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Palynomorph assemblage biozonation of Paleogene strata in Bende–Umuahia Area, Niger Delta Basin, southeastern Nigeria

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Abstract

Cenozoic sediments form extensive outcrops in the Niger Delta Basin. Detailed palynostratigraphic study was undertaken across Paleogene sequences exposed in Bende–Umuahia Area in up-dip sectors of the Niger Delta Basin, southeastern Nigeria, to establish different palynomorphs assemblage zones, with their corresponding ages. Palynological analysis was carried out on 27 selected outcrop samples, using the conventional maceration technique for recovering acid-insoluble organic-walled microfossils from sediments. Three Cenozoic lithostratigraphic units, including Imo Formation, Ameki Formation, and Ogwashi Formation, are exposed in the study area. Lithologies are sandstone, carbonaceous shale, mudstone, limestone, and the lignite. A total of 65 species of sporomorphs and 51 dinoflagellate cysts were identified. The recovered spores and pollen grains were used to establish six informal palynomorph assemblage zones, labeled as zone A – zone F, based on the first and the last occurrences of two or more species. These palynomorph assemblage zones include: (1) zone A — middle Paleocene *Scabratriporites simpliformis*–*Bombacidites annae* zone; (2) zone B — late Paleocene *Foveotricolporites crassiexinus*–*Mauritidiites crassiexinus* zone; (3) zone C — early Eocene *Striatopollis catatumbus*–*Momipites africanus* zone; (4) zone D — middle Eocene *Margocolporites umuahiaensis*–*Gemmastephanocolporites brevicolpites* zone; (5) zone E — late Eocene *Cicatricosisporites dorogensis*–*Perfotricolpites nigerianus* zone; and, (6) zone F — Oligocene–early Miocene *Verrucatosporites usmensis*–*Magnastriatites howardii* zone. The erected palynozones were correlated and compared with existing biozones in subsurface, down-dip sectors of the Niger Delta Basin, with pantropical palynological zones in tropical areas of Africa, and with palynofloral provinces of northern South America. A comparison of palynozones studied in southeastern Nigeria with other international palynozones, in this study, will assist in establishing the correlation of sediments for these areas.

Keywords: Palynology, Stratigraphy, Biozonation, Spores and pollen grains, Dinoflagellate cysts, Cenozoic, Niger Delta Basin

1 Introduction

Cenozoic palynostratigraphic data available for research on the Niger Delta Basin mostly focused on subsurface, down-dip sectors of the basin (Fig. 1). Among pioneering research, Germeraad et al. (1968) covered extensively the palynostratigraphy of Cenozoic sediments from the tropical areas of West Africa, northern South America to Sumatra and Borneo, and erected three main zonal divisions according to their lateral extent. They used data of pollen and spores to establish six pantropical palynozones, which from base to top were recognized as: (1) the Paleocene *Proxapertites operculatus* zone; (2) the Eocene *Monoporites annulatus* zone; (3) the late Eocene *Verrucatosporites usmensis* zone; (4) the Oligocene

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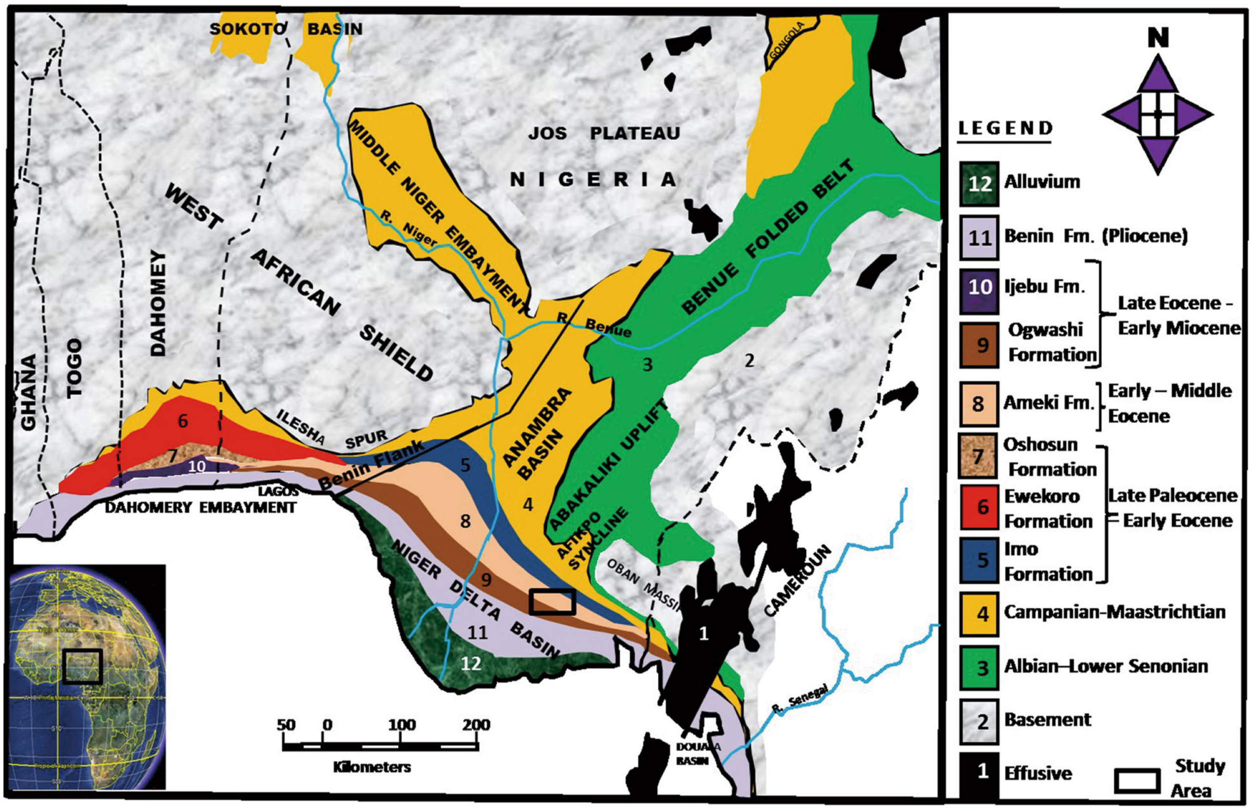

Fig. 1 General geological map and Cenozoic succession of the Niger Delta Basin and the location of the study area (modified after Murat 1972). Fm. = Formation; R. = River

Magnastriatites howardi zone; (5) the Miocene *Crassoretitriletes vanraadshoveni* zone; and, (6) the Pliocene *Echitricolporites spinosus* zone. Van Hoeken-Klinkenberg (1966) documented the occurrence of some late Paleocene–early Eocene sporomorphs of Nigeria, including *Retitricolpites clarensis*, *Psilatricolporites medius*, *Retitricolpites marginatus*, *Retitricolporites ellipticus*, *Retistephanocolpites irregularis*, *Retibrevitricolpites triangulatus*, and *Proxapertites cursus*. Other descriptions of Cenozoic palynostratigraphic data include Evamy et al. (1978), Legoux (1978), Sowunmi (1987), Oboh et al. (1992), Ojo and Salami (1992), Oboh (1995), Ojo and Adebayo (2001), Ige (2009), Durugbo et al. (2010), Lucas and Ishiekwene (2010), Adebayo et al. (2012), and, Aturamu et al. (2015). The planktonic foraminifer zonation and the calcareous nanofossil biozones of the subsurface Niger Delta have also been established by Martini (1971).

