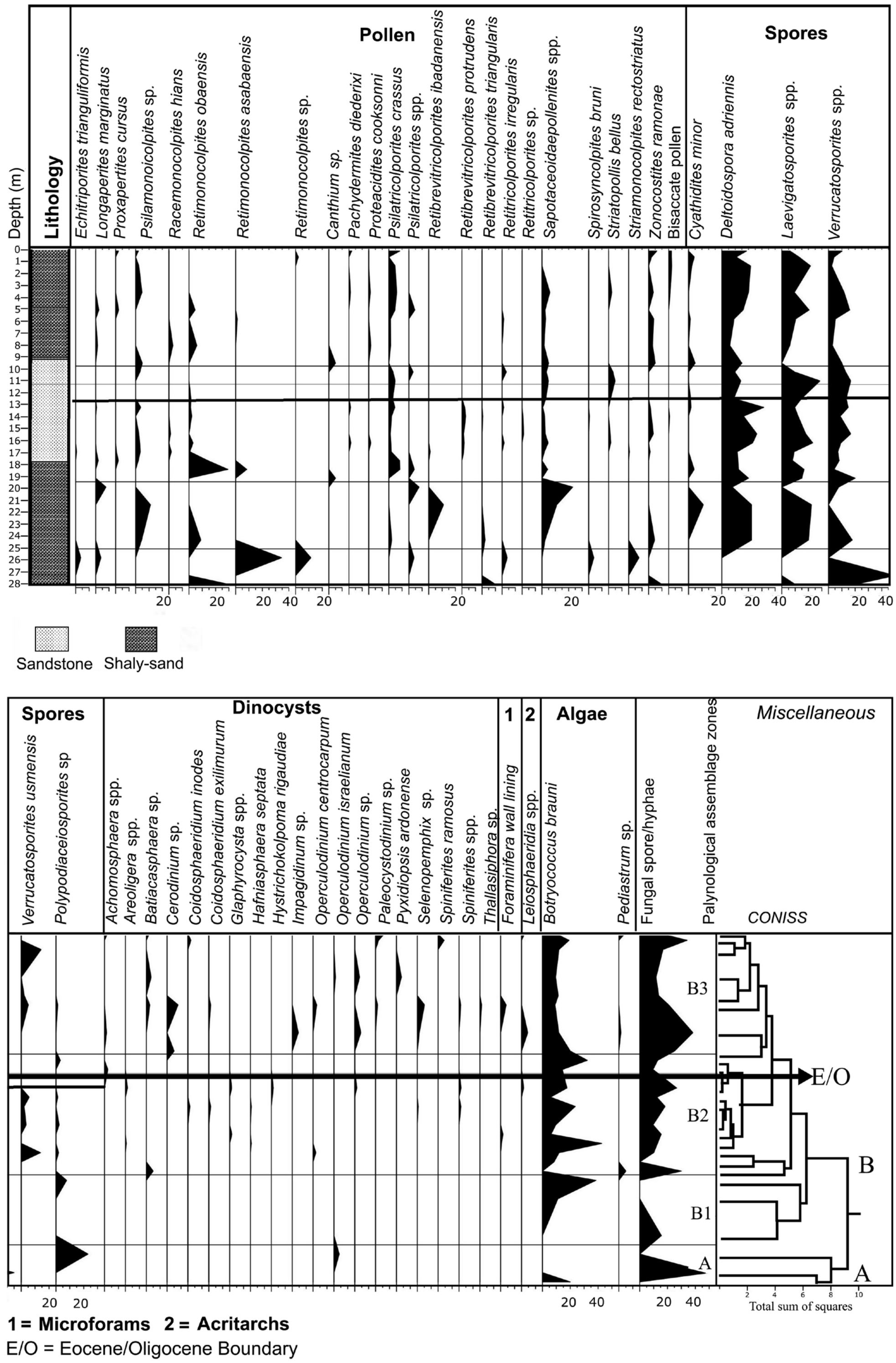

Figure 4a. Palynomorph distribution chart for Epe-1 borehole

(*Chrysophyllum africanum*; ~15%), fern spores of *Polypodiaceoisporites* sp., (~25%), fresh water swamp *Verrucatosporites* sp. (~25%), *Laevigatosporites* sp. (~20%), *Cyathides minor* (~5%), *Verrucatosporites usmensis* (~5%), *Retitricolporites irregularis* (*Amanoa*; ~5%), palms of *Psilamonocolpites* sp. (~5%), *Retimonocolpites obaensis* (~25%), mangrove of *Psilatricolporites crassus* (~15%) and mangrove swamp *Zonocostites ramonae* (*Rhizophora* spp.; 15%) associated with a few representatives of *Monoporites annulatus* (*Graminidites* sp.; ~5%) and *Cyperaceaepollis* sp. (*Cyperus*; ~5%). This palynogical assembalge indicates sediment deposition in a fluvio-deltaic/nearshore environment associated with pronounced wet climatic conditions (Durugbo and Olayiwola, 2017). The occurrence of dinocysts *Spiniferites*

