Spontaneous Article

Palynostratigraphy, biochronology and palaeobathymetry of a section of Awaizombe-1 well, eastern Niger Delta, Nigeria

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ABSTRACT: Ditch cuttings (69 samples) from a section of Awaizombe-1well located in the Northern Depobelt of the eastern Niger Delta Basin were used for this study. The lithology of the studied interval 1373–1812 m (439 m thick) consists of fissile grey shale and mudstone units. The scid method of sample preparation for palynormorphs' recovery was adopted. Analysis recorded a well-preserved and diverse assemblage of palynomorphs, rich in pollen, spores and dinoflagellate cysts (dinocysts). First and last occurrences of marker and age diagnostic species were used for palynostratigraphic interpretation. Four palynostratigraphic interval range zones were established: *Psilatriporites* sp.–*Racemonocolpites hians* Zone; early Oligocene (Rupelian age), *Praedapollis africanus*–*Doualaidites laevigatus* Zone; late Eocene (Priabonian age), middle Eocene (Lutetian and Bartonian ages), *Doualaidites laevigatus*–*Praedapollis flexibilies* Zone; and early Eocene (Ypresian age), *Verrucatosporites usmensis*–*Retitricolpites ituensis* Zone. The first downhole occurrence of *D. laevigatus* at the 1482 m marks the late Eocene/early Oligocene boundary. Established zones are useful for inter and intra basins correlation. Lithology and age of the studied section are suggestive of the lower Agbada Formation. Palaeoenvironmental interpretations using diagnostic species revealed two environments: brackish and inner neritic to upper bathyal (0–600 m) under relatively warm-water marine condition indicated by thermophilic dinocyst taxa, such as *Lingulodinium machaerophorum*, *Polysphaeridium zoharyi* and *Homotryblium* spp. The lithology and these types of environments are good sites for hydrocarbon generation.

KEY WORDS: age, palaeoenvironment, palynormorphs, palynozone.

1. Introduction

The geographical coordinates of the Awaizombe-1 well are latitude 5°60′N and longitude 6°98′E, in the Northern Depobelt of the Niger Delta Basin in Nigeria (Fig. 1). The Northern Depobelt of Niger Delta Basin consists of paralic sequences capped by alluvial sands. The paralic sequence has late Eocene to early Miocene age, while the alluvial sand is of early Miocene age (Doust & Omatsola 1990). Okosun & Osterloff (2014) studied the ostracod, diatom and radiolarian biostratigraphy of the Awaizombe-1 well, Niger Delta Basin. These authors studied in detail the record of the ostracods, diatoms and radiolarians species recovered from the Awaizombe-1 well, but no research was done regarding the palynomorphs content. The present work is focused on the palynostratigraphy, biochronology and palaeobathymetric interpretation of a section (from 1373 to 1812 m depth). Palynomorphs can be very useful in the estimation of palaeobathymetry due to the reduced size, high abundance in small samples, and wide distribution over terrestrial and marine environment, high taxonomic diversity, short stratigraphic ranges, and preference for specific environmental conditions by some species. Different palynomorphs are indicators of a particular palaeodepth: bathymetry, and depositional environment; namely inner neritic, outer neritic, bathyal and abyssal (Stover *et al*. 1996).

2. Geology of the Niger Delta

The geology of the Niger Delta Basin comprises Akata, Agbada and Benin formations (Bankole 2010). The Akata Formation is generally of open marine and prodelta dark grey shale with lenses of siltstone and sandstone. The age of the Akata Formation ranges from Palaeocene in the proximal parts of the delta to recent in the distal offshore. The Agbada Formation consists of cyclic coarsening-upward regressive sequences composed of shales, siltstones and sandstones, which include delta front and lower delta plain deposits (Reijers *et al*. 1996). The Agbada Formation ranges in age from the Eocene to Holocene. The Benin Formation is the uppermost unit in Niger Delta Basin. The Benin Formation comprises a succession of Oligocene to Holocene age, thick poorly indurated sandstones, thin shales, coals, and gravels of continental to upper delta plain origin. The Niger Delta Basin is one of the major regressive deltaic sequences of the world (Reijers *et al*. 1996). The stratigraphic succession of the Niger Delta Basin is over 12 km thick at the depocentre and occupies an area of 75,000 km^2 in the Gulf of Guinea (Ejedawe 1981).

