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Palynostratigraphy, palaeoclimates and palaeodepositional environments of the Miocene aged Agbada Formation in the Niger Delta, Nigeria

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ABSTRACT

A diverse assemblage of palynomorphs dominated by terrestrially derived pollen and spores is reported from three wells penetrating the Miocene Agbada Formation. The pteridophyte and bryophyte spores which form the background assemblages in the three wells are good indicators of humid tropical climates which might have prevailed in the Niger Delta during the Miocene. The abundance and variations of climate-sensitive taxa including mangrove affiliated pollen and spore types *Acrostichumsporites*, *Psilatricolporites crassus*, *Zonocostites ramonae* and *Graminidites annulatus* representing the savannah vegetation cover indicate a complex interplay between periods of wetter and drier climates.

Marine-derived dinoflagellate cysts and foraminiferal test linings are significantly present in the three wells. Taxa indicating freshwater contributions including *Botryococcus* spp., *Chomotriletes minor*, *Ovoidites parvus* and *Pediastrum* spp. are also represented numerically across the three wells.

The presence of age diagnostic palynomorphs such as *Crassoretitriletes vanraadshooveni*, *Retibrevitricolporites obodoensis*, *Tuberculodinium vancampoae*, *Zonocostites* ramonae and *Tuberculodinium vancampoae* recovered in the three sections studied suggest a Miocene age for the investigated Agbada Formation. The proposed age is supported by the ranges of key palynomorphs in contemporaneous basins in Africa, northern South America and other parts of the World.

1. Introduction

The discovery of commercial quantities of hydrocarbons in Olobiri Field, Niger Delta Basin, in 1956 (Kulke, 1995) signalled the establishment of the Niger Delta as a world-class petroleum province. Since then, exploration and production activities have moved from the continent into shallow-water offshore and presently into the deep-water. This very important hydrocarbon province is considered among the world's top ten in terms of oil and gas reserves. Consequently, numerous scientific papers have been published both in international and local journals on the geology and petroleum potential of the basin. The present study looks into the application of palynology as an important tool in the determination of precise depositional settings and palaeoclimates which prevailed during deposition of some of the reservoir sequences in the Niger Delta, specifically associated with the gross lithostratigraphic unit, the Agbada Formation (Figs. 1–3, Table 1).

Palynology finds its use in hydrocarbon exploration essentially as a stratigraphic tool in depositional settings such as continental, coastal, marginal marine and deep marine environments. When integrated with other fossil disciplines, seismic stratigraphy and mechanically acquired data including wire-line logs, the discipline can be widely applied for chronostratigraphic correlation, palaeoenvironmental studies, and evaluation of potential source, reservoir and sealing rocks (Copestake, 1993). Despite the effectiveness of palynology as an important tool in sequence stratigraphic analysis, it is still being grossly under-utilised in hydrocarbon exploration and production in low latitude marginal marine settings. This is primarily due to the limited floral turn-over of the parent vegetation types in humid, tropical low latitude vegetation belts. In cooler (high latitude) boreal settings, the additional use of marine microplankton types such as dinoflagellate cysts, psilate and ornamented acritarchs offer higher resolution

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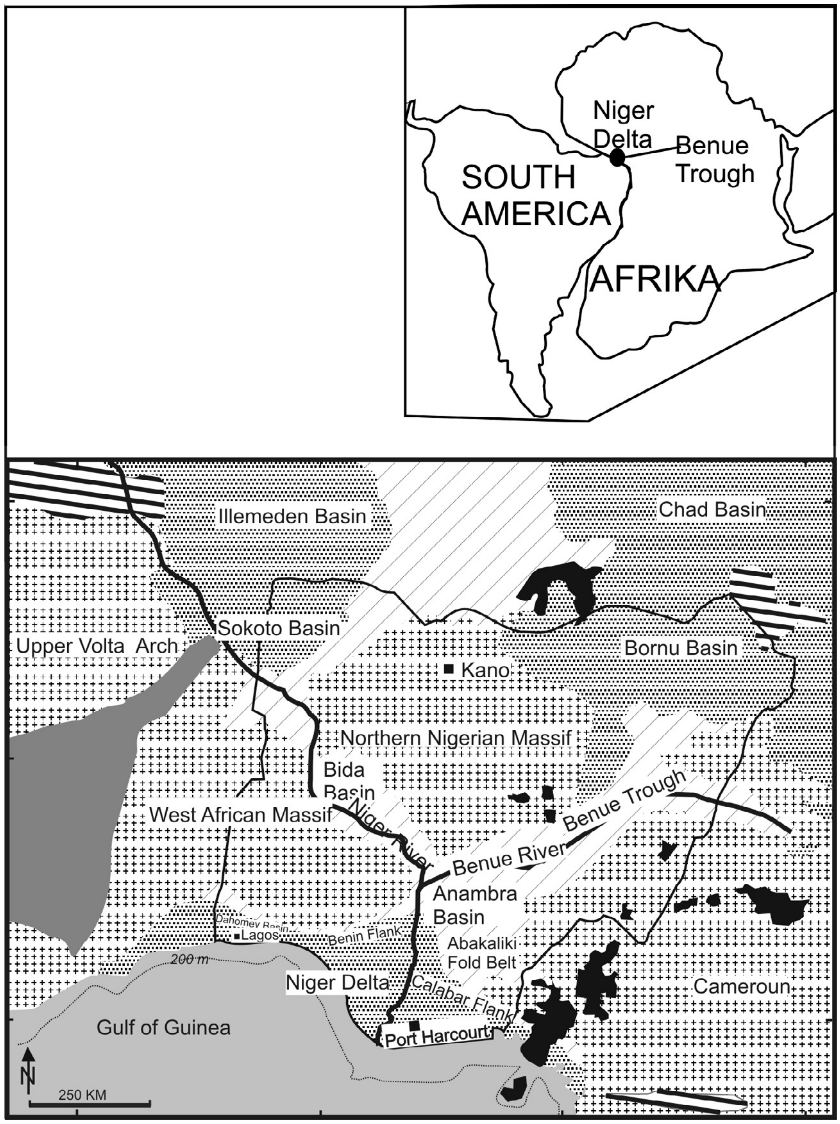

Fig. 1. Simplified geological map of Nigeria showing the location of the Niger Delta and some other Nigeria basins. Inset: Sketch map of Africa and South America (Between the Late Jurassic and Cretaceous) showing the triple junction fracture zones. Modified after the copy in Stacher (1995).

to stratigraphic subdivision being linked to more distinct oceanic climate change, namely water-mass controls and temperature.

The Cenozoic Niger Delta Basin is located at the centre of a relict triple junction, a fracture zone which initiated the separation of continental Africa from that of South America (Fig. 1 inset) occurring between the Late Jurassic and the Cretaceous (Weber and Daukoru, 1975).