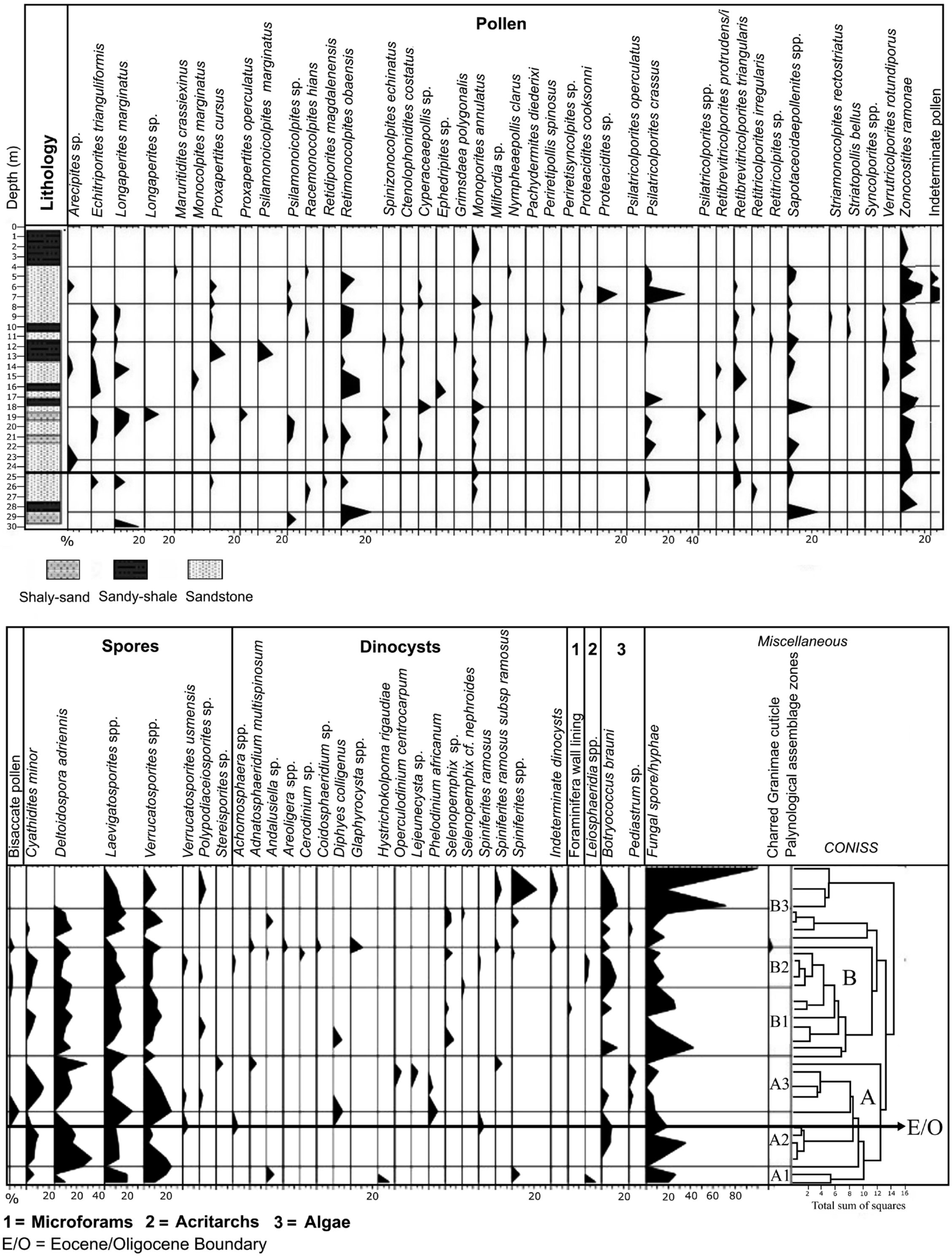

Figure 4b. Palynomorph distribution chart for Olokonla-1 borehole

ramosus (~3%), *Glaphyrocysta* sp. (~2%), *Adnatosphaeridium multispinosum* (~3%), *Phelodinium africanum* (~3%), *Operculodinium centrocarpum* (~2%), *Lejeunecysta* sp. (~3%), *Andalusiella* sp. (~3%), *Hystrichokolpoma rigaudiae* (~3%) in intermittent spots suggest occasional marine incursions (Quattrocchio et al., 2006; Guerstein et al., 2014; Mathews et al., 2018).

Fluvio-deltaic/nearshore environments of deposition have been reported from Campanian-Maastrichtian and Cenozoic sediments from the Tano Basin, Ghana and Niger Delta Basin, Nigeria, respectively (Atta-Peters et al., 2013; Durugbo and Olayiwola, 2017). The lowermost part of Olokonla-1 PAZ (palynozones A1 and A2) was dated to late Eocene due to the presence of *Verrucatosporites usmensis*,

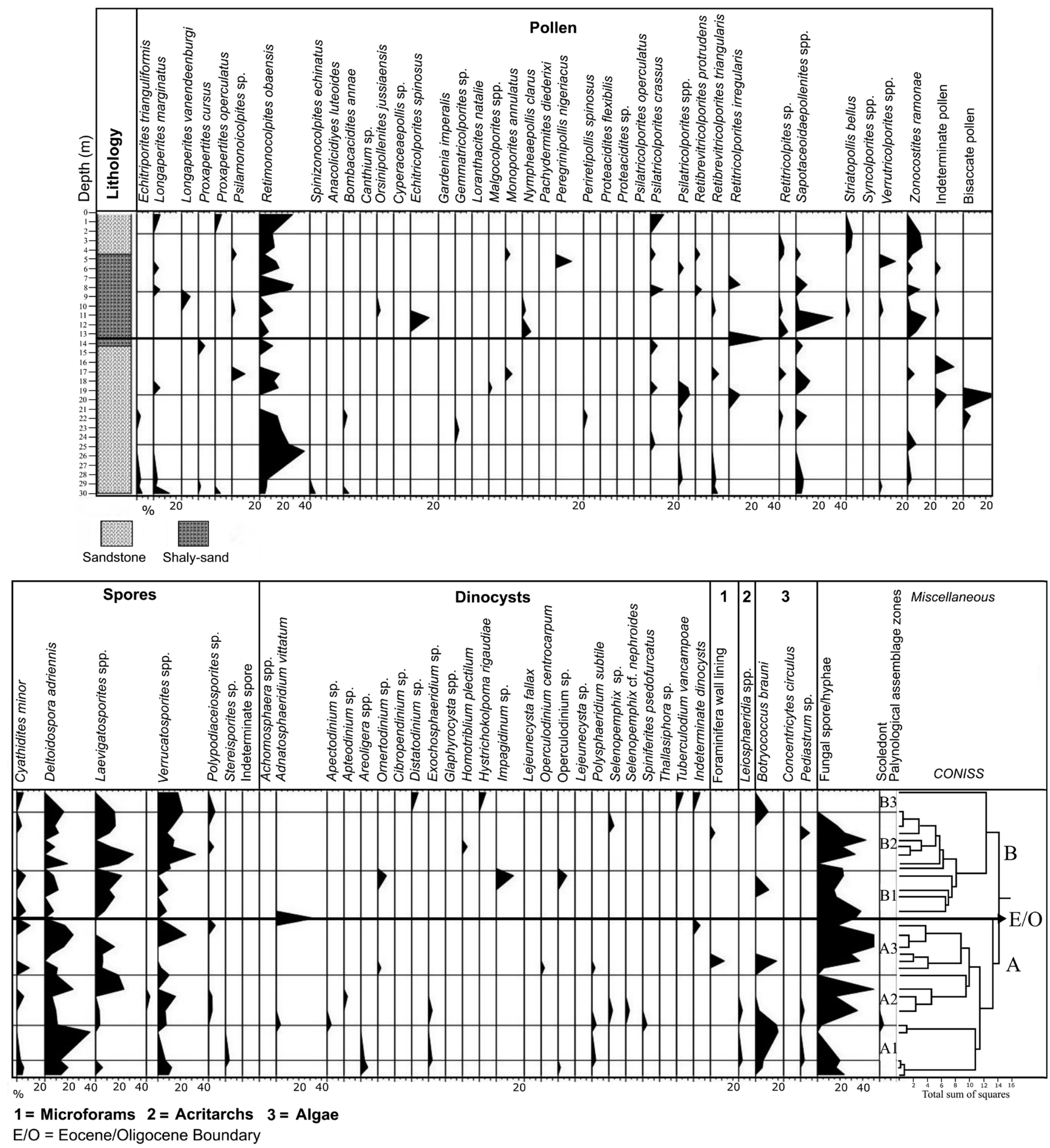

Figure 4c. Palynomorph distribution chart for Ikoyi-1 borehole

Adnatosphaeridium multispinosum and first occurrence of *Achomosphaera alcicornu* and the upper part (palynozones A3, B1, B2 and B3) was dated to early Oligocene owing to the occurrence of *Racemonocolpites hians* and *Selenopemphix nephroides* (Olayiwola et al., 2021).

PAZ in Ikoyi-1 borehole

The palynological assemblage of Ikoyi-1 borehole belongs to six informal palynozones A1 (30.0–24.75 m), A2 (24.75–19.5 m), A3 (19.5–12.50 m), B1 (12.5–8.50 m), B2 (8.50–2.50 m) and B3 (2.5–0.5 m) (Fig. 4c). The bottom of this palynological grouping is defined by the occurrence of *Echitriporites trianguliformis*, *Longapertites marginatus*, fresh water swamp fern spores *Cyathides minor* (*Cyathea* spp.), *Laevigatosporites* sp. and *Operlocudinium* sp. and the top is defined by the occurrence of *Botryococcus braunii*, lowland rainforest *Polypodiaceoisporites* sp. (fern spores) and *Striatopollis bellus*. The Ikoyi-1 PAZs were typified based on the common records of palm pollen *Longapertities marginatus* (~20%), *L. vandeenburgi* (~10%), *Retimonocolpites obaensis* (~15%), the mangrove swamp pollen *Zonocostites ramonae*