3. Methods

The lithology of the ditch cuttings was described by means of physical observation of the samples with the aid of the chart

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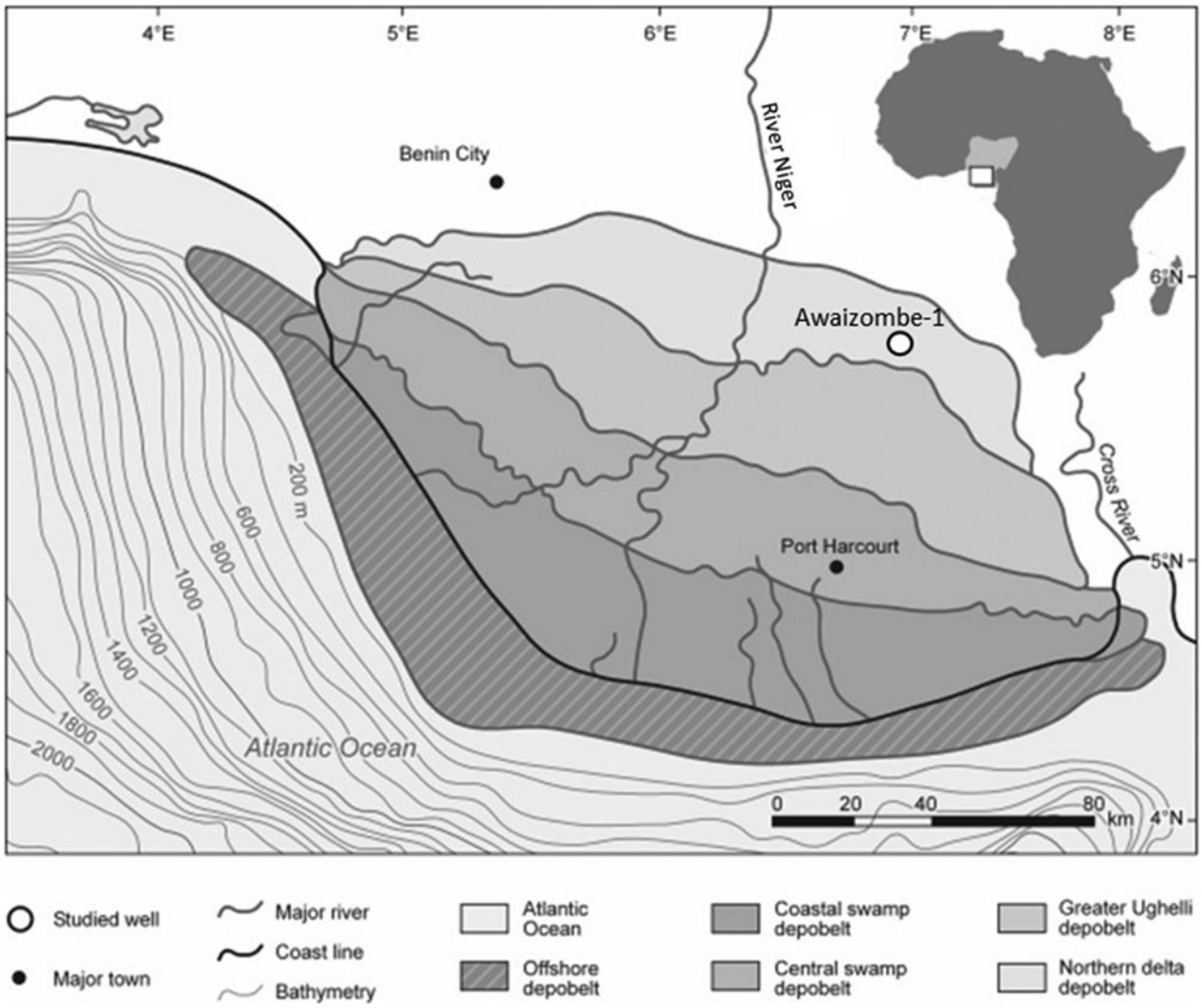

Figure 1. Location of the Awaizombe-1 well (modified after Chukwuma-Orji *et al*. 2017).

for textural analysis of clastic sediments and a magnifying hand lens.