1.1. Stratigraphy of the Cenozoic Niger Delta

The lithofacies pattern of the Cenozoic Niger Delta reflects the various depositional environments peculiar to most deltas. These depositional environments, which prevailed in the sequences of the Cenozoic Niger Delta can largely be grouped into continental, transitional and marine. The Cenozoic Niger Delta covers an area of approximately 140,000 km^2, with cumulative sedimentary sequence of about 12,000 m (Knox and Omatsola, 1989). These sequences have been subdivided into three major sedimentary units, namely the Akata, Agbada and the Benin Formations (Table 1 and Fig. 3). The oldest of these three formations is the Eocene to Recent Akata Formation (Short and Stäuble, 1967; Reijers et al., 1997, Table 1). The Akata Formation, characterised by continuous, uniform shale deposition was laid down in a marine environment. On top of the marine sequence is the Eocene to Recent Agbada Formation. The Agbada Formation constitutes the actual deltaic portion of the sequence. It is considered to have been accumulated in deltaic front, delta-topset and fluviodeltaic environments (Corredor et al., 2005). Capping the sequence is the mainly continental Benin Formation, deposited during the Oligocene to Recent (Reijers et al., 1997).

1.1.1. Akata Formation

The formation is characteristically composed of dark gray shale, sometimes sandy or silty of prodelta origin (Short and Stäuble, 1967; Akpoyovbike, 1978); the shales of this formation are largely undercompacted (Akpoyovbike, 1978).

1.1.2. Agbada Formation

The Agbada Formation which herein is subjected to detailed palynological investigation is composed mainly of alternating sandstone/sand bodies with mudstones. The Agbada Formation, according to Weber (1971), is considered to be composed of cyclic

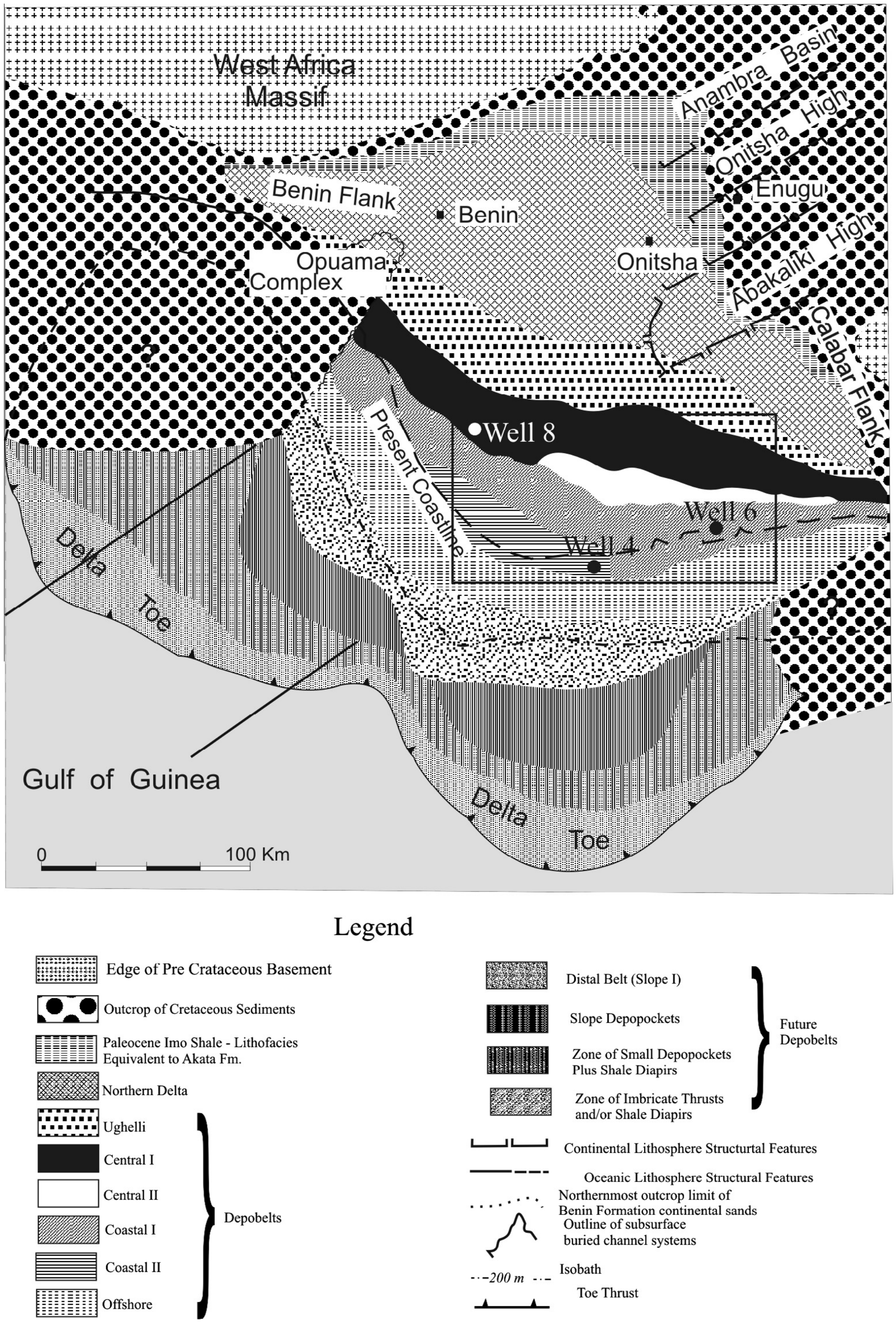

Fig. 2. Regional structural elements and depobelts of the Niger Delta. Successive phases of delta development, referred to as depobelts, may be distinguished. In each, the paralic sequence is distinct in age: for instance, the Greater Ugheli depobelt is early Miocene whereas the more seaward Central depobelt is Middle Miocene. Offshore, the delta forms two large lobes, in which depocenters are located between diapiric shale zones. Modified after Doust and Omatsola, 1990. The box indicates the location of the study area.

sequences of marine and fluvial deposits. Evidence from ditch cuttings used for the present study indicates fine to medium-grained sand/sandstones and mudstones. Lots of fairly clean coarse-grained sands have also been encountered in the samples. They are also locally calcareous, shelly, and contain pyrite. The formation as observed in the present investigation yields abundant and diverse groups of palynomorphs. Gamma Ray log data indicate high shale to sand ratio at the base of the Agbada Formation. This trend gradually reverses itself as the middle part of the formation is approached and persists to the top. The formation grades vertically into the mainly continental deposits of the Benin Formation.