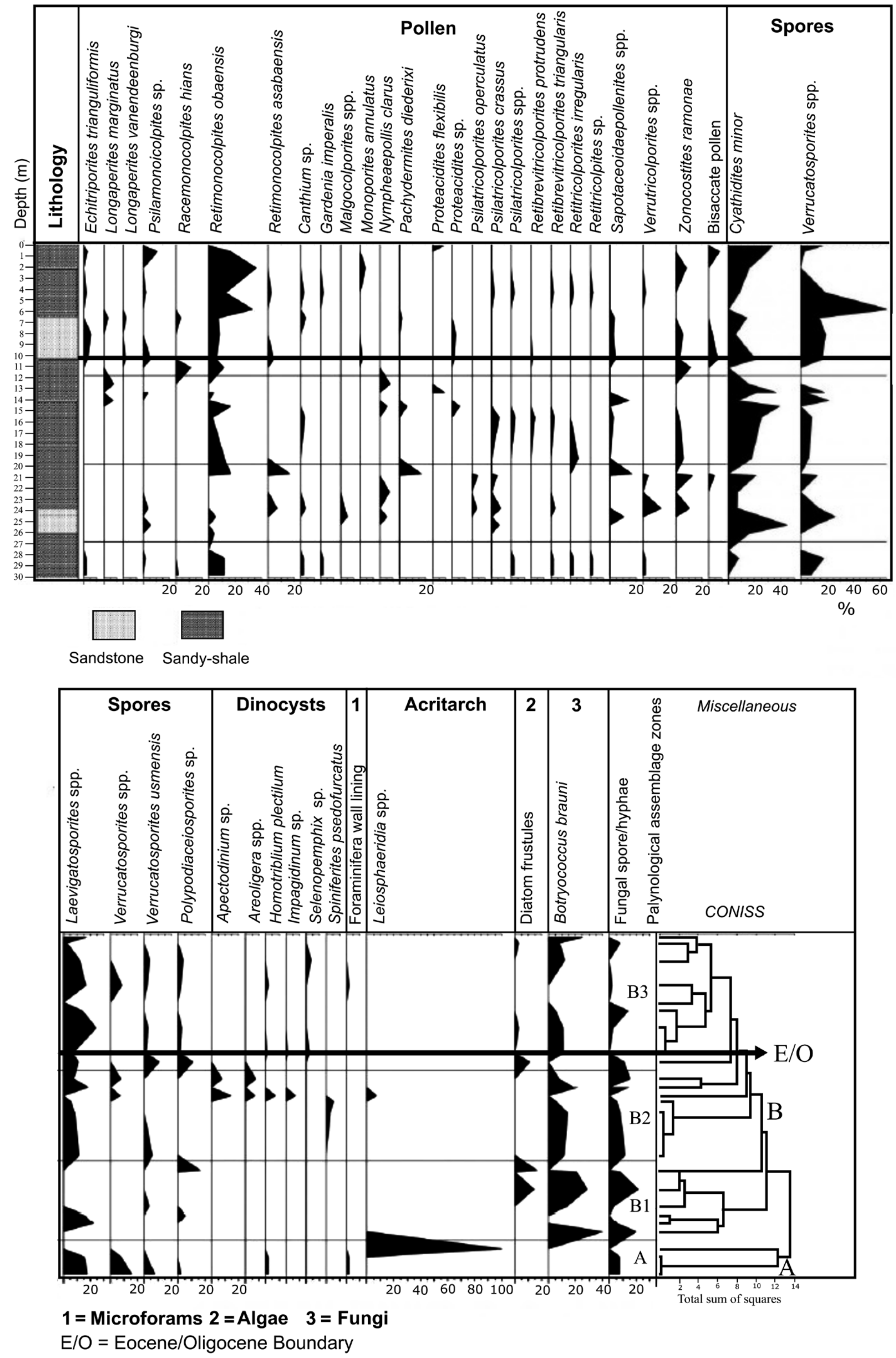

Figure 4d. Palynomorph distribution chart for Badore-1 borehole

(*Rhizophora* spp.; ~5%), *Psilatricolporites crassus* (~5%), lowland rainforest tree *Sapotaceoidaepollenites* sp. (*Chrysophyllum africanum*; ~15%), fresh water swamp *Retitricolporites irregularis* (*Amanoa* spp.; ~25%), in association with moderate records of brackish water species *Deltoidospora adriennis* (Pteridaceae; ~40%), fresh water swamp species *Verrucatosporites* sp. (fern spores; ~20%), *Laevigatosporites* sp. (fern spores; ~20%) and *Cyathidites minor* (*Cyathea* spp.; ~5%) associated with spot-like occurrences of the dinoflagellate cysts *Spiniferites pseudofurcatus* (~3%), *Adnatosphaeridium vittatum* (~15%), *Operculodinium* sp. (~5%), *Polysphaeridium subtile* (~5%), foraminiferal wall lining, fresh water algae *Botryococcus braunii* (~10%), *Pediastrum tetras* (~5%), and fungal elements (~25%) (Fig. 4c; Table 2). This assembalge suggests sediment deposition in fluvio-deltaic/nearshore and marginal marine environments during a wet climate (Guerstein et al., 2014; Mathews et al., 2018). Atta-Peters et al. (2013) and Durugbo and Olayiwola (2017) have reported fluvio-deltaic/nearshore environments for the deposition of Campanian-Maastrichtian and middle Miocene sediments from the Tano Basin, Ghana and Niger Delta Basin, Nigeria, respectively. The lowermost part of Ikoyi-1 PAZ (palynozones A1, A2 and A3) was dated to late Eocene due to the the first appearance of *Adnatosphaeridium multispinosum* and the presence of *Verrucatosporites usmensis* and the upper part (palynozones B1, B2 and B3) was dated to early Oligocene due to the presence of *Selenopemphix nephroides* and *Spiniferites pseudofurcatus* (Olayiwola et al., 2021; Fig. 3).

PAZ in Badore-1 borehole

The Badore-1 PAZ belongs to four palynozones A1 (30.00–27.00 m), B1 (27.00–20.00 m), B2 (20.00–12.00 m) and B3 (12.00–0.00 m) (Fig. 4d). Rainforest trees *Canthiumpollenites* sp. (*Rubia tinctorum*), fresh water swamp fern spores *Verrutricolporites* sp., *Retibrevitricolporites triangulatus*, *Psilatricolporites* sp. and *Echitricolporites trianguliformis* defined the base of this palynological assemblage. The Badore-1 palynological assemblage is characterized with the common records of the palm pollen *Longapertitites marginatus* (~10%), *Echitriporites trianguliformis* (~10%), *Retimonocolpites obaensis* (~10%), *R. asabaensis* (~10%), *Psilamoncolpites* sp. (~10%), *Racemonocolpites hians* (~10%), the mangrove pollen *Zonocostites ramonae* (*Rhizophora* spp.; ~10%) and *Psilatricolporites crassus* (*Alchornea cordifolia*; ~10%), rainforest trees *Sapotaceoidaepollenites* sp. (*Chrysophyllum africanum*; ~10%) and fresh water swamp *Retitricolporites irregularis* (*Amanoa* spp.; ~15%) in association with moderate records of pteridophyte spores *Deltoidospora adriennis* (Pteridaceae; ~15%), *Verrucatosporites usmensis* (fern spore; ~15%), *Laevigatosporites* spp. (~20%), *Cyathidites minor* (~10%), lowland rainforest trees *Canthiumpollenites* sp. (*Rubia tinctorum*; ~10%) and lowland rainforest fern spores *Polypodiaceoisporites* sp. (~10%), spot-like occurrences of the dinoflagellate cysts *Selenopemphix* sp., *Leiosphaeridia* sp., *Impagidinium* sp., *Homotryblium plectilum* and foraminiferal wall lining, fresh water algae *Botryococccus braunii* and fungal elements. Moderate to abundant records of the palms, fresh water swamp, lowland rainforest pollen co-occurring with frequent mangrove pollen suggests sediment deposition in a nearshore/deltaic environment in the lower part of Badore-1 borehole (palynozones A, B1 and B2; Fig. 4d) (Guerstein et al., 2014; Mathews et al., 2018). Moderate to spot-like occurrence of dinocysts and high percentage of acritarchs indicate marginal marine conditions in the upper part of Badore-1 (palynozone B3; Fig. 4d) (Guerstein et al., 2014; Mathews et al., 2018). The sediments were deposited during a wet climate as inferred from regular occurrence of palms, mangrove species, fresh water swamp species and common pteridophyte spores (Durugbo and Olayiwola, 2017). Atta-Peters et al. (2013) and Durugbo and Olayiwola (2017) have reported fluvio-deltaic/nearshore environments for the deposition of Campanian-Maastrichtian and Cenozoic sediments from the Tano Basin, Ghana and Niger Delta Basin, Nigeria, respectively. The lowermost part of Badore-1 (palynozones A, B1 and B2) was dated to late Eocene owing to the occurrence of *V. usmensis*, and the FADs of *H. plectilum* and *A. alcicornu*, while the upper part (palynozone B3) was dated to early Oligocene due to the occurrence of *Selenopemphix nephroides*, *Spiniferites Pseudofurcatus*, as well as *Racemonocolpites hians* (Olayiwola et al., 2021).