Sixty-nine (69) ditch cuttings from Awaizombe-1 well (interval 1373–1812 m) were processed for palynomorph recovery through the standard palynological acid maceration technique. Fifteen grams of each sample were poured into well labelled plastic cups and positioned in a fume cupboard. Each sample was digested for 35 min in 40% hydrochloric acid for removal of carbonate and 24 h in 40% hydrofluoric acid for the removal of silicate. Sieving was done using a Branson Sonifier™ to filter away any remaining inorganic matter (silicates, clay and mud) and heavy minerals to concentrate organic matter present in the sample. Controlled oxidation was given to the sieved residue using concentrated nitric acid. The residue was stained with Safranin O, strew mounted on glass slides and examined under a transmitted light Olympus CX41 microscope.

4. Results and discussion

The lithology of the studied interval 1373–1812 m (439 m thick), consists of fissile grey shale and mudstone units (Fig. 2). This is suggestive of lower Agbada Formation which is also a good hydrocarbon source rock in the Niger Delta Basin (Short & Stauble 1967). The lower Agbada paralic units consist of thick shale unit and thin sandy units (Durugbo & Uzodimma 2013).

The result of the analysis carried out on 69 ditch cuttings of the studied Awaizombe-1 well consist of 89 palynomorphs specimens comprising 58 pollen, 11 spores, 18 dinocysts and 2 algae taxa (Fig. 2). The palynomorphs recovered are abundant, diverse and well preserved in almost all the intervals. Photomicrographs of the selected palynomorphs are presented in Fig. 3. The palynofloral assemblage was dominated by pollen and spores, namely: *Acrostichum aureum*; *Laevigatosporites* sp.; *Pachydermites diederixi*; *Psilatricolporites crassus*; R*etimonocolpites obaensis*; *Zonocostites ramonae*; *Verrucatosporites* sp.; and *Verrucatosporites usmensis.* Two algal species were identified: *Botryococcus braunii*; and *Pediastrum* sp. Notable dinocysts include: *Achomosphaera ramulifera*; *Leiosphaeridia* sp.; *Lingulodinium machaerophorum*; *Oligosphaeridium pulcherimum*; *Polyspheridium zoharyi*; and *Spiniferites* sp.

4.1. Palynostratigraphy and biochronology

Palynostratigraphy can be defined as the application of palynological methods to stratigraphy. The first downhole occurrences (FDOs) and last downhole occurrences (LDOs) of age diagnostic palynomorphs species, such as *Doualaidites laevigatus*, *Praedapollis africanus*, *Praedapollis flexibilies*, *Psilatriporites* sp., *Racemonocolpites hians*, *Retimonocolporites* sp., *Retitricolpites ituensis*, *Verrucatosporites usmensis* and the dinocyst taxa *Homotryblium oceanicum*, were used for the palynostratigraphic and biochronology interpretations. Four floral biostratigraphic interval zones are established in this study (Table 1). The zones span through early Eocene (Ypresian) to early Oligocene (Rupelian)