1.1.3. Benin Formation

The formation represents an almost continuous series of continental deposits (with very rare short-lived marine incursions) ranging from medium to coarse-grained sands/sandstones. Short

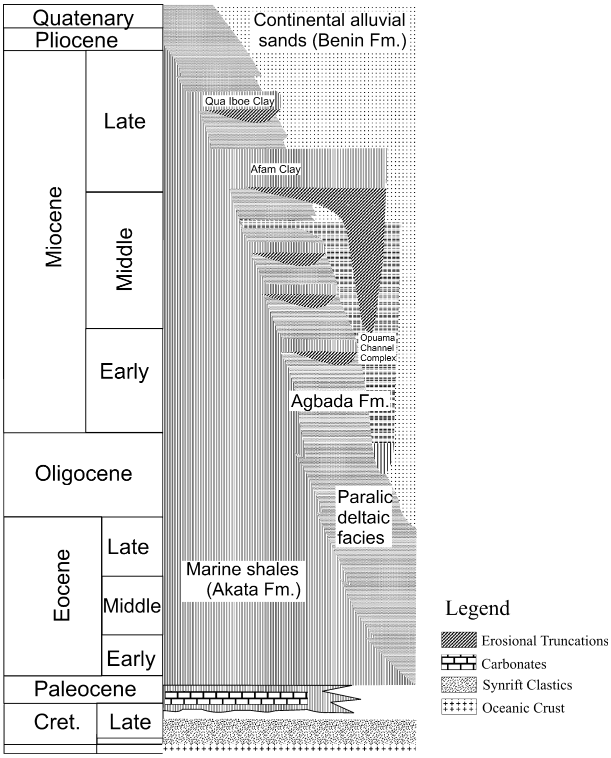

Fig. 3. Schematic representation of the diachronous nature of major lithofacies units, and the stratigraphic relationships of clay-filled channels on the delta flanks. Modified after Doust and Omatsola (1990) and Lawrence et al. (2002).

and Stäuble (1967) have described the sands/sandstones of the Benin Formation to be generally coarse-grained, very granulate and pebbly but also ranging in grain-size to fine-grained. From a few samples of the Benin Formation included in the study materials used for the present investigation indicate medium to coarse-grained sands/sandstones. They are generally fairly clean but evidence of organic remnants (such as wood fragments) has been found in some of the samples.

1.1.4. Biostratigraphic outlook of the Agbada Formation

Palynological information from the Agbada Formation is often not available due to the fact that most of the palynological investigations in the Niger Delta are carried out by the oil companies and such studies are always confidential. However, biostratigraphic studies on the Agbada Formation *sensu lato* from other localities in the Niger Delta, largely based on foraminifera, have assigned an Oligocene–Pliocene age to the formation (Petters, 1979, 1983; Ozumba, 1994; Adeniran, 1997). The same age range has also been assigned to most of the pollen recovered from the formation from other localities in the Niger Delta by Legoux (1978). This age range (Oligecene–Pliocene) points to an improvement to the earlier works of Short and Stäuble (1967) as modified after Akpoyovbike (1978) in Table 1 herein.

1.2. Previous palynological work in the Niger Delta

A great deal of palynological investigations has been conducted in the Niger Delta. Some of the pioneering palynological investigations include those of Van Hoeken-Klinkenberg (1966) on the Maastrichtian, Paleocene and Eocene pollen and spores from Nigeria and the systematic description of new sporomorphs from the Upper Tertiary (Neogene) of Nigeria (Clarke, 1966; Clarke and Frederiksen, 1968). Shell as global pioneers in palynostratigraphy of hydrocarbon basins around the World during the 1950s and 1960s were actively collecting palynological data which was ultimately published by Germeraad et al. (1968). This paper touched on the palynology of Tertiary (Cenezoic) sediments from tropical areas but focused on the Niger Delta as one of the important basins on which the publication is based. Legoux (1978), Jan du Chêne and Salami (1978) and Oloto (1992) have carried out palynological investigations including systematic description and age determination of the sedimentary sequences in the Niger Delta. The applied palynological studies in the basin include those of Morley and Richards (1993) who used Gramineae cuticle as a tool for climate change monitoring during the Late Cenozoic Niger Delta. The high resolution sequence stratigraphic work of Armentrout et al. (1999) from the Oso Field, Niger Delta, emphasised the importance of palynology in detailed sequence stratigraphic resolution. In addition, Van der Zwan and Brugman (1999), indicated the importance of palynology as one of a number of biosignals in the EA Field, Niger Delta. Ige (2009) is based on the pollen and spores record from the Niger Delta and their palaeo-vegetational implications. Oboh et al. (1992) and Oboh (1995) are other important palynological contributions in the understanding of the Niger Delta Basin.

2. Material and methods

Ditch cutting samples and log data yielded the data-base for the present investigation. The data and the location map of the selected wells were provided by the Shell Petroleum Development Company of Nigeria (SPDC).

Following standard palynological preparation method, with inputs from the procedures established at the palynological section of the Exploration Geology Department of the Technische Universität Berlin, Germany, 407 ditch cutting samples from the three

Table 1
Lithostratigraphic subdivisions of the Niger Delta, Nigeria. Modified after Akpoyovbike (1978). The original modified after Short and Stäuble (1967).

Subsurface			Surface outcrops		
Youngest known age		Oldest known age	Youngest known age		Oldest known age
Recent	Benin Formation	Oligocene	Plio. Pleistocene	Benin Formation	Miocene?
	Afam/Qua Iboe				
Recent	Agbada Formation	Eocene	Miocene	Ogwashi-Asaba Formation	Oligocene
			Eocene	Ameki Formation	Eocene
Recent	Akata Formation	Eocene	Late Eocene	Imo Formation	Paleocene
			Paleocene	Nsuka Fm.	Maastrichtian
Equivalents not known			Maastrichtian	Ajali Formation	Maastrichtian
			Campanian	Mamu Formation	Campanian
			Camp./Maest.	Nkporo Shale	Santonian
			Coniacian/Santonian	Agwu Shale	Turonian
			Turonian	Eze Aku Shale	Turonian
			Albian	Asu River Group	Albian

wells were subjected to investigation. Ten grams of each sample was washed, then treated with 10% HCl (in excess) and 35% HF for the complete removal of carbonates and the dissolution of silicates respectively. Using a 15 μm sieve, the residue was carefully sieved in an ultrasonic machine for a maximum of 5 min to improve palynomorph recovery. One to two drops of the residue are carefully dropped at the centre of each slide. A drop of warm Kaiser's Glycerol Gelatine is placed on a cover slip which is then gently lowered onto the slide containing the residue. A minimum of two slides were made from each sample.