BIOSTRATIGRAPHIC EVENTS (BIOEVENTS) IN OLOKONLA-1, EPE-1, BADORE-1 AND IKOYI-1

Palynofloral assemblages of the boreholes (Olokonla-1, Epe-1, Badore-1 and Ikoyi-1) were characterized based on the pan-tropical palynomorphs of Germeraad et al. (1968). On the basis of these palynomorph assemblages, a late Eocene–early Oligocene age was allotted to the sediments of the boreholes. The Eocene–Oligocene (P470-P480/P520-P540) boundaries were placed at depths of 25.25 m, 11.25 m, 13.5 m and 10.5 m in Olokonla-1, Epe-1, Ikoyi-1, as well as Badore-1, respectively (Figs 3 and 4a–d). The late Eocene strata of these boreholes belong to P470-P480 subzones with the top characterized by the first appearance datum of *A. alcicornu* at depths 25.25 m, 11.25 m and 10.50 m in Epe-1, Olokonla-1 and Badore-1, correspondingly (Figs 3 and 4a–d). The FAD of *A. alcicornu* have been previously reported to have characterized the boundary between late Eocene and early Oligocene of the Marche-Umbria Basin, Italy (Odin and Montanari, 1989). In addition, the FAD of *H. plectilum* at a depth of 10.50 m in Badore-1 defined the boundary between late Eocene and early Oligocene in this borehole and this had been previously reported to have been linked to the eustatic curve of Haq et al. (1987). Besides, the FAD of *A. multispinosum* found at the depth of 13.5 m within Ikoyi-1 defined the E/O boundary in Ikoyi-1 (e.g. Haq et al., 1987). Moreover, the LAD of *H. tenuispinosum* was encountered at depths of 5.95 m (Ikoyi-1), 4.50 m (Badore-1) and 16.50 m (Epe-1) marked the top of these subzones in these boreholes (Figs 3 and 4a–d). However, *H. tenuispinosum* had been previously stratigraphically detailed from the late Eocene of Egypt (El Beialy, 1988). Conversely, the early Oligocene fits into the P520-P540 subzones with the base characterized through FAD of *A. alcicornu* at depths of 11.25 m in Epe-1 and 25.5 m in Olokonla-1 (Figs 3 and 4a, b). In addition, the FAD of *H. plectilum* at a depth of 10.50 m in Badore-1 borehole defined the bottom of this sub-zone in Badore-1 (Figs 3 and 4d). The FAD of *Adnatosphaeridium multispinosumat* at a depth of 13.50 m indicated the bottom of P520-P540 subzones in Ikoyi-1 borehole (Figs 3 and 4c). However, *H. plectilum* was found earlier from the early Oligocene within ODP Hole 959A, West Africa (Awad and Oboh-Ikuenobe, 2019).

RELATIVE RATE OF SEDIMENT ACCUMULATION

Graphic correlation of CS (Epe-1 borehole) against Olokonla-1, Ikoyi-1 and Badore-1 boreholes showed that each meter of sediment accretion in Epe-1 (CS) amounted to only 0.47 m, 0.56 m and 0.31 m of sediment exposed in Badore-1, Ikoyi-1 and Olokonla-1, respectively (Fig. 5A–C). The graphic correlation analysis showed that the rate of sediment accretion in Olokonla-1, Ikoyi-1 and Badore-1 is smaller amount than that in Epe-1 borehole. This implies that probably there was extra erosion going on and/or additional accommodation gap within Olokonla-1, Ikoyi-1 and Badore-1 compared to Epe-1. This has a sequence stratigraphic importance because changes in equilibrium versus rates of sediment accretion lead to accommodation gaps, which may correspond to transgressions and regressions locally (Catuneanu, 2002; Coe et al., 2002). For example, each meter of rock formed at Shangasi corresponds to just 0.2 m of sediment deposited at Guryul Ravine (Sweet, 1992). In addition, each meter of sediment at Maffett road corresponds to barely 0.6 m of rock formed at Cincinnati (28 km from each other) and the southeastern part of Indiana (Anstey and Rabbio, 1989). Moreover, Olayiwola et al. (2017) summarized that a single meter of sediment accretion in Well-E corresponds to merely 0.88 m, 0.76 m, 0.87 m, as well as 0.87 m of sediment in wells A, B, C and D, respectively, of the Niger Delta area. Furthermore, the application of graphic correlation for the estimation of the comparative rates of sediment accretion in five rock sections by Edwards (1984) showed different rates of sediment accumulation as follows: sections V (0.75), III (0.5), II (1.2), and I (1.0) have a distinct linear rate of accretion, whilst rock sections IV and VI have two and three subsections with different rates of accretion, respectively (1.5 and 1.25 in section IV), and (1.5, 2.5 and 3.0 in section VI). In addition, Edwards (1989) utilized complementary graphic correlation (CGC) to define four periods of deposition in the cores of the easternmost boreholes in relation to the cores of the western boreholes from the Virginia Coastal Plain. He revealed that two main alterations in the rock source and supply were documented throughout the late Paleocene, as well as early Eocene periods and these caused an increase in the relative sediment accretion rates of in the easterly, as well as northerly courses during those times, correspondingly. Besides, Belka et al. (1997) applied graphic correlation methods that showed significant variations in the rate of rock accretion linking the Tafilalt Platform with condensed sedimentation of ~2.5 m/Ma, as well as the Mader Basin, with rates equal to 40 m/Ma.

CORRELATION OF BIOSTRATIGRAPHIC EVENTS IN OLOKONLA-1, EPE-1, IKOYI-1 AND BADORE-1

The correlation equations obtained from the graphic correlation graphs (Fig. 5A–C) are engaged, in combination with the values of slope and intercept, in correlating the biostratigraphic events (i.e. bioevents; Fig. 3) in the boreholes (Epe-1, Olokonla-1, Ikoyi-1 and Badore-1; Table 3). These biostratigraphic events/bioevents, which have been explained in the palynostratigraphical zonation section above, comprise FAD of *Achomosphaera alcicornu*; FAD of *A. multispinosum*; LAD of *H. tenuispinosum*, as well as FAD of *H. plectilum* (i.e. mark P480/P520; Eocene–Oligocene boundaries; Fig. 3), and they are connected in the investigated four boreholes (Table 3). Regarding the fact that there are no models up