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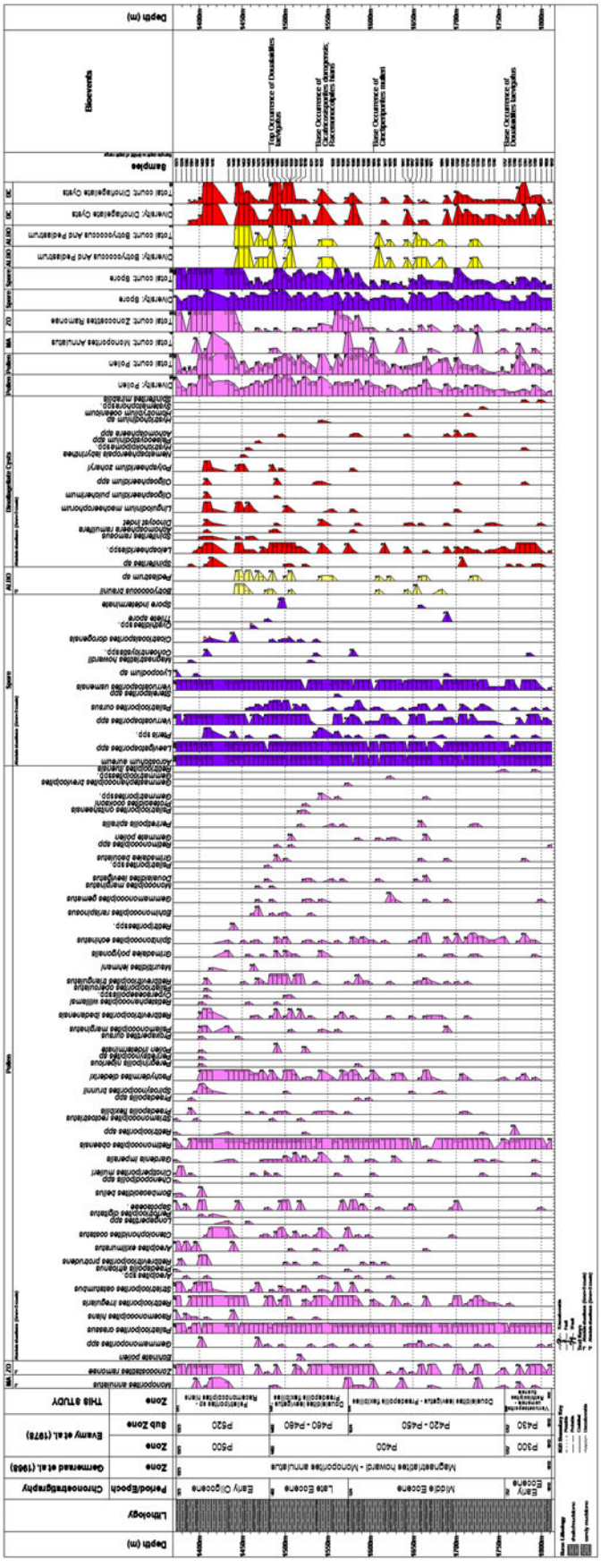

Figure 2. Palynomorph distribution chart of Awaizombe-1 well.

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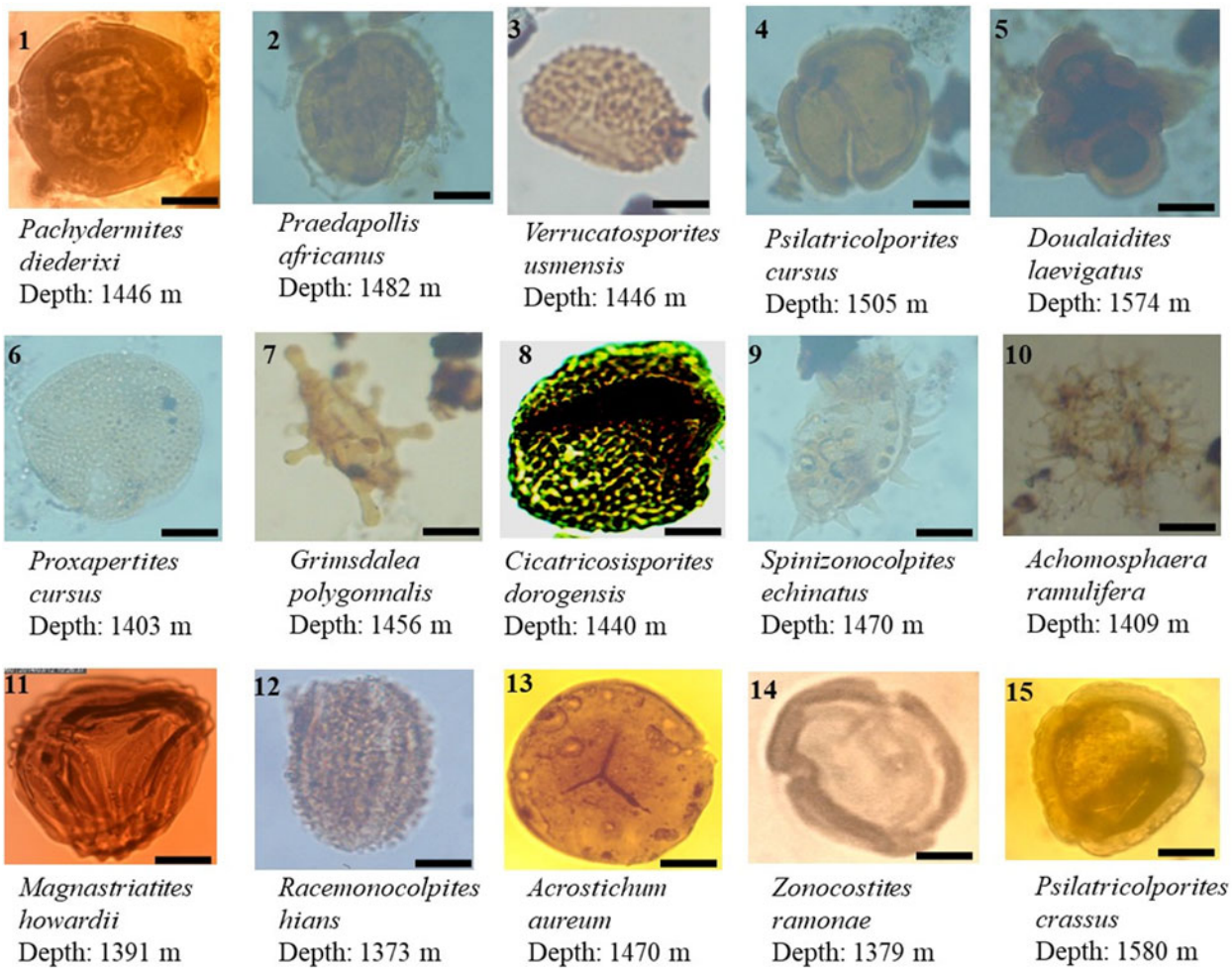