Microscopic scanning of the palynomorphs was carried out using a Leitz Diaplan Microscope (Leitz Wetzlar; Type 307-148.001). Photographic work was done using Olympus Digital Camera DP 12. All slides, sieved and unsieved residues, are stored at the Institüt für Angewandte Geowissenschaften, Technische Universität Berlin, Germany. During visual assessment of each sample, at least 200 palynomorphs (pollen, spores, dinocysts, microforaminiferal test linings, fungal haphae, freshwater/brackish marine algae and inaperturates) are counted where possible. Percentage contributions of the mentioned components in each of the samples were calculated and depicted in Figs. 4–6.

3. Palynostratigraphy

Palynomorphs including pteridophyte and bryophyte spores, gymnosperm and angiosperm pollen, dinocysts, freshwater algae and fungal spores were recovered from the three wells investigated. Terrestrial plant tissues such as cuticle, xylem and woody components are also abundantly present but were not considered in the present work. Percentage quantitative composition curves, distribution patterns of the palynofloral elements encountered and range charts are shown in Figs. 4–9 and 12 respectively. Of the recovered components, terrestrially-derived forms (pollen and spores) constitute approximately 80%, whereas less than 8% are of marine origin (dinoflagellates and foraminiferal test linings) (Figs. 4–6). Freshwater algae, fungal spores and inaperturate pollen types represent the remaining 12%. The low abundance of dinoflagellates might be a consequence of a high siliciclastic discharge rate of the Proto-Niger River into the Atlantic Ocean (Gulf of Guinea) and also the tidal effects emanating from the ocean-land interface itself.

Cumulatively, 85 genera, represented by 149 palynomorph species (excluding freshwater algae, inaperturate pollen and fungi) were identified (Appendix A). Approximately 66% of the samples analysed were productive with the remaining 34% being barren.

Fern spores constitute the most abundant (*ca.* 42%) elements of the palynoflora recovered from the three wells (Figs. 4–6). They are present in all the samples analysed. The monolete fern spores are represented by four genera comprising the following species: *Laevigatosporites nitidus crassicoides*, *L. haardti crassicus*, *L. discordatus*, *L. javanicus*, *L. nitidus*, *Perinomonoletes* sp. 1, *P.* sp. 2, *Reticulosporis miocenicus*, *R.* sp., *Verrucatosporites alienus*, *V. favus*, *V. balticus major*, *V. ornatus* and *V. usmensis.*

The trilete fern spores are mainly represented by: *Acrostichumsporites meghalayaensis*, *A.* sp. 1, *A.* sp. 2, *Crassoretitriletes vanraadshooveni*, *Cyathidites congoensis*, *Dictyophyllidites trilobiformis*, *Leiotriletes maxoides*, *L. microsinuosoides*, *L.* spp., *Magnastriatites howardi*, *Todisporites flavatus*, *T. major*, *Triplanosporites microsinuosus* and *Undulatisporites structuris* among others. A comprehensive list of the species of fern spores is included in Appendix A.

Angiosperm pollen are also abundantly present in all the three studied sections. They constitute approximately 40% of the recovered palynomorphs represented herein among others by: *Praedapollis flexibilis*, *Caprifoliipites superbus*, *Crototricolpites densus*,

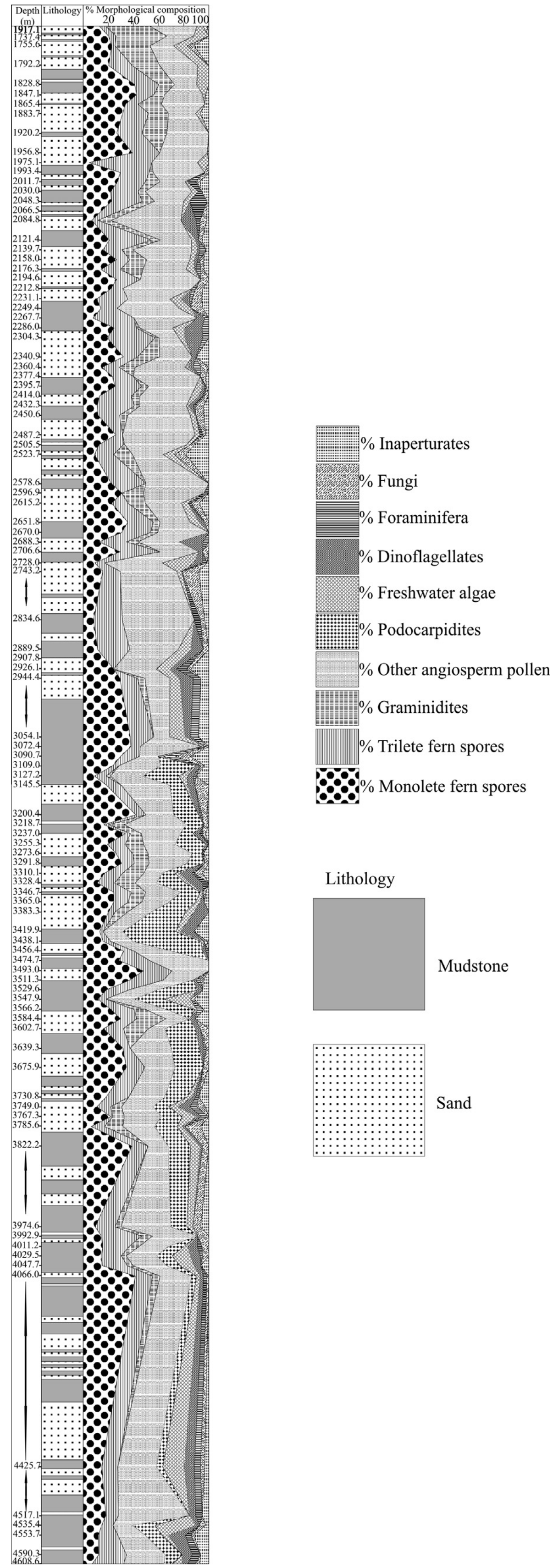

Fig. 4. Quantitative composition of the palynomorph assemblages in well 4. *Note:* The double headed arrows indicate large sample intervals resulting from barrenness or non-availability of samples.