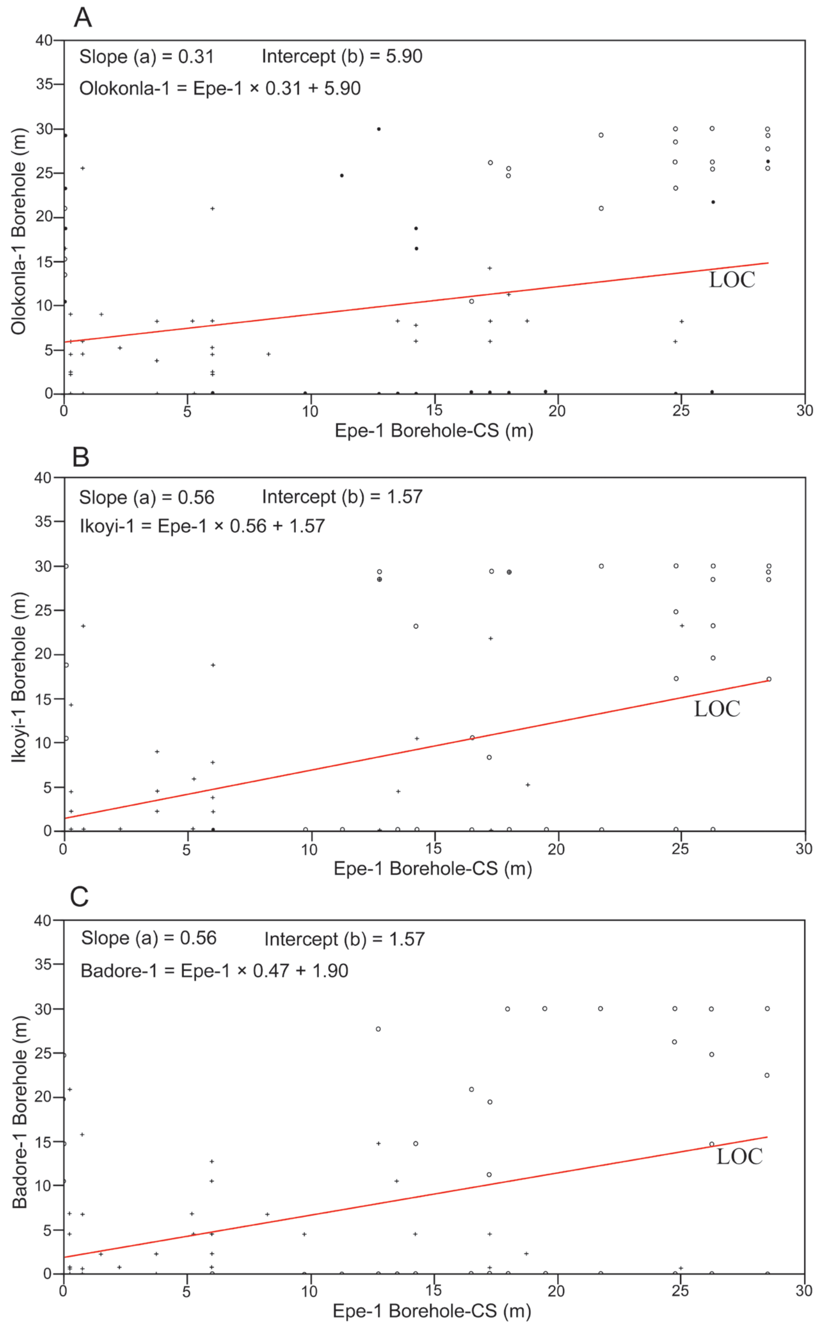

Figure 5. Graphic correlation plot of biostratigraphic ranges from (**A**) Epe-1 borehole (CS) vs Olokonla-1 borehole; (**B**) Epe-1 borehole (CS) vs Ikoyi-1 borehole and (**C**) Epe-1 borehole (CS) vs Badore-1 borehole. "+" represents last appearance datum LAD (tops), "o" represents first appearance datum FAD (bases) and LOC = Line of Correlation

to now from the Dahomey Basin, reports of comparable studies in other places are employed to illustrate these points as follows. Belka et al. (1997) assembled into a chronostratigraphic framework the total biostratigraphic ranges of 52 conodont taxa in seven Eifelian sections of the eastern Anti-Atlas in southern Morocco, north Africa. In addition, Anstey and Rabbio (1989) employed both gradient analysis and graphic correlation to designate significant regional correlations between sections, and a strong biostratigraphic zonation in the Edenian Basin (Kope Formation, Cincinnati Area), north America. Furthermore, Murphy and Berry (1983) utilized graphic correlation to link shelf and basin faunas, produce precise shelf margin histories and connect provincial shelf faunas of Central Nevada and other parts of the world. Besides, Rabe and Cisne (1980) work on graphic correlation that concluded in the association of two rocks of the Denley Limestone Basin (New York) on the basis of conodont biostratigraphic information. Another graphic correlation study on central North Sea

Table 3. Correlation of equivalent depth of biostratigraphic events in Epe-1, Olokonla-1, Ikoyi-1 and Badore-1 boreholes (note: precise equivalent depth). FAD – First appearance datum, LAD – Last appearance datum

Biostratigraphic events	Boundaries	Depth equivalent and palynofacies results in the studied four boreholes			
		Epe-1	Olokonla-1	Ikoyi-1	Badore-1
FAD of *Achomosphaera alcicornu*	P480/P520; Eocene/Oligocene	11.25 m	25.00 m	13.63 m	11.50 m
FAD of *Adnatosphaeridium multispinosum*	–	21.30 m	12.50 m	13.50 m	11.91 m
LAD of *Homotryblium tenuispinosum*	–	16.50 m	11.01 m	10.81 m	9.66 m
FAD of *Homotryblium plectilum*	–	20.40 m	12.22 m	13.00 m	11.50 m

subsurface rock section and Paleogene rock outcrops from N and NW Europe established a chronostratigraphic framework for the Paleogene of NW Europe (Neal et al., 1994). Finally, the high-resolution correlation of nine Middle Devonian rock sections of the Belgian Ardennes was established with the support of graphic correlation (Gouwy and Bultynck, 2000).

CONCLUSION

The lithostratigraphic study of the late Eocene to early Oligocene sedimentary rocks from the Dahomey Basin revealed three (3) lithologies, shaly sand, sandstone, and sandy-shale. The sandstone and shaly sand which form during period of sea level fall are possibly reservoir rocks, while sandy-shale, which forms due to sea level rise, forms most likely source, as well as seal rocks in the studied boreholes of the Dahomey Basin.

Two key palynological zones, namely the *V. usmensis*, as well as *M. howardi* pan-tropical were delineated. These were associated with P500, as well as P400 zones of Evamy et al. (1978) that were further differentiated into subzones, especially the P470 and P480, and the P520 and P540. First appearance datum (FAD) of *Achomosphaera alcicornu* marked the late Eocene–early Oligocene boundary (E/O) in boreholes Epe-1, Olokonla-1, and Badore-1, while FAD of *Adnatosphaeridium multispinosum* defined the late Eocene–early Oligocene boundary (E/O) in the Ikoy-1 borehole. In addition, FADs of *A. alcicornu*, *H. plectilum* and *A. multispinosum*; the LAD of *H. tenuispinosum*; and the occurrence of *V. usmensis*, as well as *R. hians* are the palynological conditions that characterized late Eocene (P470-P480 subzone). Furthermore, the occurrence of *Selenopemphix nephroides* and *Spiniferites pseudofurcatus*, the base FAD of *Racemonocolpites hians*, and the occurrence of *A. exilimuratus* are the palynological conditions that defined the lower Oligocene (P520-P540 subzone). Two informal palynological assemblage zones (PAZ A and PAZ B) were delineated in the four boreholes. The frequent occurrence of palms, mangrove, fresh water swamp, brackish water swamp species and common pteridophyte spores with spot-like records of marine elements, dinoflagellate cyst, microforaminiferal wall lining and algae species during occasional marine incursion suggested the fluctuation of depositional environments from fluvio-deltaic/nearshore to marginal marine. The graphic correlation technique revealed that there is either extra erosion and/or a smaller accommodation gap in Epe-1 borehole than in the rest of the three investigated boreholes for the reason that for a single meter of sediment accretion in Epe-1 borehole 44–69% less sediment was deposited in Olokonla-1, Ikoyi-1 and Badore-1 boreholes (0.31 m, 0.56 m and 0.47 m, respectively). The graphic correlation method allows the correlation of four biostratigraphic events (FAD of *A. alcicornu*, FAD of *A. multispinosum*, LAD of *H. tenuispinosum* and FAD of *Homotryblium plectilum* (Fig. 3). The results of this investigation will be practical in the interpretation of both local and regional correlations of well sections, interpretation of depositional sequences, as well as environments and instituting the chronostratigraphic framework for basins. Therefore, graphic correlation has added speedy computation of the relative rate of the accumulation of sediments and the rapid correlation of geological events via equation of correlation to the existing methods.