However, in the inland part of the Niger Delta Basin, work has focused on the macrofauna and foraminifera biostratigraphy, while little attention was given to palynological biostratigraphy. Notable palynostratigraphic studies include the work of Jan du Chêne et al. (1978), who reported some new Eocene pollen from the Ogwashi Formation, and other recent work by Umeji (2002, 2003), Oboh-Ikuenobe et al. (2005), Chiaghanam et al. (2014), Umeji and Nwajide (2014), Ikegwuonu and Umeji (2016) and Okeke and Umeji (2016), whose work focused on the age and palaeoenvironments of outcropping sediments of the Niger Delta Basin. Ikegwuonu and Umeji (2016) documented the palynological age and the depositional palaeoenvironment of the Mid-Cenozoic sediments around Umuahia in the Niger Delta Basin, southeastern Nigeria. They argued that the recovered index sporomorphs, including *Verrucatosporites usmensis*, *Magnastriatites howardii*, *Retibrevitricolporites obodoensis*, *Retibrevitricolporites ibadanensis*, *Psilatricolporites crassus*, *Echiperiporites icacinoides*, *Echiperiporites minor*, *Retibrevitricolporites protrudens*, *Chenopodipollis disperses* and *Retitricolporites irregularis*, could represent the Oligocene–early Miocene *Verrucatosporites usmensis*/*Magnastriatites howardii* pantropical palynozone of Germeraad et al. (1968). Okeke and Umeji (2016) studied palynostratigraphy, palynofacies and depositional palaeoenvironments of the Selandian–Aquitanian sediments along the Onitsha–Awka transect in the Niger Delta Basin, southeastern Nigeria. They interpreted the Imo Formation to have been generally deposited in shallow waters of the inner and coastal zone, whereas the overlying Nanka Formation was deposited under alternating coastal and inner neritic conditions, and the Ogwashi Formation was deposited under oscillating coastal plain and brackish water conditions. These previous studies, however, focused mostly on the age of deposition, palaeoecology, and palaeoenvironment of the formations, whereas no significant attention was paid to palynomorph biozonation of the inland part of the basin.

This study, therefore, attempts to document, for the first time, the palynomorph assemblage biozonation of the Paleogene up-dip outcropping strata in Bende–Umuahia Area, Niger Delta Basin, southeastern Nigeria. As more studies develop, new results are added to the existing database, and tie in the current results from the up-dip outcropping strata of the basin to results from the subsurface, in order to develop a basin-wide regional correlation.

The study area covers approximately 235 km^2 between latitudes of 5°27′N–5°40′N and longitudes of 7°25′E–7°43′E, within the Niger Delta Basin in southeastern Nigeria (Fig. 2). Three Cenozoic formations, including the Imo Formation, the Ameki Formation and the Ogwashi Formation, outcrop in the study area (Figs. 1 and 2).

2 Geological setting and stratigraphy

Geographically, the Niger Delta Basin is located between latitudes of 3°N and 6°N and longitudes of 5°E and 8°E, and occupies the continental margin of the Gulf of Guinea in equatorial West Africa (Fig. 1). It has a total area of about 75,000 km^2 and an entirely clastic sedimentary-fill up to 12,000 m thick (Reijers et al. 1997). The fill was supplied by large continental drainage systems which constructed arcuate and bird-foot deltaic wedges prograde basinward into the oceanic crusts (Short and Stauble 1967).

Paleogene sediments including the Imo, Ameki, and Ogwashi Formations were regarded as a part of the Afikpo Basin by the previous research in the region (Reyment 1965; Arua 1986; Arua and Rao 1987; Oboh-Ikuenobe et al. 2005). These sediments are separated from the Campano–Maastrichtian stages developed in Anambra and Afikpo Basins based on dating results. The Imo, Ameki, and Ogwashi Formations have similar microfloral assemblages with those in the subsurface Niger Delta. These formations form the up-dip series of the Niger Delta Basin and are the lateral equivalents of the down-dip Akata and Agbada Formations (Fig. 3).

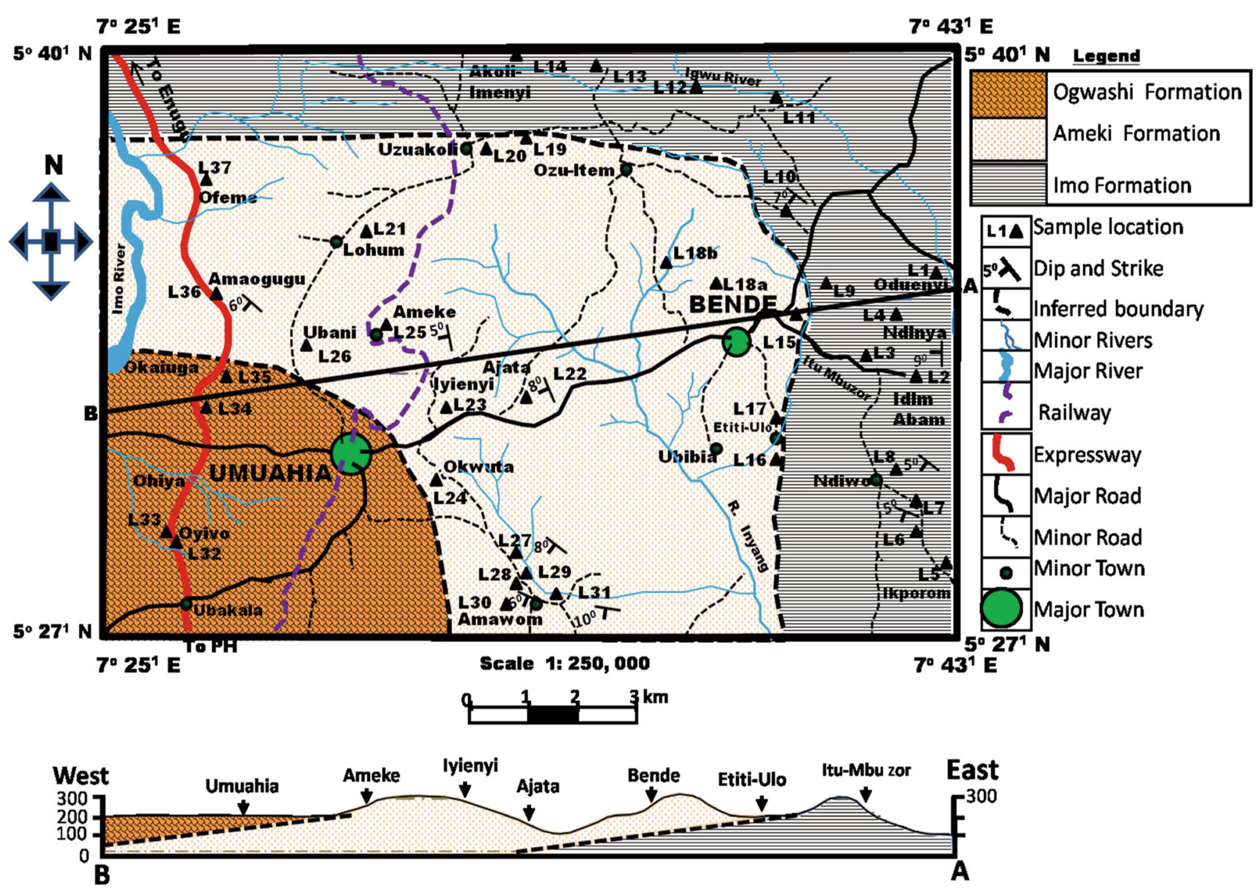

Fig. 2 Geological map of the study area showing location, accessibility and sample sites. L = Location numbers