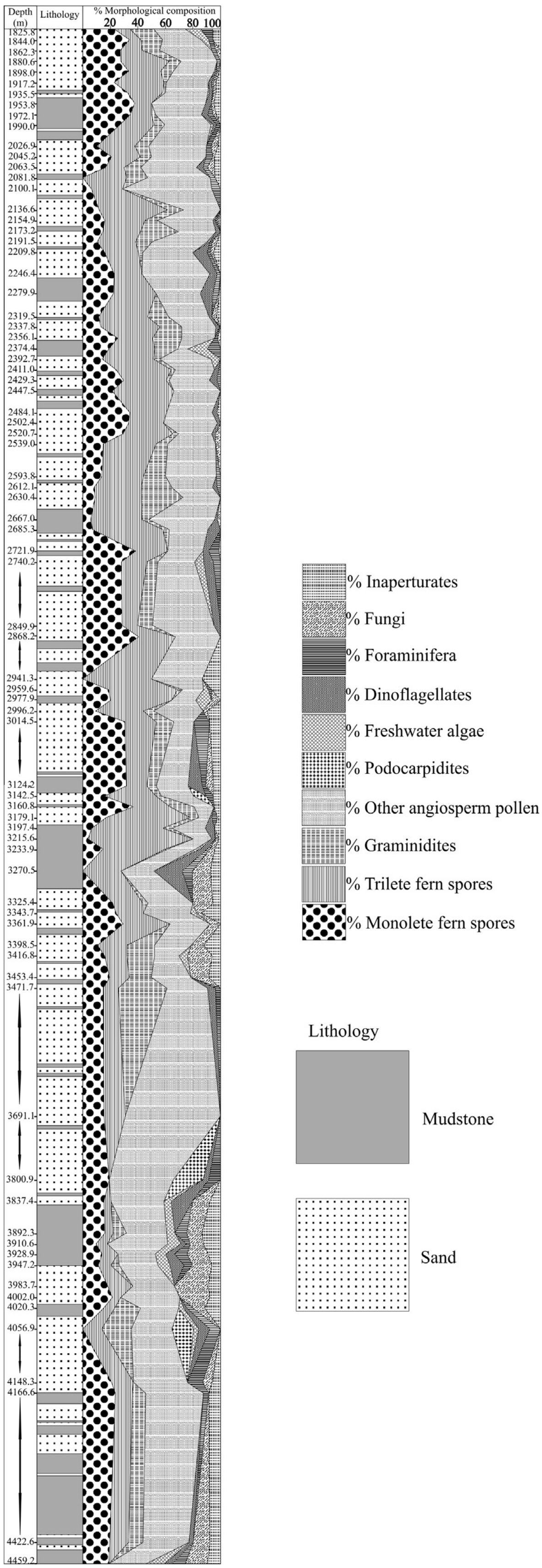

Fig. 5. Quantitative composition of the palynomorph assemblages in well 6. *Note:* The double headed arrows indicate large sample intervals resulting from barrenness or non-availability of samples.

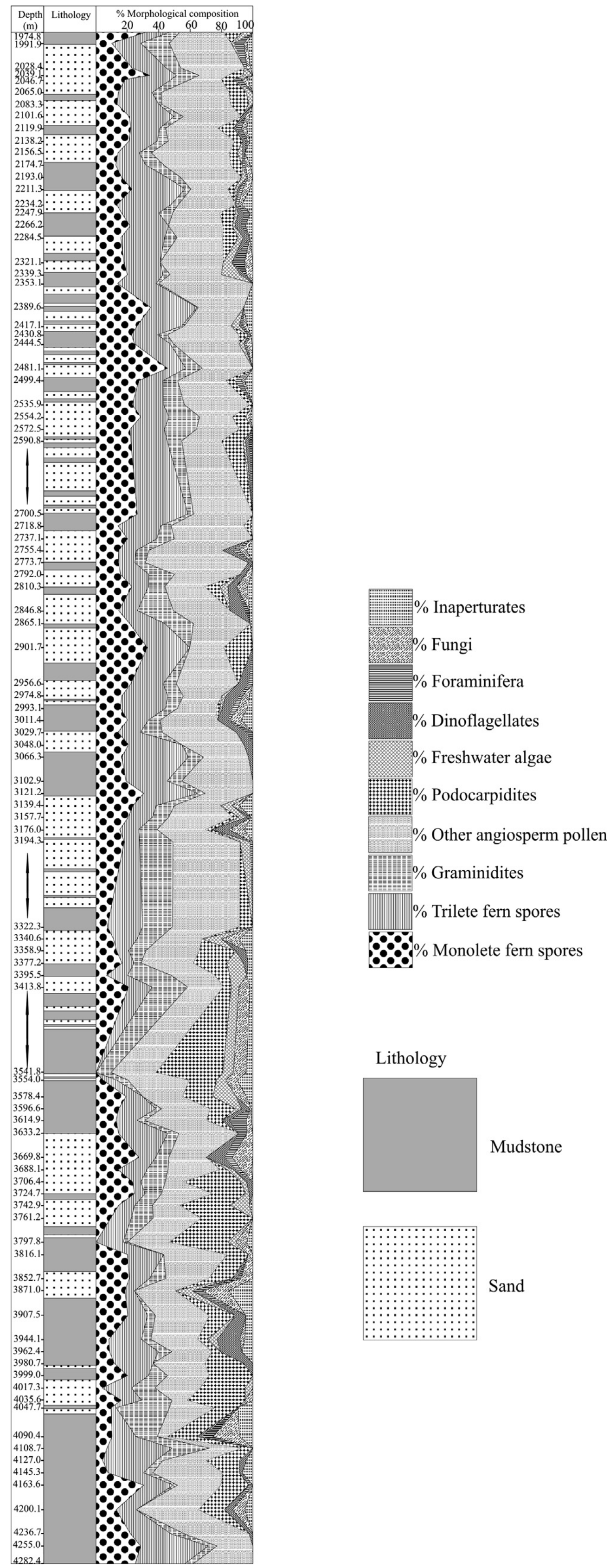

Fig. 6. Quantitative composition of the palynomorph assemblages in well 8. *Note:* The double headed arrows indicate large sample intervals resulting from barrenness or non-availability of samples.

Ctenolophonidites costatus, *C.* sp., *Graminidites annulatus*, *Pachydermites diederixi*, *Peregrinipollis nigericus*, *Polyadopollenites indecorus*, *Psilastephanocolporites laevigatus*, *P.* cf. *perforatus*, *P.* sp., *P.* spp., *Psilatricolporites crassus*, *Racemonocolpites hians*, *R. racematus*, *Retibrevitricolporites obodoensis*, *R.* sp. cf. *obodoensis*, *Retitricolporites* cf. *annulatus*, *R.* sp. cf. *guianensis*, *R. irregularis*, *Retitrescolpites* cf. *splendens*, *R. typicus*, *Striatopollis bellus*, *S. catatumbus*, *S. nigericus*, *S. variabilis*, *S. striatellus* and *Zonocostites* cf. *ramonae*. A comprehensive list of the angiosperm pollen encountered in the section is included in the Appendix A.

Another pollen group of significant abundance in the studied sections are the gymnosperms represented herein by the genera *Araucariacites* and *Podocarpidites.* The genus *Podocarpidites* is represented in large numbers in wells 4 and 8, but of limited representation in well 6 (Figs. 4–9).