Figure 3. Microphotograph of selected sporomorph recovered.

and are described from the oldest to the youngest (Table 1). The zones were recognised based on the work of Murphy & Salvador (1999).

4.1.1. *Psilatriporites* sp.–*Racemonocolpites hians* Zone (interval range zone). Stratigraphic interval: 1482–1373 m (109 m thick).

Definition: The top of the zone is defined by the FDO of *R. hians* while the base is marked by the FDOs of *Psilatriporites* sp. and *Doualaidites laevigatus*. This zone is an interval range zone.

Characteristics: It is characterised by the presence of *D. laevigatus* and *Zonocostites ramonae*. Other characteristic palynomorphs within this zone include: *Acrostichum aureum*; *Laevigatosporites* sp.; Psilatricolporites crassus Pteris sp.; and *Verrucatosporites* sp. This zone is also characterised by the first appearance of these sporomorph taxa: *Echmonocolpites gematus*, *Magnastriatites howardii*, *Monocolpites maginatus*; and *Spinizonocolpites echinatus*; the dinocysts taxa *Achomosphaera ramulifera*, *Leiosphaeridia* sp., *Lingulodinium machaerophorum*, *Nematosphaeropsis labyrinthea*, *Oligosphaeridium pulcherimum*, *Polyspheridium zoharyi*, *Spiniferites* sp., and *Spiniferites ramosus*; and fresh water algae taxa *Botrycoccus braunii* and *Pediastrum* sp.

Age: The zone is dated early Oligocene (Rupelian age, 33.0–28.5 Ma). This zone is equivalent to the P500 zone and P520 subzone of Evamy *et al*. (1978). The FDO of *D. laevigatus* at the base of the zone (1482 m) is an indication of the Eocene–Oligocene boundary (Chukwuma-Orji *et al*. 2021). The FDOs of *Monocolpites marginatus* and *Spinizonocolpites echinatus*; and dinocyst taxa *Oligosphaeridium* sp., and *Oligosphaeridium pulcherimum*, within the zone are diagnostic of early Oligocene age.

4.1.2. *Praedapollis africanus–Doualaidites laevigatus* Zone (interval range zone). Stratigraphic interval: 1574–1482 m (92 m thick).

Definition: The top of the zone is defined by the FDO of *D. laevigatus* while the base is marked by the LDO of *P. africanus*. This zone is an interval range zone.