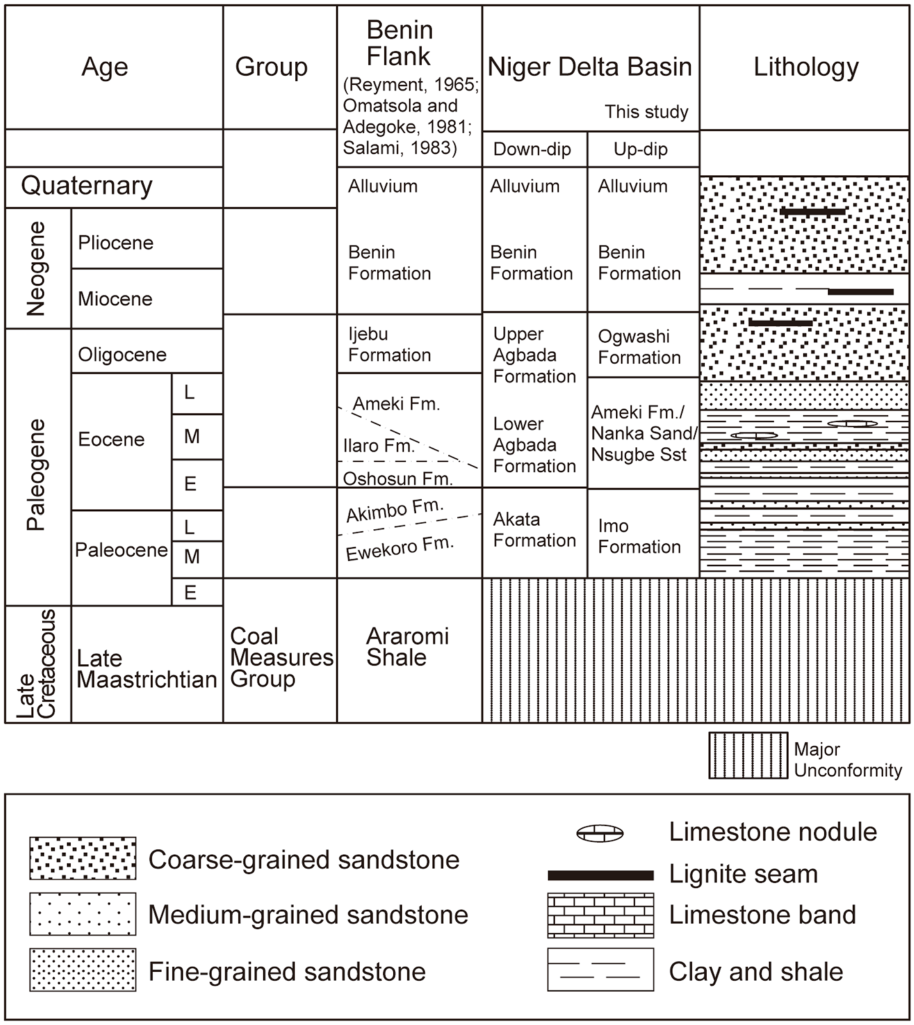

Fig. 3 Stratigraphic column of Niger Delta Basin and other coastal basins in Nigeria (according to Reyment 1965; Omatsola and Adegoke 1981; Salami 1983). E = Early; M = Middle; L = Late

The Imo Formation is the oldest stratigraphic unit in the inland part of the Niger Delta Basin. It consists of blue-grey clay and shale, black shale, with bands of calcareous sandstone, limestone, and marl (Reyment 1965). And, the lateral variations into sandstone facies (members) occur in some places such as Ebenebe, Umuna, and Igbabu (Reyment 1965) (Fig. 3). In western Nigeria, the Imo Formation passes partially into a thick shaly and in places, arenaceous limestone (the Ewekoro Formation; Fig. 3). In the east, the Imo Formation unconformably overlies the Nsukka Formation, outcrops at Oduenyi village extending westward through Ndiwo, and terminates at Itu-Mbuzor where it is conformably overlain by the Ameki Formation (Ikegwuonu 2015). The Ameki Formation predominantly consists of alternating shale, sandy shale, clay sandstone, and fine-grained fossiliferous sandstone, with thin bands of limestone (Reyment 1965; Arua 1986; Arua and Rao 1987). The formation is exposed at Bende Itu-Mbuzor town extending northwestward through Ozu-Item to Uzuakoli town and terminates at Amogugu town where it is overlain by the Ogwashi Formation (Fig. 3). The Ogwashi Formation consists of alternating coarse-grained sandstone, lignite, and light-colored clays of continental origin (Kogbe 1976) (Fig. 3). The Benin Formation consists of massive coarse- to fine-grained sandstones and gravels, with minor shale intercalations. The formation is deposited in alluvial or coastal plain environments following a southward shift of the delta into a new depobelt (Doust and Omatsola 1990). The deposits become thinner offshore and disappear near the shelf edge.

3 Materials and methods

The materials for this study were collected through a systematic profile logging of approximately 260-m-thick sections from the base to the top of Paleogene strata in the study area (Figs. 2 and 3). Twenty-seven (27) samples, distributed in the Imo Formation (12 samples), Ameki Formation (12 samples), and Ogwashi Formation (3 samples), were obtained.

The studied methods included lithologic profile logging, laboratory processing, and transmitted-light microscopy observation. The sediments were processed for palynomorph content analyses. Sample preparation was carried out using the conventional maceration technique for recovering acid-insoluble organic-walled microfossils. During sample pretreatment, the sediments were digested for 30 min in 40% hydrochloric acid to remove carbonates and 72 h in 48% hydrofluoric acid to remove silicates; oxidized for 30 min in 70% HNO_3 to render fossils translucent for transmitted-light microscopy observation; rinsed in 2% KOH solution to neutralize the acid; swirled and stained with Safranin-O to increase contrast for identification and photography. Demineralization was not necessary for the coals and they were oxidized as with the clastic sediments.

Aliquots were dispersed with polyvinyl alcohol, dried on cover-slips and mounted in Araldite poxy resin. Five slides were made from each sample, from which a minimum of 200 grains were counted. The occurrence of each species was converted to percentage frequency, shown as: > 15% means very abundant; 10%–15% means abundant; 5%–10% means common; 1%–5% means occasional; and, < 1% means rare (Ikegwuonu and Umeji 2016). The recovered spores and pollen species enabled the establishment of stratigraphic distribution chart and subdivision of palynological zones (Figs. 4 and 5).

4 Results

The distribution of total yield of palynomorphs (terrigenous and marine species) counted per 5 g of the sediment shows an irregular trend with low values at the base and with increase fluctuation towards the top of the sections (Figs. 6 and 7). At the base of studied sections, values of the palynomorph yield per 5 g of the sediment ranged from 210 grains in sample L2/01 to 431 grains in sample L8/02 up to the sections of the Imo Formation (see Fig. 2 for reference). Towards the top of the sections, values from Location 33 of the Ogwashi Formation ranged from 383 grains in sample L33/01 to 497 grains in sample L33/03 above. In general, the maximum value throughout the studied sections was obtained in sample L23/02 at the middle of the Ameki Formation, which could be as high as 630 grains. The sample with highest total counts produced low marine and high terrigenous abundance.

The recovered palynomorph genera and species are typical of the African and South American pantropical palynoflora province, stated by Germeraad et al. (1968), to which Nigeria belongs. A total of 65 sporomorph species were identified, and the important stratigraphic index species are illustrated in Figs. 8, 9, 10.