Marine forms such as dinoflagellate cysts and microforaminiferal test linings are a significant component in the studied material. Dinoflagellate cysts are represented by *Lingulodinium* sp. cf. *machaerophorum* and *Lingulodinium* sp. cf. *sicula.* Other taxa with varying degrees of representation include the genera *Adnatosphaeridium*, *Cordosphaeridium*, *Dapsilidinium*, *Homotryblium*, *Lejeunecysta*, *Polysphaeridium*, *Spiniferites* and *Tuberculodinium*.

4. Palaeoclimate

The climate of an area is reflected by its vegetation type (Samant and Phadtare, 1997). Changes in plant communities or variations in composition/abundance of an assemblage or individual species are usually partly a direct consequence of variation in climate and/ or environment. The effect of this variation on floral communities depends on whether such a climate change favours or prejudices against the plant community or individual plant in question. Qualitative and quantitative assessment of the various groups of palynomorphs undertaken here is aimed at deducing the climate phase and types of environments which prevailed during the deposition of the Agbada Formation in the Miocene.

Pteridophyte and bryophyte fern spores such as those encountered in this study including the genera *Biretisporites*,

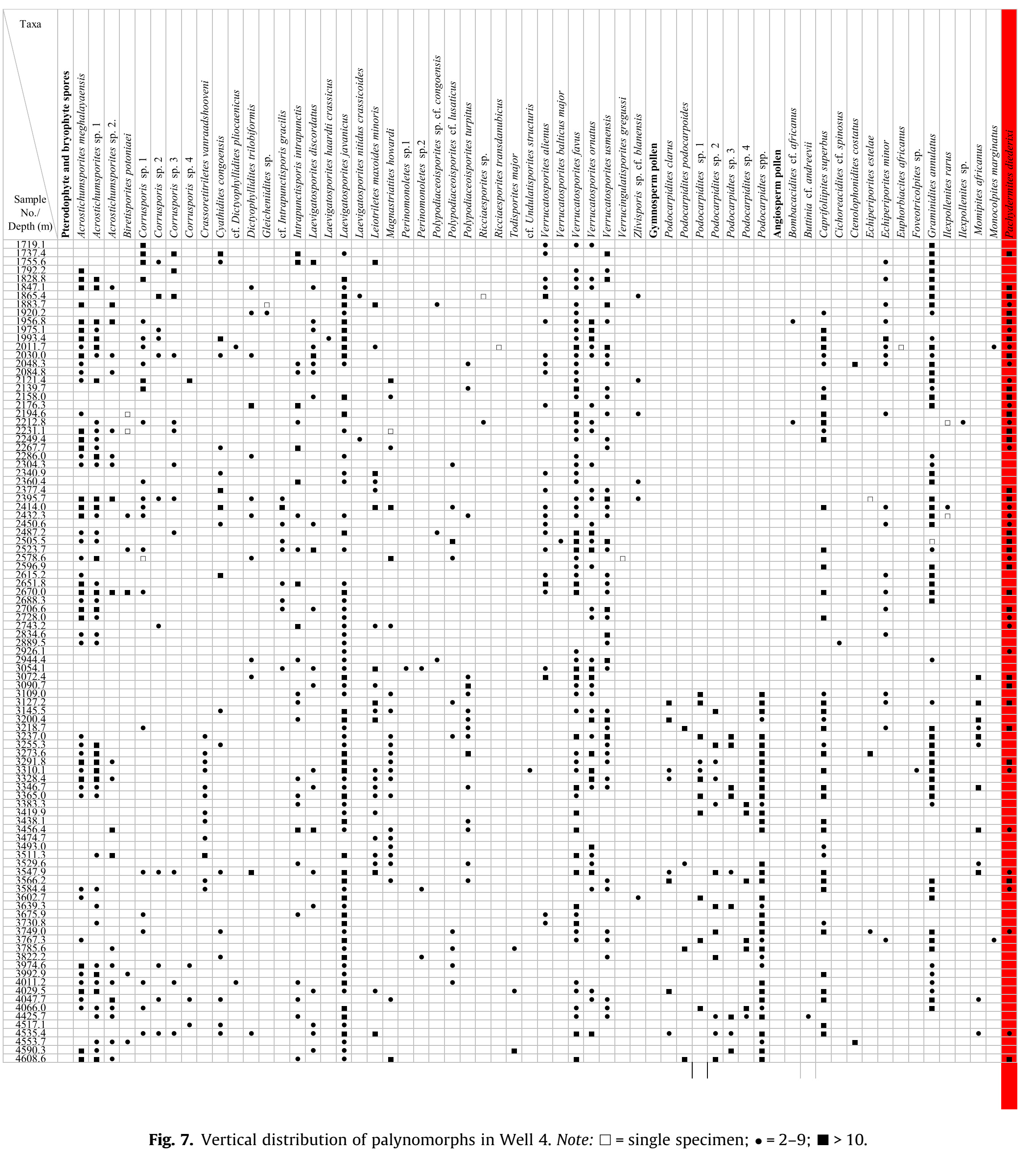

Fig. 7. Vertical distribution of palynomorphs in Well 4. *Note:* □ = single specimen; • = 2–9; ■ > 10.

Sample No./ Depth (m) \ Taxa	**Angiosperm pollen cont.**	*Peregrinipollis nigericus*	*Perfotricolpites digitatus*	*Pollatricolporites mocinnii*	*Polyadopollenites indecorus*	*Polygalacidites* sp.	*Proteacidites* sp. cf. *P. cooksoni,*	*Psilamonocolpites* sp. cf. *medius*	*Psilastephanocolporites laevigatus*	*Psilastephanocolporites* cf. *perforatus*	*Psilastephanocolporites* spp.	*Psilatricolporites crassus*	*Racemonocolpites hians*	*Racemonocolpites racematus*	*Retibrevitricolporites obodoensis*	*Retibrevitricolporites* sp. cf. *obodoensis*	*Retitrescolpites* cf. *splendens*	*Retitrescolpites typicus*	*Retitricolporites heteroreticulatus*	*Retitricolporites* sp. cf. *guianensis*	*Retitricolporites irregularis*	*Striatopollis catatumbus*	*Striatopollis nigericus*	*Striatopollis striatellus*	*Syncolporites* sp. cf. *marginatus*	*Tetracolporites firmus*	*Triorites gracilis*	*Zonocostites* cf. *ramonae*	**Freshwater algae**	*Botryococcus* spp.	*Chomotriletes minor*	*Pediastrum* spp.	**Fungi**	*Callimothallus pertusus*	*Callimothallus* spp.	*Fusiformisporites crabii*	*Parmathyrites* sp.	**Inaperturates**	**Dinoflagellates**	*Adnatosphaeridium multispinosum*	*Adnatosphaeridium* sp.	*Cordosphaeridium fibrospinosum*	*Dapsilidinium stelacum*	*Homotryblium* spp.	cf. *Ifecysta pachyderma*	*Lejeunecysta globosa*	*Lejeunecysta lata*	*Lejeunecysta* sp. 1	*Lejeunecysta* cf. *tenella*	*Lingulodinium* sp. cf. *machaerophorum*	*Lingulodinium* sp. cf. *sicula*	*Polysphaeridium subtile*	*Tuberculodinium vancampoae*	**Foraminifera test lining**
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Fig. 7 (*continued*)