Characteristics: Highly abundant and diverse palynomorphs were recovered within this zone which includes *Cinctiperiporites mulleri*, *Doualaidites laevigatus Laevigatosporites* sp., *Psilatricolporites crassus*, *Retimonocolporites obaensis*, *Verrucatosporites usmensis* and *Zonocostites ramonae*, and also *Leiosphaeridia* sp. This abundant diversity at the upper part (1452–1604 m) may have been due to the availability of light and oxygen for photosynthesis of the taxa.

Table 1. Established palynozones

Period		Epoch		Age	Age (Ma)	Palynozones (this study)
Palaeogene	Palaeocene	Oligocene	Early	Rupelian	28.5–33.0	*Psilatriporites*sp–*Racemoncolpites hians*
		Eocene	Late	Priabonian	33.0–33.7	*Praedapollis africanus–Doualaidites laevigatus*
			Middle	Bartonian – Lutetian	33.7–49.0	*Doualaidites laevigatus–Praedapollis flexibilis*
			Early	Ypresian	49.0–54.8	*Verrucatosporites usmensis–Retitrcolpites ituensis*

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Age: The zone is dated late Eocene (Priabonian age, 33.7–33.0 Ma). This zone is equivalent to the P400 zone and P460–P480 subzone of Evamy *et al*. (1978). The LDOs of *Bombacacidites bellus* and *Peregrinipollis nigericus*, are diagnostic of late Eocene.

4.1.3. *Doualaidites laevigatus–Praedapollis flexibilies* Zone (interval range zone). Stratigraphic interval: 1757–1574 m (183 m thick).

Definition: The top of the zone is defined by the LDO of *P. flexibilies* while the base is marked by the LDO of *D. laevigatus*. This zone is an interval range zone.

Characteristics: It is characterised by *Acrostichum aureum*, *Cinctiperiporites mulleri*, *Doualaidites laevigatus*, *Laevigatosporites* sp., *Pachydemites diederixi*, *Psilatricolporites crassus* and *Zonocostites ramonae*. The only (first and last) occurrence of *Gemmatricolporites* sp. at a depth of 1623 m was recorded within this zone.

Age: The zone is dated middle Eocene [Lutetian (49.0–41.3 Ma)–Bartonian (41.3–37.0 Ma) age]. This zone is equivalent to the P400 zone and P420–P450 subzone of Evamy *et al*. (1978). The LDOs of *Retibrevitricolporites protrudens* and *Ctenolophonidites costatus* are diagnostic of middle Eocene (Legoux 1978).

4.1.4. *Verrucatosporites usmensis–Retitricolpites ituensis* Zone (interval range zone). Stratigraphic interval: 1812–1757 m (55 m thick).

Definition: The top of the zone is defined by the FDO of *R. ituensis* while the base is marked by the last LDO of *V. usmensis*, *Retimonocolporites* sp.

Characteristics: The zone is characterised by few recoveries of palynomorph taxa and absence of *Botryococcus braunii* and *Pediastrum* sp., suggesting no freshwater incursion within the interval. It is also characterised by considerably abundant recoveries of *Laevigatosporites* sp., *Psilatricolporites crassus*, *Retimonocolpites obaensis*, *Spinizonocolpites echinatus*, *Verrucatosporites usmensis*, *Verrucatosporites* sp., and *Leiosphaeridia* sp.

Age: The zone is dated Early Eocene (Ypresian age, 54.8–49.0 Ma). This zone is equivalent to the P300 zone and P430 subzone of Evamy *et al*. (1978). The occurrence of *Monoporites annulatus*, *Psilatricolporites cursus*, *Retitricolporites irregularis* and *Verrucatosporites usmensis* are also diagnostic of early Eocene.