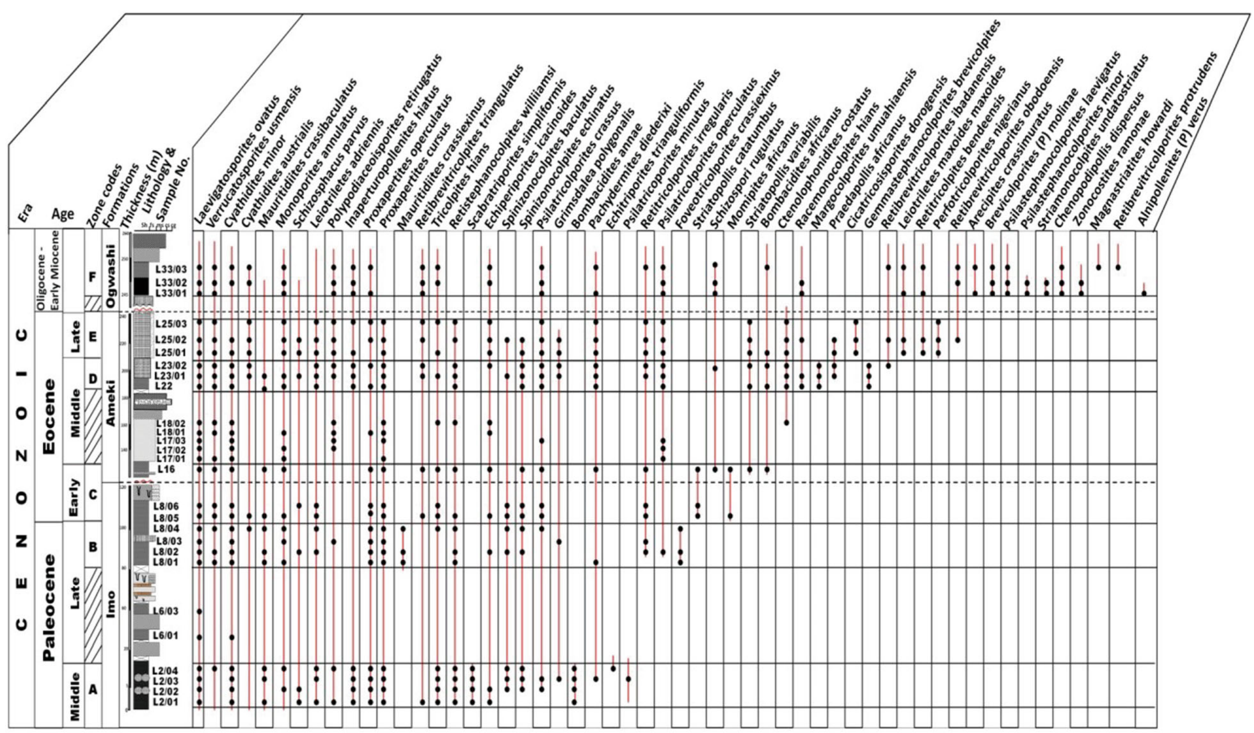

Fig. 4 Stratigraphic distribution of sporomorphs and subdivision of palynological zones of the studied Cenozoic sections in Niger Delta Basin

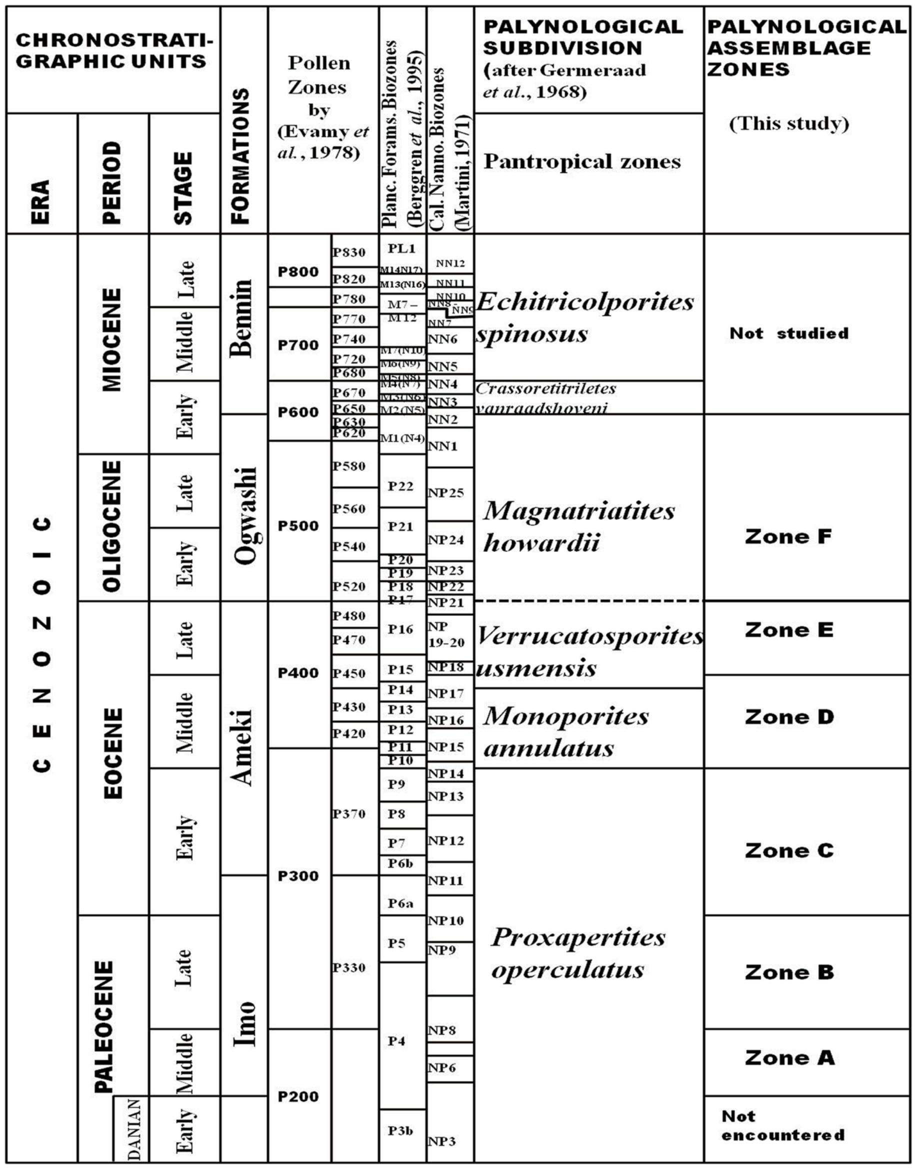

Fig. 5 Correlation chart of biozones and palynological zones of the studied Cenozoic sections in Niger Delta Basin

The monoletes, triletes, and pollen grains of inaperturates, monocolpates, tricolpates, stephanocolpates, monoporates and polyporates were identified. The important pollen genera including *Proxapertites*, *Spinizonocolpites*, *Scabratriporites*, *Striatopollis*, *Bombacidites*, *Magnastriatites*, *Psilastephanocolporites* and *Retibrevitricolporites* are also illustrated in Figs. 8, 9, 10.

5 Discussion

Six informal palynomorph assemblage zones, labeled A–F as their zone codes, were established based on the first and last occurrences of two or more sporomorph species (Fig. 4). The palynozones were correlated and compared with existing biozones in the subsurface, down-dip series of the Niger Delta Basin, and with the pantropical palynozones of Germeraad et al. (1968), in the tropical areas (Fig. 5). The zonal species are presented in Figs. 8, 9, 10.