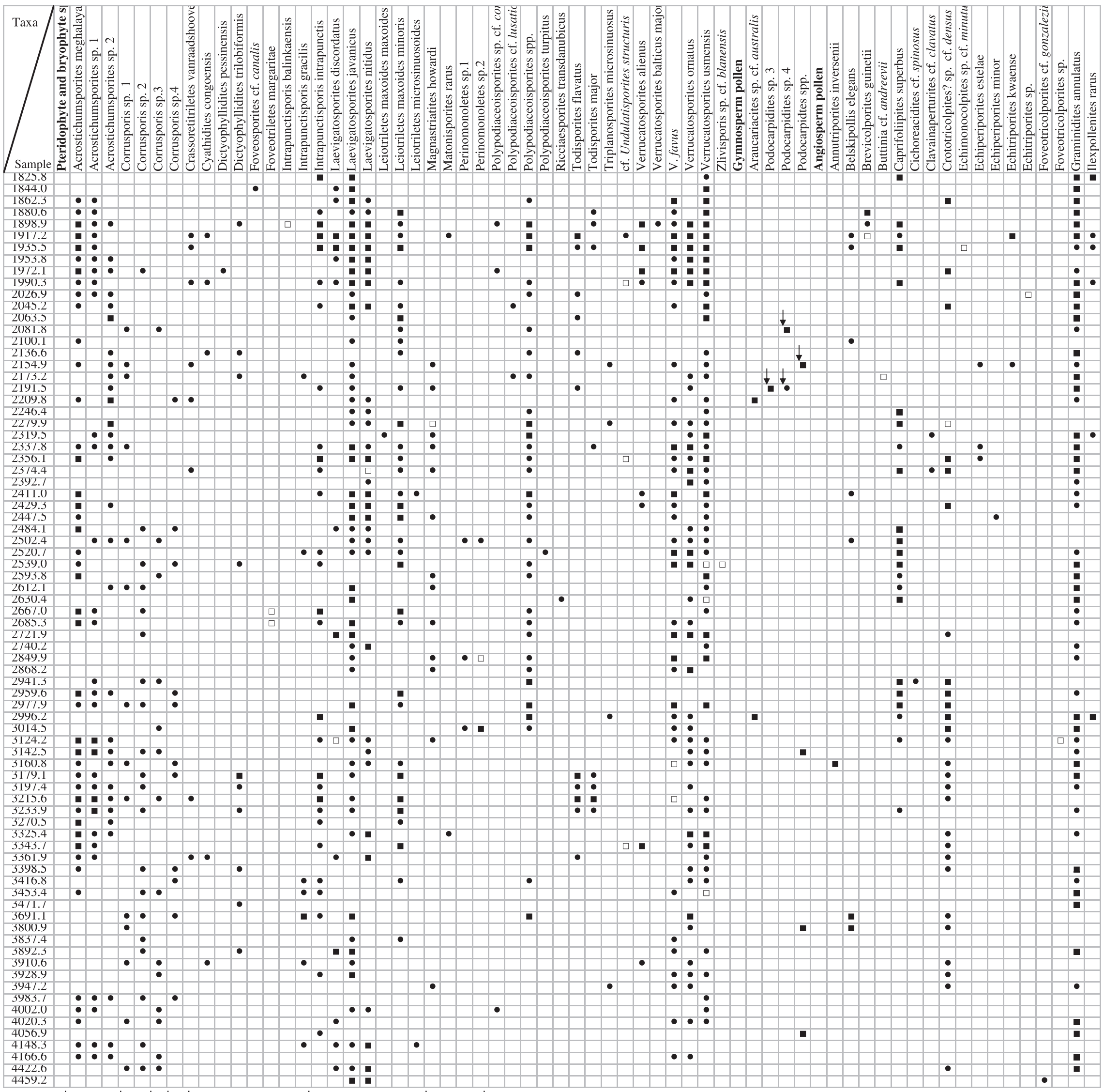

Fig. 8. Vertical distribution of palynomorphs in well 6. *Note:* □ = single specimen; • = 2–9; ■ > 10. *Note:* → = Contaminated samples resulting from sampling error.

Concavisporites, *Cyathidites*, *Dictyophylidites*, *Intrapunctisporis*, *Laevigatosporites*, *Leiotriletes*, *Magnastriatites*, *Matonisporites*, *Perinomonoletes*, *Reticulosporis* and *Verrucatosporites* collectively indicate humid tropical climates (Rull, 1998, 2001). However, fluctuations are generally noticed in the palynomorphs distribution charts (Figs. 7–9) and in the quantitative composition curves (Figs. 4–6) generated from the quantitative assessment of the encountered palynomorphs. This fluctuation is a direct response of the microflora to a variety of climate, environmental and taphonomic factors witnessed within the ecosystem.

Obvious climate and environment sensitive taxa including *Acrostichumsporites meghalayaensis*, *Psilatricolporites crassus* and *Zonocostites ramonae* (mangrove taxa) and *Graminidites annulatus* (savanna to upper coastal plain grassland taxon) are abundantly recorded in all the wells investigated. These taxa have been suggested to be diagnostic of vegetation cycles attributed to climate fluctuation which could be linked to successive phases of humidity versus aridity (Armentrout et al., 1999; Poumot, 1989). The fluctuation in abundance of these taxa is directly linked to climate phase change, which in turn may be linked directly with sea-level oscillation (eustatic transgression/regression) along many other local and global factors (Poumot, 1989; Morley and Richards, 1993). Sea level changes may thus be linked with growth and loss of polar ice caps resulting in global sea level rise and fall.

As earlier indicated, mangrove taxa flourish well in prevailing warm ecosystems (average temperature greater than 22 °C) constantly under the influence of marine water inundation, a condition which prevails during sea level rise (Fig. 10) resulting in the encroachment of the coastal areas. This is also a period of increased precipitation usually associated with wetter climate conditions.

Abundant occurrence of the savanna to upper coastal plain taxon *Graminidites annulatus* is linked to a fall in sea-level (Fig. 11) associated with drier climate events. The fluctuations in abundance of these "climate" indicating taxa recorded in the present work suggest the prevalence of wetter climate conditions during relative maxima of mangrove taxa and drier climatic conditions during relative minima of mangrove taxa and vice versa for the savanna to upper coastal plain forest taxa.