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REFERENCES

Adeigbe, O.C., Ola-Buraimo, A.O., Moronhunkola, A.O., 2013. Palynological Characterization of the Tertiary Offshore Emi-1 Well, Dahomey Basin, Southwestern Nigeria. International Journal of Scientific and Technology Research 2, 58–70. http://www.ijstr.or

Adeniran, O.A., 2015. Upper Cretaceous to paleogene palynosequence stratigraphy of H-1 welloffshore Eastern Dahomey Basin, Southwestern Nigeria. International Journal of Research and Innovations in Earth Science 2(3), 2394–1375.

Adojoh, O., Marret, F., Duller, R., Osterloff, P., 2017. Tropical palaeovegetation dynamics, environmental and climate change impact from the low latitude Coastal Offshore Margin, Niger Delta, Gulf of Guinea. In: Runge, J. (ed.), The African Neogene – Climate, Environments and People. Palaeoecolgy of Africa, pp. 1–38.

Adojoh, O., Fabienne, M., Duller, R., Osterloff, P., 2019. Taxonomy and phytoecology of palynomorphs and non-pollen palynomorphs: a refined compendium from the West Africa Margin. Biodiversity International Journal 3(5), 188–200. https://doi.org/10.15406/bij.2019.03.00145

Al-Areeq, N.M., Albaroot, M., 2019. Source rocks evaluation and thermal maturity evolution of the Dhamar Ali Field, Sab'atayn Basin, Yemen. Asian Journal of Science and Technology 10(1), 9364–9374.

Aniefiok, E.I., Usenobong, F.U., Margaret, U.I., Idongesit, O.I., Udo, J.I., 2016. Petroleum Industry in Nigeria: Environmental Issues, National Environmental Legislation and Implementation of International Environmental Law. American Journal of Environmental Protection 4(1), 21–37. https://doi.org/10.12691/env-4-1-3

Anstey, R.L., Rabbio, S.F., 1989. Regional bryozoan biostratigraphy and taphonomy of the Edenian Stratotype (Kope Formation, Cincinnati Area): graphic correlation and gradient analysis. Palaios 4, 574–584. https://doi.org/10.2307/3514747

Asadu, A.N., Nkem, J.F., 2020. Palynostratigraphy of Well Z., OPL 310, Offshore Dahomey Basin, South-Western Nigeria. IOSR Journal of Applied Geology and Geophysics 8(2), 51–61.

Atta-Peters, C.I., Agama, D.K., Asiedu, E.A., 2013. Palynology, palynofacies and palaeoenvironments of sedimentary organic matter from Bonyere-1 Well, Tano basin, western Ghana. International Letters of Natural Sciences 5, 27–45.

Awad, W.K., Oboh-Ikuenobe, F.E., 2019. Paleogene-early Neogene paleoenvironmental reconstruction based on palynological analysis of ODP Hole 959A, West Africa. Marine Micropaleontology 148, 29–45. https://doi.org/10.1016/j.marmicro.2019.03.003

Babalola, O.O., 1988. Tectonic Evolution and Hydrocarbon Prospectivity of Nigerian Frontier Grabens of Dahomey Basin from Interpretation of New Aeromagnetic and Existing Seismic and Geophysical Data. AAPG Search and Discovery Article #91030©1988 AAPG Annual Convention, Houston, Texas, 20–23 March 1988. https://www.searchanddiscovery.com/abstracts/html/1988/annual/abstracts/0156c.htm. Cited on June 07 2022.

Bankole, S.I., Shrank, E., Erdtmann, B.D., Akande, S.O., 2006. Palynostratigraphic age and paleoenvironments of the newly exposed section of the Oshosun Formation in the Sagamu quarry, Dahomey Basin, Southwestern, Nigeria. Nigerian Association of Petroleum Explorationists Bulletin 19, 25–34.

Bankole, S.I., Schrank, E., Adeonipekun, P., 2016. Paleoecology of the Neogene Agbada Formation, Niger Delta, Nigeria. Ife Journal of Science Special Edition 18, 845–859.

Belka, Z., Kaufmann, B., Bultynck, P., 1997. Conodont-based quantitative biostratigraphy for the Eifelian of the eastern Anti-Atlas, Morocco. Geological Society of America Bulletin 109(6), 643–651.

Berggren, W.A., Prothero, D.R., 1992. Eocene-Oligocene climatic and biotic evolution: An overview. In: Berggren, W.A., Prothero, D.R. (eds), Eocene-Oligocene Climatic and Biotic Evolution, pp. 1–28. Princeton University Press. http://www.jstor.org/stable/j.ctt7zvp65.5

Billman, H.G., 1976. Offshore stratigraphy and paleontology of the Dahomey embayment. Proceedings of the 7th African Micropaleontological Colloquium, March 16–28, Ile-Ife, Nigeria.

Bolaji, T.A., Ndukwe, O.S., Oyebamiji, A.R., Ikegwuonu, O.N., 2020. Palynological Age Control and Paleoenvironments of the Paleogene Strata in Eastern Dahomey Basin, Southwestern Nigeria. Science Reports 10, 8991. https://doi.org/10.1038/s41598-020-65462-7

Brownfield, M.E., Charpentier, R.R., 2006. Geology and total petroleum systems of the Gulf of Guinea Province of West Africa. U.S. Geological Survey Bulletin 2207-C, pp. 1–32.

Burroughs, W.J., 2001. Climate Change: A multidisciplinary approach. Cambridge: Cambridge University press.

Burroughs, W.J., 2007. Climate Change: A multidisciplinary approach. Cambridge: Cambridge university press.

Catuneanu, O., 2002. Sequence stratigraphy of clastic systems: concepts, merits, and pitfalls, Journal of African Earth Sciences 35(1), 1–43. https://doi.org/10.1016/S0899-5362(02)00004-0

Chukwuma-Orji, J.N., Okosun, E.A., Goro, I.A., Waziri, S.H., 2017. Palynofacies, sedimentology and palaeoenvironment evidenced by studies on IDA-6 well, Niger Delta, Nigeria. Palaeoecology of Africa 34, 87–105.

Coe, A., Bosence, D., Church, K., Flint, S., Howell, J., Wilson, Ch., 2002. The Sedimentary Record of Sea Level Change. Cambridge University Press, 288 pp.

Cronin, T.N., 2010. Paleoclimates: understanding climate change past and present. New York: Columbia University Press.

Descalzi, C., 2015. World Oil and Gas Review. https://www.eni.com/assets/documents/WOGR-2015-unico.pdf

Dim, C.I.P., Mode, A.W., Okwara, I.C., 2018. Signatures of key petroleum system elements: outcrop examples from the Anambra Basin. Southeastern Nigeria. Journal of Petroleum Exploration and Production Technology, 1–17. https://doi.org/10.1007/s13202-018-0589-2

Dockery, D.T., 1986. Punctuated succession of Paleogene mollusks in the Northern Gulf Coastal Plain. Palaios 1, 582–589. https://doi.org/10.2307/3514708

Dowsett, H.J., 1989. Application of the graphic correlation method to Pliocene marine sequences. Marine Micropaleontology 14(1–3), 3–32. https://doi.org/10.1016/0377-8398(89)90030-3

Durugbo, E.U., Olayiwola, M.A., 2017. Palynological dating and palaeoenvironments of the M1 well, Middle Miocene, Niger Delta, Nigeria. Palaeontologia Africana 52, 46–57.

Edwards, L.E., 1984. Insight s on why graphic correlation (Shaw's method) work. The Journal of Geology 92, 583–597.