5.1 Zone A: *Scabratriporites simpliformis*–*Bombacidites annae* zone, middle Paleocene

The palynological zone A has middle Paleocene index species such as *Scabratriporites simpliformis*, *Bombacidites annae* and *Echitriporites trianguliformis*. Some species of the pollen group such as *Bombacidites* (similar to that of extant *Bombax* and relatives) are characteristic of middle Paleocene–Eocene (Jaramillo and Dilcher 2000), and several of their Paleocene species have regional

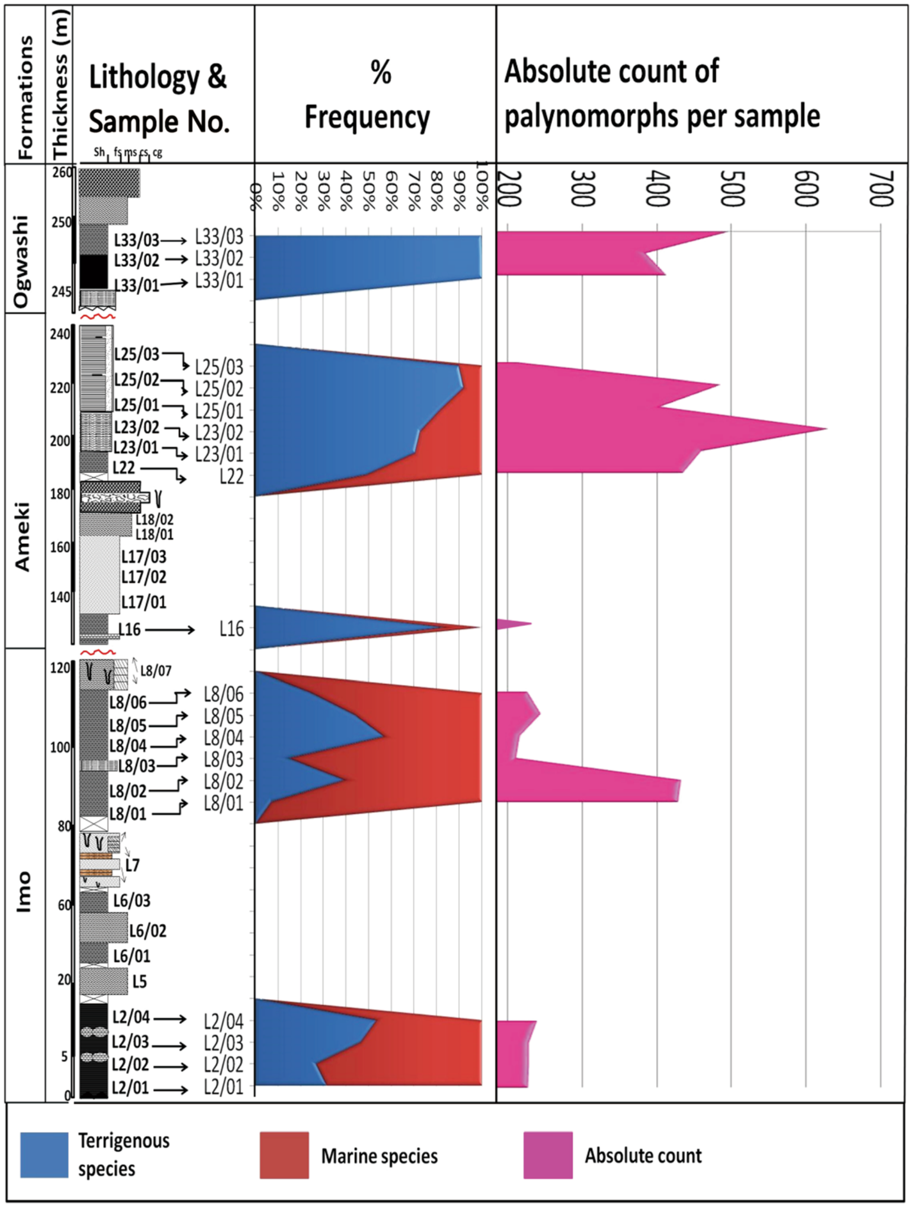

Fig. 6 Distribution of the abundance (absolute count) of marine–terrigenous species and the total yield of palynomorphs per sample in the studied sections

extinctions at the end of the Paleocene (e.g. *Bombacidites annae*). Here, *Bombacidites annae* was recorded only in this zone and was absent in the subsequent zones up the stratigraphic sequence.

The first abundance peak of the peridiniacean species, *Apectodinium homomorphum* (38%), also associated with this zone. Samples L2/01 to L2/04 fall within this zone and were recognized in the carbonaceous dark shale at Loc 2 in the Imo Formation. The absence of *Scabratriporites simpliformis*, *Bombacidites annae* and *Echitriporites trianguliformis* in the section above sample L2/04, marks the top of this zone (Fig. 4).

5.2 Zone B: *Foveotricolporites crassiexinus–Mauritidiites crassiexinus* zone, late Paleocene

Samples of zone B were found from L8/01 to L8/04 (Fig. 4). The base was defined by the disappearance of the middle Paleocene sporomorphs assemblage *Scabratriporites simpliformis*, *Bombacidites annae* and *Echitriporites trianguliformis* of zone A, and the appearance of the late Paleocene *Foveotricolporites crassiexinus* and *Mauritidiites crassiexinus*. The dinoflagellate cyst assemblage from this zone includes *Kallosphaeridium brevibarbatum*, *Apectodinium* spp., *Homotryblium abbreviatum, Adnatosphaeridium multispinosum*, and *Oligosphaeridium complex*. Other rare to occasional species,