4.2. Palaeoenvironmental/palaeobathymetric interpretation

Palaeobathymetry of the Awaizombe-1 well was determined using the occurrences, co-occurrences and relative abundances of microfloral elements that are indicative of palaeo-water depth. The composition and relative abundance of different types of palynomorphs are indicative of changes in palaeobathymetry. Marine indicators such as dinocysts are ideal for palaeoenvironmental interpretations (Stover & Williams 1982). They tend to be most abundant in rocks deposited in middle neritic to upper bathyal environments and their abundance decreases landward. Dinocysts used in palaeoenvironmental interpretation include: *Homotryblium oceanicum* and *zoharyi* (these taxa are common in inner neritic to oceanic warm and high saline water environments, in subtropical to tropical regions, which may have a high productivity); *Lingulodinium machaerophorum* (it is assigned to inner neritic environments with low to normal salinity and warm temperate water species and an indicator of nutrient enrichment reflecting increased productivity and may proliferate in the vicinity of the active upwelling cells or near river mouths); *Achomosphaera* sp., *Hystrichosphaeropsis minimum*, *Spiniferites* sp., *Spiniferites mirabilis* (these taxa are assigned to neritic to oceanic setting with stable salinity, this group can be cosmopolitan and also can reach high relative abundances in high productivity areas such as upwelling regions and areas influenced by river discharge); *Nematosphaeropsis labyrinthea* (this taxa is related to outer neritic to oceanic environments, its occurrence can also indicates an increase in sea level); and *Leisphaeridia* sp. is suggestive of an outer neritic to upper bathyal (Stover *et al*. 1996; Chekar *et al*. 2018). Other occurring palynomorphs include spores, pollens, bissacate pollen and algae (Fig. 4). Palynomorphs' distribution presented in Figs 2, 4 represent a schematic model of the palaeobathymetry.

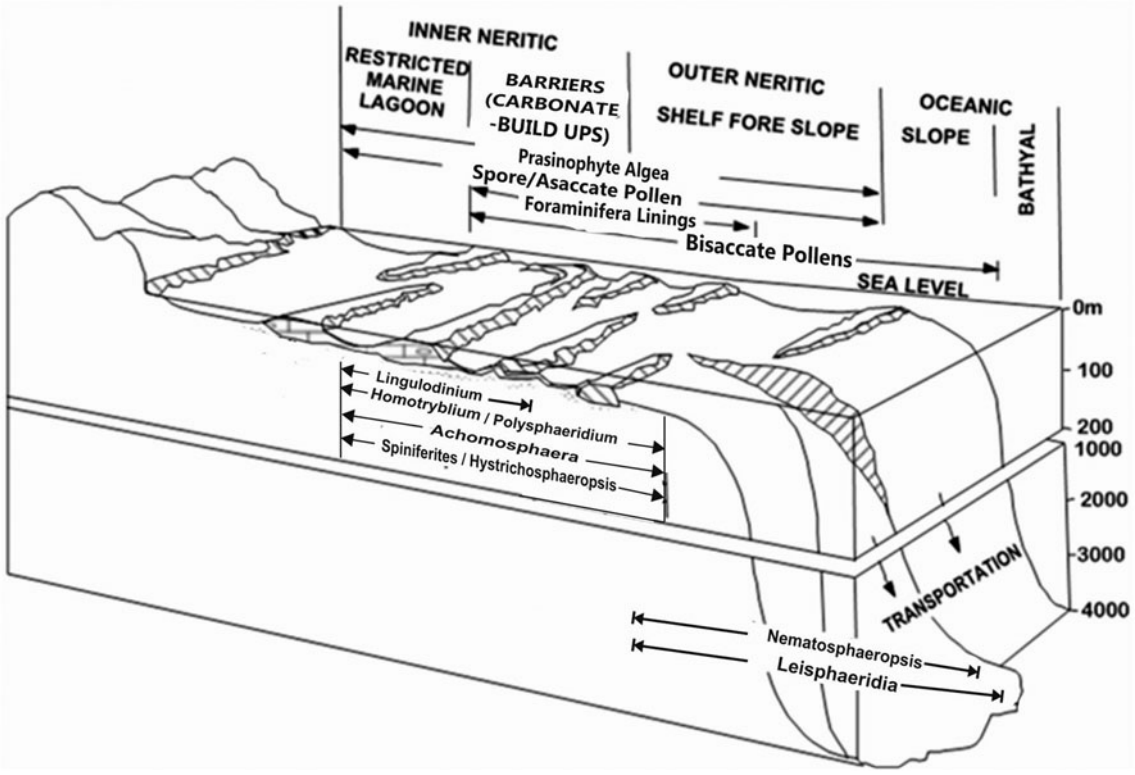

Figure 4. Schematic model of the dinocysts and other palynomorph distribution patterns from continental shelf–slope (modified after Stover *et al*. 1996).