Edwards, L.E., 1989. Supplemented graphic correlation: a powerful tool for paleontologists and nonpaleontologists. Palaios 4(2), 127–143. https://doi.org/10.2307/3514601

El Atfy, H., El Diasty, W.S., El Beialy, S.Y., Gheith, A.M., Batten, D.J., Agha, N.N., 2017. Palynofacies and geochemical analyses of the Upper Cretaceous–Eocene succession, western Sirte Basin, Libya: Palaeoenvironmental interpretation and implications for hydrocarbon generation potential. Journal of Petroleum Science and Engineering 157, 148–163. https://doi.org/10.1016/j.petrol.2017.07.021

El Atfy, H., El Beialy, S.Y., El Khoriby, E.M., Uhl, D., 2021. Continental palynomorphs from the Dabaa Formation, North-Western Desert, Egypt: a contribution to the reconstruction of the vegetation on the southern shores of the Tethys Ocean during the Early Oligocene. Botanical Journal of the Linnean Society 197, 291–321. https://doi.org/10.1093/botlinnean/boab024

El Atfy, H., El Beialy, S.Y., Zobaa, M.K., Tahaa, A.A., Uhl, D., 2022. A snapshot into the Oligocene vegetation of the Tethyan southern shores: new fossil pollen evidence from North Africa (Egypt). Palynology 46(3), 1–17. https://doi.org/10.1080/01916122.2021.2023057

El Beialy, S.Y., 1988. Palynostratigraphy of late Tertiary sediments of Kafr El Dawar well no. 1, Nile Delta, Egypt. Revue de Micropaléontologie 30, 249–260.

El Beialy, S.Y., Head, M.J., El Atfy, H., El Khoriby, E.M., 2019. Dinoflagellate cyst evidence for the age and palaeoenvironments of the Upper Eocene–Oligocene Dabaa Formation, Qattara Depression, north Western Desert, Egypt. Palynology 43, 268–291. https://doi.org/10.1080/01916122.2018.1434696

Evamy, B.D., Haremboure, J., Kamerling, P., Knapp, W.A., Molloy, F.A., Rowlands, P.H., 1978. Hydrocarbon habitat of the Tertiary Niger delta. American Association of Petroleum Geologists Bulletin 62, 1–39.

Fadiya, S.L., Jaiyeola-Ganiyu, F.A., Fajemila, O.T., 2014. Foraminifera biostratigraphy and paleoenvironment of sediments from Well AM-2, Niger Delta. Ife Journal of Science 16(1), 61–72.

Fajemila, O.T., 2012. Foraminifera Biostratigraphy and Paleoenvironmental Studies of Two Wells from Offshore Western Niger Delta. Ife Journal of Science 14(2), 369–384.

Fajemila, O.T., Olayiwola, M.A., Durugbo, E.U., 2022. Palynostratigraphy and paleoenvironmental analysis of late Miocene-early Pliocene sediments from ML-1 well, Offshore Eastern Niger Delta, Nigeria. Neues Jahrbuch fur Geologie und Paläontologie Abhandlungen 304(2), 205–220. https://doi.org/10.1127/njgpa/2022/1065

Faegri, K., Iversen, J., Kaland, P.E., Krzywinski, K., 1989. Textbook of pollen analysis (4th ed.). John Wiley and Sons, Chichester, pp. 1–328.

Fozao, K.F., Djieto-Lordon, A.E., Ali, E.A.A., Agying, C.M., Ndeh, D.M., Zebaze, D.M.K., 2019. Analysis of shaly sand reservoir rocks in the eastern Niger Delta Basin using geophysical well logs. Journal of Petroleum and Gas Engineering 10(1), 1–13. https://doi.org/10.5897/JPGE2018.0300

Frederiksen, N.O., 1988. Sporomorph biostratigraphy, floral changes, and palaeoclimatology, Eocene and Earliest Oligocene of the Eastern Gulf Coast. U. S. Geological Survey Professional Paper 1448, 1–68.

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

Gough, A., Hall, R., 2017. Oligocene Fluvio-Deltaic Depositional Environments Salin Sub-Basin, Central Myanmar. American Geophysical Union, Fall Meeting 2017, abstract #EP21F-1904. https://ui.adsabs.harvard.edu/abs/2017AGUFMEP21F1904G/abstract

Gouwy, S., Bultynck, P., 2000. Graphic correlation of Frasnian sections (upper Devonian) in the ardennes, Belgium. Bulletin De l'Institut Royal Des Sciences Naturelles De Belgique, Sciences De La Terre 70, 25–52.

Guerstein, G.R., González, E.M., Sol Alperín, M.I., Casadío, S.A., Archangelsky, S., 2014. Correlation and paleoenvironments of middle Paleogene marine beds based on dinoflagellate cysts in southwestern Patagonia, Argentina. Journal of South American Earth Sciences 52, 166–178. https://doi.org/10.1016/j.jsames.2014.02.011

Haasl, D.M., Hansen, T.A., 1996. Timing of latest Eocene molluscan extinction patterns in Mississippi. Palaios 11, 487–494.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2007. PAST: Paleontological Statistics Software Package for

Education and Data Analysis. Palaeontologia Electronica 4(1), art. 4.

Haq, B.U., Handerbol, J., Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. Science 235, 1156–1167. https://doi.org/10.1126/science.235.4793.1156

Ikegwuonu, O.N., Umeji, O.P., 2016. Palynological age and palaeoenvironment of deposition of Mid-Cenozoic sediments around Umuahia, Niger delta basin, southeastern Nigeria. Journal of African Earth Sciences 117(1), 160–170. https://doi.org/10.1016/j.jafrearsci.2016.01.010

Ikegwuonu, O.N., Umeji, O.P., Chiaghanam, O.I., Nwozor, K.K., Ndukwe, O.S., 2020. Palynomorph assemblage biozonation of Paleogene strata in Bende–Umuahia Area, Niger Delta Basin, southeastern Nigeria. Journal of Palaeogeography 9, 13. https://doi.org/10.1186/s42501-020-00061-1

Ivany, L., Patterson, W., Lohmann, K., 2000. Cooler winters as a possible cause of mass extinctions at the Eocene/Oligocene boundary. Nature 407, 887–890. https://doi.org/10.1038/35038044

Jaramillo, C., Rueda, M., Bayona, G., Santos, C., Florez, P., Parra, F., 2009. Biostratigraphy breaking paradigms: dating the Mirador Formation in the llanos Basin of Colombia. In: Demchuk, T. (ed.), Biostratigraphic Applications. SEPM Special Publication 93, 29–40.

Jones, H.A., Hockey, R.D., 1964. The geology of part of Southwestern Nigeria. Geological Survey Nigeria. Bulletin 31, 1–101.

Kadafa, A.A., 2012. Environmental Impacts of Oil Exploration and Exploitation in the Niger Delta of Nigeria. Global Journal of Science Frontier Research Environment & Earth Sciences 12(3), 19–28.

Kadafa, A.A., Mohamad, P.Z., Othman, F., 2012. Oil Spillage and Pollution in Nigeria: Organizational Management and Institutional Framework. Journal of Environment and Earth Science 2(4), 2224–3216.

Krapez, B., 1996. Sequence stratigraphic concepts applied to the identification of basin-filling rhythms in Precambrian successions. Australian Journal of Earth Sciences 43(4), 355–380. https://doi.org/10.1080/08120099608728260

Krapez, B., 1997. Sequence-stratigraphic concepts applied to the identification of depositional basins and global tectonic cycles. Australian Journal of Earth Sciences 44(1), 1–36. https://doi.org/10.1080/08120099708728291

Krebs, W.N., 2011. Upper Tertiary chronosequence stratigraphy of offshore Sabah and Sarawak, NW Borneo, Malaysia: a unified scheme based on graphic correlation. Bulletin of the Geological Society of Malaysia 57, 39–46.

Krebs, W.N., Wescott, W.A., Nummedal, D., Gaafar, I., Azazi, G., Karamat, S., 1997. Graphic Correlation and sequence stratigraphy of Neogene rocks in the Gulf of Suez. Bulletin de la Société Géologique de France 168(1), 63–71.

Legoux, O., 1978. Quelques espaces de pollen caracteristiques du Neogane du Nigeria; Bulletin Centres Recherche Exploration-Production d'Elf-Aquitaine 2(2), 265–317.

Lehner, P., De Ruiter, P.A.C., 1977. Structural history of Atlantic Margin of Africa. The American Association of Petroleum Geologist Bulletin 61(7), 961–981.