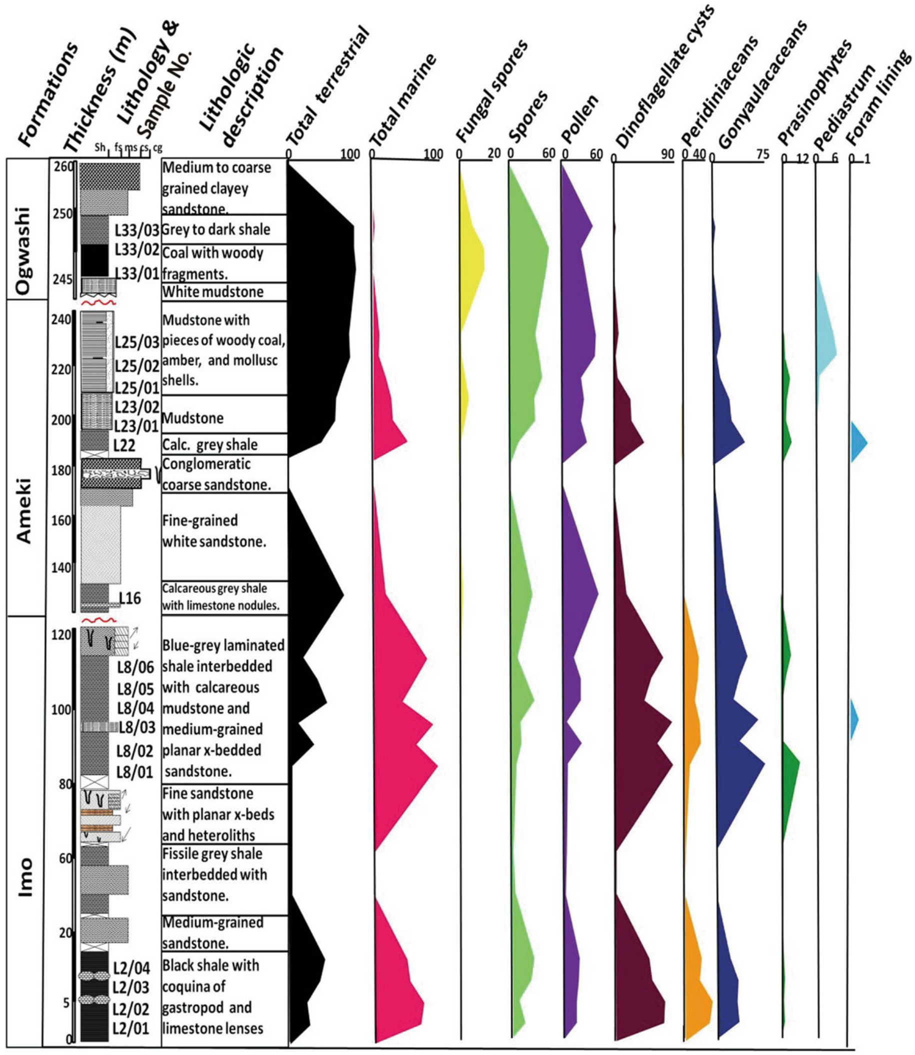

Fig. 7 Composite histogram of the studied sections and graphs of the percent frequency distribution of palynomorph groups developed in the sections

which are also confined in this zone include, *Cylonephelium spinetum*, *Glaphyrocysta exuberans*, *Ifecysta* spp., and *Muratodinium fimbriatum*.

Awad and Oboh-Ikuenobe (2016), referring to Masure et al. (1998), used the species of *Apectodinium* spp. and *Adnatosphaeridium multispinosum* to determine a late Paleocene age at the Depth of 828.70 m of ODP Hole 959D, in the CÔte d'Ivoire-Ghana Transform Margin. They also held that the occurrence of *Ifecysta pachyderma* supports an age designation of late Paleocene, which was confirmed by earlier researchers in West Africa (Jan du Chêne and Adediran 1985; Antolinez 2006; Antolinez and Oboh-Ikuenobe 2007; Bankole et al. 2007). The top of this zone was marked by the disappearance of the late Paleocene index species, *Foveotricolporites crassiexinus* and *Mauritidiites crassiexinus*.

5.3 Zone C: *Striatopollis catatumbus*–*Momipites africanus* zone, early Eocene

The base of zone C was defined by disappearance of the late Paleocene species, *Foveotricolporites crassiexinus* and *Mauritidiites crassiexinus*, and the appearance of early Eocene index species, *Striatopollis catatumbus* and *Momipites africanus*. Samples L8/05 to L16 fall within this zone (Fig. 4). *Striatopollis catatumbus* first occurred in early Eocene deposits in Colombia (González Guzmán 1967), Nigeria (Takahashi and Jux 1989), Venezuela (Colmenares and Teran 1993), and Qatar (El Beialy 1998). González Guzmán (1967) further remarked that the taxon also occurs in the Caribbean, and at the base of the *Retibrevitricolpites triangulatus* zone in Nigeria.

Towards the base of this zone, sample L8/05 marks the topmost Paleocene strata and the beginning of early Eocene deposition, i.e., the Paleocene–Eocene boundary.

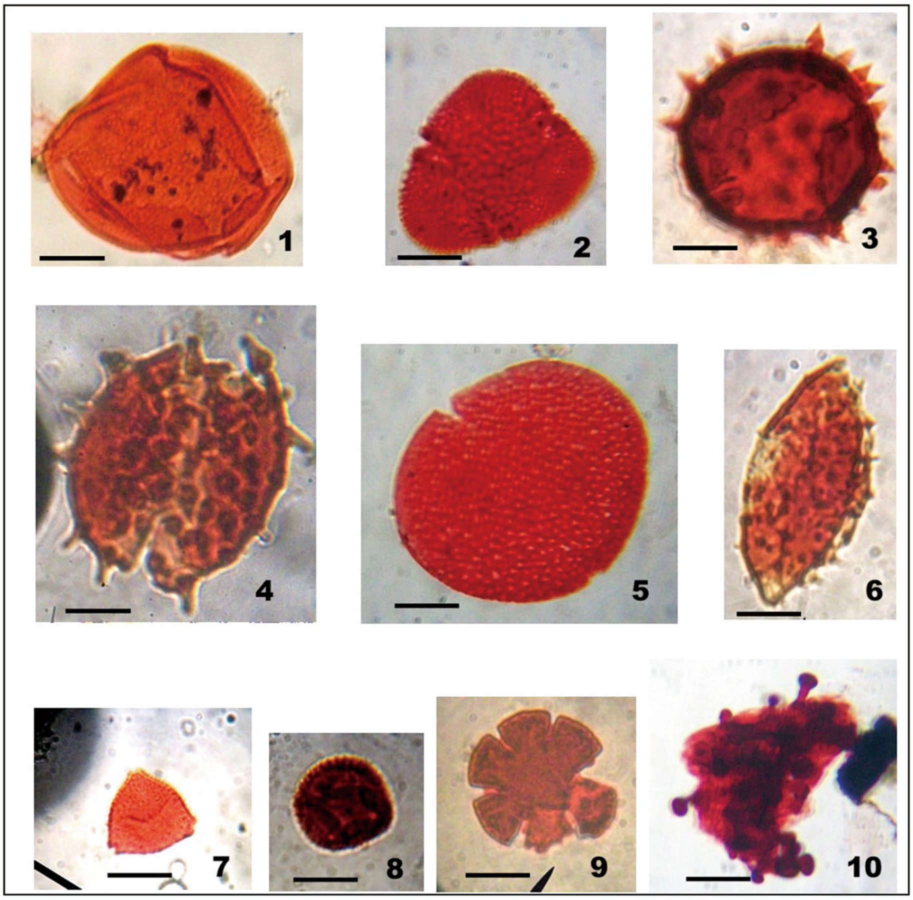

Fig. 8 Micrographs of some spores and pollen grains from the Imo Formation. **1** – *Proxapertites operculatus* Germeraad, Hopping and Muller 1968 (70–80 μm); **2** – *Bombacidites annae* (Van der Hammen 1954) Leidelmeyer 1966 (37–40 μm); **3** – *Mauritidiites crassiexinus* Jan du Chêne, Onyike, and Sowunmi 1978 (45–50 μm); **4** – *Spinizonocolpites baculatus* Muller 1968 (60 × 55 μm); **5** – *Proxapertites cursus* Van Hoeken-Klinkenberg 1966 (75–85 μm); **6** – *Mauritidiites crassibaculatus* Van Hoeken-Klinkenberg 1964 (60 × 31 μm); **7** – *Echitriporites trianguliformis* Van Hoeken-Klinkenberg 1964 (26 μm); **8** – *Foveotricolporites crassiexinus* Van Hoeken-Klinkenberg 1966 (25 × 23 μm); **9** – *Retistephanocolpites williamsi* Germeraad, Hopping and Muller 1968 (36 μm); **10** – *Grimsdalea polygonalis* Jan du Chêne, Onyike, and Sowunmi 1978 (47–62 μm). Bar scale = 20 μm

At the Paleocene–Eocene boundary, in sample L8/05, *Proxapertites operculatus* reaches its abundance peak (11%); the Paleocene index species assemblage of *Scabratriporites simpliformis*, *Bombacidites annae*, *Foveotricolporites crassiexinus*, and *Mauritidiites crassiexinus* disappeared and early Eocene markers, *Striatopollis catatumbus* and *Momipites africanus* first appeared. Moreover, the percentage abundance of the dinoflagellate cyst species, *Apectodinium homomorphum*, remained high (15%) across the P/E boundary. A characteristic assemblage of gonyaulacacean, *Spiniferites ramosus*, was commonly developed and reached its abundance peak at the top of this zone. Thus, the disappearance of the early Eocene index species in sample L17/01 above sample L16, marks the top of this zone (Fig. 4).