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The palaeoenvironmental interpretations of the studied well, can be inferred as follows:

The interval of 1373 to 1391 m is inferred to have been deposited in brackish (terrestrial) environment due to the preponderance of *Acrostichum aureum*, *Psilatricolporites crassus* and *Zonocostites ramonae* (brackish water indicators), and the absence of marine dinocysts' indicators. The following taxa occurring within this interval are: *Racemonocolpites hians*; *Arecipites exilimuratus*; *Verrucatosporites usmensis*; *Retimonocolpites obaensis*; *Striatricolporites catatumbus*; *Verrucatosporites* sp.; *Laevigatosporites* sp.; *Retitricolporites irregularis*; *Retbrevitricolporites protrudens*; and *Cinctiperiporites mulleri*. These taxa suggest brackish (terrestrial) environment.

The interval of 1391 to 1812 m is inferred to have been deposited within inner neritic to upper bathyal environments (0–600 m). This deduction is due to the occurrences of *Leisphaeridia* sp. throughout the interval. Other dinocysts recorded within the interval include: *Spiniferites* sp.; *Spiniferites mirabilis*; *Spiniferites ramosus*; *Hystrichosphaeropsis minimum*; *Lingulodinium machaerophorum*; *Homotryblium oceanicum*; *Polysphaeridium zoharyi* (temperate to tropical species); and *Achomosphaera ramulifera*, *Achomosphaera* sp., *Nematosphaeropsis labyrinthea* (cool to temperate species) (Stover *et al*. 1996). The presence of the observed cool to temperate taxa within this interval may have been due to cryospheric circulation of ocean currents in areas of upwelling or the Palaeocene–Eocene Thermal Maximum of this time. The occurrence of *Botrycoccus braunii* and *Pediastrum* sp. algal species within 1446–1726 m suggests fresh water incursion. The presence of thermophilic dinocyst taxa such as *Spiniferites ramosus*, *Spiniferites ramosus*, *Spiniferites* sp., *Polysphaeridium zoharyi*, *Lingulodinium machaerophorum*, and *Homotryblium* sp. suggest warm-water marine conditions with salinity of 7–10% within tropical latitudes.

5. Conclusion

The palynological analysis of the Eocene–Oligocene succession from a section of the Awaizombe-1 well in the Northern Delta Depobelt of eastern Niger Delta reveals the presence of well-preserved and diverse assemblage of palynomorph, rich in pollen, spores and dinoflagellate cysts (dinocysts). The palynomorph marker events used for the biostratigraphic interpretations include the first and last occurrences of marker species, such as *Racemonocolpites hians*, *Psilatriporites* sp. and *Doualaidites laevigatus*, *Praedapollis africanus*, *Homotryblium oceanicum*, *Praedapollis flexibilies*, *Retitricolpites ituensis*, *Verrucatosporites usmensis*, and *Retimonocolporites* sp. The following interval range zones were established: *Psilatriporites* sp.–*Racemonocolpites hians* Zone; *Praedapollis africanus*–*Doualaidites laevigatus* Zone; *Doualaidites laevigatus*–*Praedapollis flexibilies* Zone; and *Verrucatosporites usmensis* –*Retitricolpites ituensis* Zone. The lowermost part of the Awaizombe-1 well is assigned to the Early Eocene (Ypresian age), the middle section is assigned Middle Eocene (Lutetian and Bartonian) and its upper part to the Late Eocene (Priabonian) and Early Oligocene (Rupelian). The FDO of *D. laevigatus* at the 1482 m is an indication of the late Eocene–early Oligocene boundary. The assigned age to the studied interval agrees with the previous work which stated that the Northern Delta Depobelt ranges from Eocene to Miocene (Doust & Omatsola 1990). The established interval biozones are useful for inter and intra basin biostratigraphic correlations. Qualitative and quantitative analyses permit palaeoenvironmental and palaeobathymetric interpretations. The occurrences of dinocyst groups, spores and pollen lead to the distinction of two environments: brackish (terrestrial) and inner neritic to upper bathyal (0–600 m) under relatively warm-water marine conditions with salinity of 7–10% within tropical latitudes. These types of environments are good sites for hydrocarbon generation.

6. Conflicts of interest

None.

7. References

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