Mann, K.O., Lane, H.R., 1995. Graphic Correlation: A Powerful Stratigraphic Technique Comes of Age. In: Mann, K.O., Lane, R. Scholle, P.A. (eds), Graphic Corellation. SEPM Society for Sedimentary Geology 53. https://doi.org/10.2110/pec.95.53.0003

Mathews, R.P., Singh, B., Singh, H., Singh, V.P., Singh, A., 2018. Characterization of Panandhro Lignite Deposits (Kachchh Basin), western India: Results from the Bulk Geochemical and Palynofloral Compositions. Journal of the Geological Society of India 91(3), 281–289. https://doi.org/10.1007/s12594-018-0851-8

Miller, F.X., 1977. The graphic correlation method in biostratigraphy. In: Kauffman, E., Hazel, J. (eds), Concepts and Methods of Biostratigraphy. Hutchinson, and Ross, Stroudsburg, Dowden, pp. 165–186.

Mkinga, O.J., Skogen, E., Kleppe, J., 2020. Petrophysical interpretation in shaly sand formation of a gas field in Tanzania. Journal of Petroleum Exploration and Production Technology 10, 1201–1213.

Murphy, M.A., Berry, W.B.N., 1983. Early Devonian conodont-graptolite collation and correlations with brachiopod and coral zones, central Nevada. AAPG Bulletin 67(3), 371–379.

Neal, J.E., Stein, J.A., Gamber, J.H., 1994. Graphic correlation and sequence stratigraphy of the Paleogene of NW Europe. Journal of Micropalaeontology 13, 55–80. https://doi.org/10.1144/jm.13.1.55

Obaje, N.G., 2009. Geology and Mineral Resources of Nigeria. Lecture Notes in Earth Sciences, vol. 120. Springer, Berlin, Heidelberg, pp. 103–108. https://doi.org/10.1007/978-3-540-92685-6_9

Oboh, F.E., Jaramillo, C.A., Reeves-Morris, L.M., 1996. Late Eocene-Early Oligocene paleofloristic patterns in southern Mississippi and Alabama, US Gulf Coast. Review of Palaeobotany and Palynology 91, 23–34. https://doi.org/10.1016/0034-6667(95)00075-5

Odeyemi, O., Ogunseitan, O.A., 1985. Petroleum Industry and its Pollution Potential in Nigeria. Oil and Petroleum Pollution, Elsevier Applied Science Publishers Ltd, England 2, 223–229. http://dx.doi.org/10.1016/S0143-7127(85)90218-2

Odin, G.S., Montanari, A., 1989. Age radiométrique et stratotype de la limite Éocène Oligocène. Comptes Rendus de l'Académie des Sciences, Paris, 309, 1939–1945.

Ogbe, F.G.A., 1972. Stratigraphy of Strata exposed in Ewekoro quarry, Western Nigeria. In: Dessauvagie, T.F.J., Whiteman, A.J. (eds), African Geology. Ibadan University Press, pp. 305–322.

Okosun, E.A., 1990. A review of the Cretaceous Stratigraphy of Dahomey Embayment West Africa. Cretaceous Research 11, 17–27.

Olayiwola, M.A., 2021. Sequence stratigraphy and depositional systems of late Miocene to early Pliocene deep offshore Niger Delta, southeastern Nigeria. Arabian Journal of Geosciences 14, 979. https://doi.org/10.1007/s12517-021-07361-3

Olayiwola, M.A., Bamford, K.M., 2019. Depositional environment and reservoir characterization of the deep offshore Upper Miocene to Early Pliocene Agbada Formation, Niger delta, Nigeria. Journal of African Earth Sciences 159, 103578. https://doi.org/10.1016/j.jafrearsci.2019.103578

Olayiwola, M.A., Bamford, M.K., Durugbo, E.U., 2017. Graphic correlation: A powerful tool for biostratigraphic correlation of petroleum exploration and production in the Cenozoic deep offshore Niger Delta, Nigeria. Journal of African Earth Sciences 131, 156–165.

Olayiwola, M.A., Durugbo, E.U., Fajemila, O.T., Oyebanjo, M.O., 2021. Sequence stratigraphy of subsurface upper Eocene-lower Oligocene deposits, Dahomey Basin, Southwestern Nigeria: palynological and palynofacies approach. Arabian Journal of Geosciences 14, 1420. https://doi.org/10.1007/s12517-021-07693-0

Olayiwola, M.A., Aderogba, A.A., Durugbo, U.E., Fajemila, T.O., Aderanti, A.A., 2022. Palaeoenvironmental Reconstruction and Hydrocarbon Potential of some Mid-Upper Cretaceous and Late Eocene-Early Oligocene sediments from two Southern Nigerian Inland Basins: Insights from Palynology and Palynofacies. Journal of Mining and Geology 58(1), 173–188.

Omatsola, M.E., Adegoke, O.S., 1981. Tectonic evolution and Cretaceous stratigraphy of the Dahomey Basin. Journal of Mining and Geology 18(1), 130–137.

Onuoha, K.M., Dim, C.I., 2016. Prospects and Challenges of Developing Unconventional Petroleum Resources in the Anambra Inland Basin of Nigeria. Paper presented at the SPE/AAPG Africa Energy and Technology Conference, Nairobi City, Kenya, December 2016. Paper Number: SPE-AFRC-2571791-MS. https://doi.org/10.2118/AFRC-2571791-MS

Quattrocchio, M.E., Martínez. M.A., Carpinelli Pavisich, A., Volkheimer, W., 2006. Early Cretaceous palynostratigraphy, palynofacies and palaeoenvironments of well sections in northeastern Tierra del Fuego, Argentina. Cretaceous Research 27(4), 584–602. https://doi.org/10.1016/j.cretres.2005.11.012

Rabe, B.D., Cisne, J.L., 1980, Chronostratigraphic accuracy of ecostratigraphic correlation. Lethaia 13, 109–118.

Reyment, R.A., 1965. Aspects of the geology of Nigeria. Ibadan University Press, pp. 1–144.

Rull, V., 2002. High-Impact Palynology in Petroleum Geology: Applications from Venezuela (Northern South America). AAPG Bulletin 86(2), 279–300.

Salami, M.B., 1983. Upper Senonian and Lower Tertiary pollen grains from the Southern Nigeria Sedimentary Basin. Revista Espanola de Micropaleontologia 25, 5–26.

Sciumbata, M., Weedon, J.T., Bogota-Angel, G., Hoorn, C., 2021. Linking modern-day relicts to a Miocene mangrove community of western Amazonia. Palaeobiodiversity and Palaeoenvironments 101(1), 123–140. https://doi.org/10.1007/s12549-020-00470-z

Selley, R.C., 1976. Subsurface environmental analysis of North Sea sediments. Bulletin of the American Association of Petroleum Geologist 60, 184–195.

Shaw, A.B., 1964. Time in Stratigraphy. McGraw Hill Book Co. New York, pp. 1–365.

Short, K.C., Stauble, A.J., 1967. Outline of Geology of Niger delta: American Association of Petroleum Geologists Bulletin 51, 761–779.

Singh, H., Prasad, M., Kumar, K., Singh, S.K., 2015. Early Eocene macroflora and associated palynofossils from the Cambay Shale Formation, western India: Phytogeographic and palaeoclimatic implications. Palaeoworld 24, 293–323.

Stuchlik, L., 2001. Atlas of pollen and spores of the Polish Neogene. Vol. 1 – Spores. 158. W. Szafer Institute of Botany, Polish Acadamy of Sciences, Kraków.

Sweet, W.C., 1992. A Conodont-based high-resolution biostratigraphy of the PermoTriassic boundary interval. In: Sweet, W.C., Yang, Z.Y., Dickins, J.M., Yin, H.F. (eds), Permo-Triassic Events in Eastern Tethys. Cambridge University Press, Cambridge, pp. 120–133.

Willumsen, P.S., 2004. Palynology of the Lower Eocene deposits of northwest Jutland, Denmark. Bulletin of the Geological Society of Denmark 52, 141–157.

Zarei, E., 2017. Palynofacies analysis and paleoenvironmental interpretation of the Dalichai Formation, northeast of Semnan. Geopersia 7(1), 27–34. https://doi.org/10.22059/geope.2017.224223.648291