5.4 Zone D: *Margocolporites umuahiaensis*–*Gemmastephanocolporites brevicolpites* zone, middle Eocene

The base of zone D was marked by the disappearance of early Eocene index species and the appearance of middle Eocene taxa of *Margocolporites umuahiaensis* and *Gemmastephanocolporites brevicolpites*. Samples L22 to L23/02 fall within this zone (Fig. 4), in which shows the abundance peak of *Psilatricolporites crassus* (20%). The dinoflagellate cyst, *Glaphyrocysta ordinata*, also reached its abundance peak while the foraminifer linings become common. *Margocolporites umuahiaensis* and *Gemmastephanocolporites brevicolpites* were first described from middle Eocene sediments around Oba, Nnewi and Orlu areas, southeastern Nigeria (Jan du Chêne et al. 1978). The related species, *Margocolporites vanwijhei*, was reported by Germeraad et al. (1968) as having an Eocene–Oligocene age range in West Africa, Caribbean and Borneo. The top of this zone was marked by the

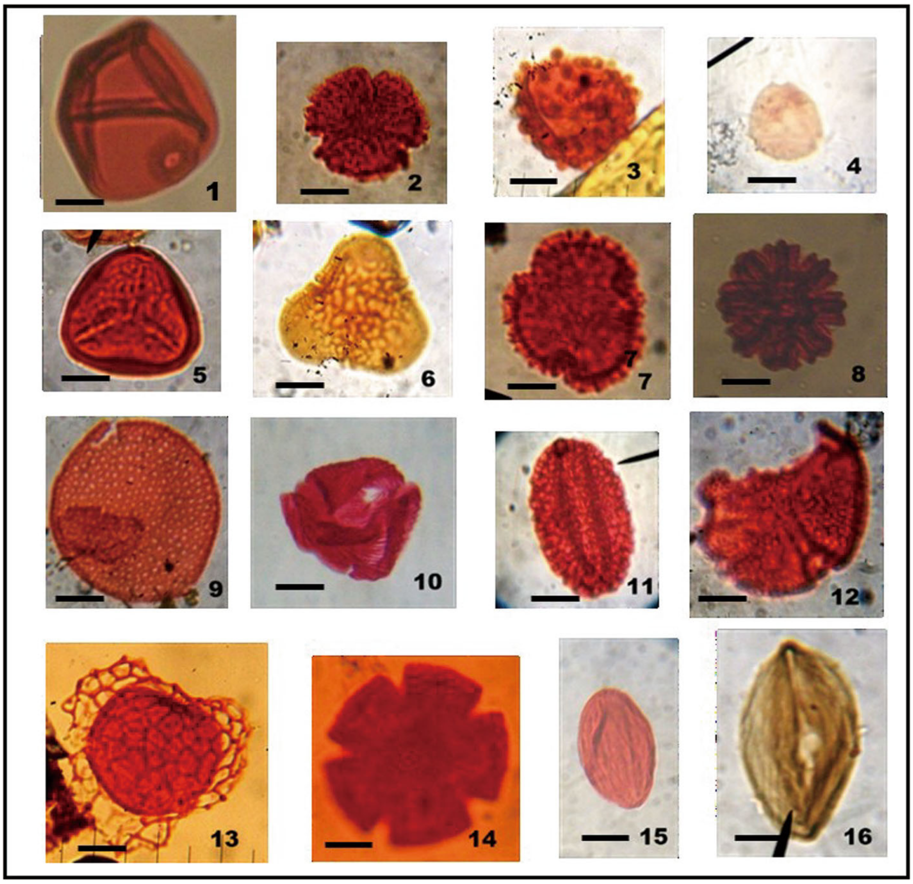

Fig. 9 Micrographs of some sporomorph species from the Ameki Formation. **1** – *Monoporites annulatus* Van der Hammen 1954 (34–42 μm); **2** – *Retibrevitricolpites triangulatus* Van Hoeken-Klinkenberg 1966 (35 μm); **3** – *Gemmastephanocolporites brevicolpites* Jan du Chêne, Onyike, and Sowunmi 1978 (23–25 μm); **4** – *Momipites africanus* Van Hoeken-Klinkenberg 1966 (29–30 μm); **5** – *Polypodiaceoisporites retirugatus* Muller 1968 (30–32 μm); **6** – *Bombacidites africanus* Takahashi and Jux 1989 (33 μm); **7** – *Retitricolporites irregularis* Van der Hammen et Wymstra 1964 (30–35 μm); **8** – *Ctenolophonidites costatus* Van Hoeken-Klinkenberg 1966 (40 μm); **9** – *Proxapertites cursus* Van Hoeken-Klinkenberg 1966 (50–55 μm); **10** – *Cicatricosisporites dorogensis* Potonié et Gelletich 1933 (25–30 μm); **11** – *Perfotricolpites nigerianus* Takahashi and Jux 1989 (60 × 35 μm); **12** – *Margocolporites umuahiaensis* Jan du Chêne, Onyike, and Sowunmi 1978 (40–55 μm); **13** – *Praedapollis africanus* Boltenhagen 1976 (52–55 μm); **14** – *Retistephanocolpites williamsi* Germeraad, Hopping and Muller 1968 (55 μm); **15** – *Striatopollis catatumbus* Gonzálaz Guzmán 1967 (47 × 38 μm); **16** – *Striatopollis variabilis* Takahashi and Jux 1989 (40 × 25 μm). Bar scale = 20 μm

disappearance of *Margocolporites umuahiaensis* and *Gemmastephanocolporites brevicolpites* species (Fig. 4).

5.5 Zone E: *Cicatricosisporites dorogensis*–*Perfotricolpites nigerianus* zone, late Eocene

Samples L25/01 to L25/03 were recognized in the fossiliferous mudstone section of the Ameki Formation in Loc 25 at Isiadu-Ameke town, and fall within zone E (Fig. 4). The base of this zone was defined by the disappearance of *Margocolporites umuahiaensis* and *Gemmastephanocolporites brevicolpites* species, and the appearance of late Eocene *Cicatricosisporites dorogensis* and *Perfotricolpites nigerianus* species.

Perfotricolpites nigerianus was first reported from Middle Tertiary lacustrine deposits in the Jos Plateau (Takahashi and Jux 1989). The related species, *Perfotricolpites digitatus*, was first recognized from early–middle Eocene strata of Columbia (González Guzmán 1967), and then from Oligocene strata of New Zealand (Pocknall 1982). This species was also reported by Germeraad et al. (1968) from the Caribbean and Nigeria, occurring for the first time approximately at the base of the *Verrucatosporites usmensis* zone (late middle Eocene–late Eocene). This taxon also has a fossil record extending into the Late Neogene of the West Coast of Africa (Partridge 1978). Moreover, Germeraad et al. (1968) held that the species of *Cicatricosisporites dorogensis* had initial worldwide distribution in Early Cretaceous sediments but contracted in Late Cretaceous time; and in the middle Eocene, its second expansion took place in the Caribbean and Nigeria, but declined at the end of the Oligocene Epoch.

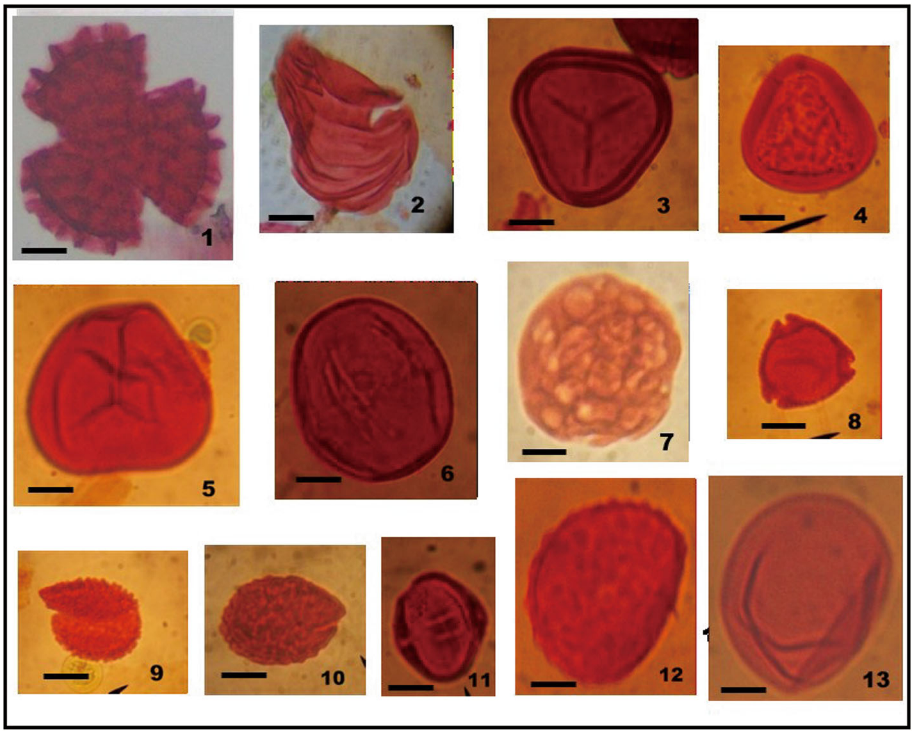

Fig. 10 Micrographs of some Oligocene–early Miocene sporomorph species. **1** – *Retitricolporites irregulalis* Van der Hammen et Wymstra 1964 (65 μm); **2** – *Magnastriatites howardii* Germeraad, Hopping and Muller 1968 (65–70 μm); **3** – *Cyathidites australis* Couper 1953 (48–50 μm); **4** – *Polypodiaceoisporites retirugatus* Muller 1968 (45 μm); **5** – *Leiotriletes adriennis* Potonié et Gelletich, 1933 (62 μm); **6** – *Psilastephanocolporites laevigatus* Salard-Chelboldaeff 1978 (33 × 30 μm); **7** – *Chenopodipollis dispersus* Takahashi and Jux 1989 (45 μm); **8** – *Retibrevitricolporites obodoensis* Legoux 1978 (35 μm); **9** – *Racemonocolpites hians* Legoux 1978 (36 × 27 μm); **10** – *Retibrevitricolporites protrudens* Legoux 1978 (41 × 30 μm); **11** – *Zonocostites ramonae* Germeraad, Hopping and Muller 1968 (21–24 μm); **12** – *Verrucatosporites usmensis* (van der Hammen) Germeraad, Hopping and Muller 1968 (40–32 μm); **13** – *Laevigatosporites ovatus* Wilson and Webster 1946 (40 × 28 μm). Bar scale = 20 μm

Also associated with this zone are the abundance peaks of *Monoporites annulatus* (11%) and *Verrucatosporites usmensis* (11–18%). The freshwater ferns, *Pediastrum botryanum* and *P. simplex*, are common. The dinoflagellate cyst, *Achilleodinium biformoides*, also reached its abundance peak. This zone was also characterized by the abundance and diversity of macrofaunae such as gastropod and bivalve shell fragments. The disappearance of the late Eocene *Cicatricosisporites dorogensis* and *Perfotricolpites nigerianus*, in sample L33/01 above sample L25/03, marked the top of this zone (Fig. 4).

5.6 Zone F: *Verrucatosporites usmensis–Magnastriatites howardii* zone, Oligocene–early Miocene

Samples L33/01 to L33/03 were recognized in coal and the overlying grey shale at Loc 33 in the Ogwashi Formation, and fall within zone F (Fig. 4). The base of this zone was defined by the disappearance of late Eocene *Cicatricosisporites dorogensis* and *Perfotricolpites nigerianus*, and the first appearance of Oligocene–early Miocene assemblage, *Zonocostites ramonae*, *Retibrevitricolporites protrudens*, and *Magnastriatites howardii*, with the abundance peak of *Verrucatosporites usmensis* (25%). The rhizophora pollen, *Zonocostites ramonae*, was reported by Germeraad et al. (1968) to have made its first appearance during the Oligo-Miocene in the coastal and offshore marine sediments. Also, the *Ceratopteris* pollen (*Magnastriatites howardii*) made its first appearance in the Oligo-Miocene (Germeraad et al. 1968).

This zone comprises the abundance peaks of freshwater fern spore, *Laevigatosporites ovatus* (26%), and fungal spore, *Fusiformisporites pseudocrabbi* (14%). Other species found in this zone include *Striamonocolpites undatostriatus*, *Psilastephanocolporites minor*, *Psilastephanocolporites laevigatus*, *Arecipites crassimuratus*, *Chenepodipollis dispersus*, and *Periporopollenites* spp. This zone shows the initial appearance of dinoflagellate species, *Distatodinium ellipticum*. The top of this zone, however, was not encountered in this study.

6 Conclusions

This study documents, for the first time, the palynomorph assemblage biozonations of the up-dip areas of Paleogene strata of the Niger Delta Basin, exposed along the Bende–Umuahia axis, southeastern Nigeria. The recovered palynomorphs from the organic-rich outcrop samples in the study area have enabled the demarcation and establishment of six informal palynomorphs assemblage zones, labeled zone A to zone F, based on the first and/or the last occurrence of two or more species. The newly erected palynozones are correlated to other existing biozones in the subsurface series of the Niger Delta Basin, and with the pantropical palynological zones of Germeraad et al. (1968) and the palynofloral provinces of Herngreen and Chlonova (1981), in tropical areas of Africa and northern South America. Comparison of palynozones studied in southeastern Nigeria with international palynozones worldwide will assist correlation of sediments of these areas.

The results presented in this work provide a better understanding for the palynological biostratigraphy of the region as a whole. Further integrated works, especially in the aspects of foraminifers and nanofossils biostratigraphy, are required to strengthen the biozonation study for the strata in the area. And also, as work develops, further additions to the existing database will help to link the current results from the up-dip outcropping strata of the Niger Delta Basin to the results from the subsurface, to provide adequate basin-wide regional correlations.

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Authors' contributions
ONI carried out the research work including laboratory and microscopic investigations; OPU supervised and provided the requisite text; OIC and KKN proofread and made useful inputs regarding the regional geology; OSN and KCC assisted in the fieldwork, proofread and made helpful suggestions on the manuscript. The consent of authorship and the order of authors have been approved by all of us. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed.

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The authors declare that they have no competing interests.

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