A model for the flora distribution from the coastal area through the hinterland in response to climate variation resulting from sea-level oscillation is depicted in Figs. 10 and 11 (adapted from Poumot, 1989). During relative rise in sea-level (Fig. 10), there is a shift in coastline toward the continent resulting in the

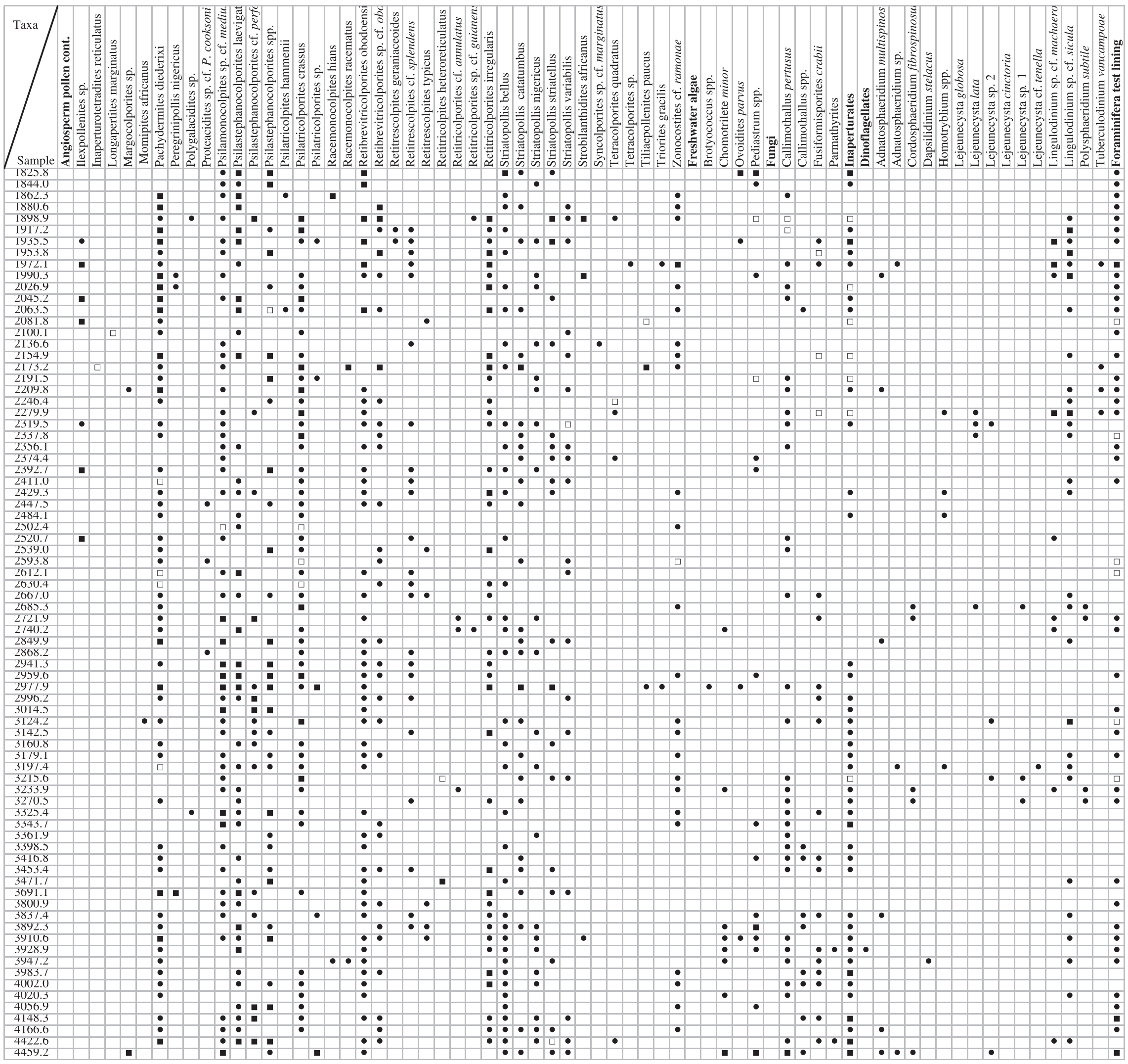

Fig. 8 (*continued*)

inundation of coast with marine water. During this period, the mangrove ecosystem is well established leading to the extension of mangrove vegetation or to a landward shift of the mangrove belt due to their preference for saline water. A consequence of the relative rise in sea level is also the increased precipitation leading to the prevalence of wetter climate. This is also a period where coastal vegetations such as ferns, palms and other plants typical of upper and lower coastal plains flourish. The pollen record during this period is mainly dominated by mangrove elements with some fern spores and typical marine-derived components including dinoflagellate cysts and microforaminiferal test linings. When the sea level falls (Fig. 11), the coastline is shifted in a basinward direction. The shelf area previously under marine influence is exposed and probably incised by fluvial activities. Terrestrially-derived materials are deposited in the palaeo-shelf area. This fall in sea level consequently results in a reduction in precipitation leading to the establishment of drier climate. The climate reversal ultimately results in an extension of the savanna vegetation belt (Fig. 11). The pollen record of this event is dominated by typical savanna (grass) floral elements. Note should be made in Figs. 10 and 11 of the near disappearance of savanna and mangrove ecosystem during transgressive and regressive events respectively.

4.1. Age determination

Palynological studies of the Agbada Formation elsewhere in the basin have dated the formation as Middle Miocene (Oboh, 1992, 1995). A similar study by Legoux (1978) also assigned the age range of the Agbada Formation to between Oligocene and Early Miocene.

The range chart of stratigraphically important palynomorphs recovered from the three sections is given in Fig. 12. The stratigraphically important palynomorphs selected include the following species: *Crassoretitriletes vanraadshooveni*, *Crototricolpites* sp. cf. *densus*, *Echitriporites kwaense*, *Echiperiporites minor*, *Foveotricolporites* cf. *gonzalezii*, *Retibrevitricolporites obodoensis*, *R.* sp. cf. *obodoensis*, *Tuberculodinium vancampoae* and *Zonocostites ramonae*.

Crassoretitriletes vanraadshooveni is in general a Miocene index fossil (Germeraad et al., 1968, Nigeria, Borneo and the Caribbean; Kar and Jain, 1981, India; Lorente, 1986, Venezuela; Li and Huang, 1990, Taiwan; Oboh et al., 1992, Nigeria). The latest occurrence of the fossil according to the same authors is between Pliocene and Pleistocene. The occurrence of *Crassoretitriletes vanraadshooveni* in the studied wells is a strong indication that the deposition of the Agbada Formation occurred between the Miocene and Pleistocene.

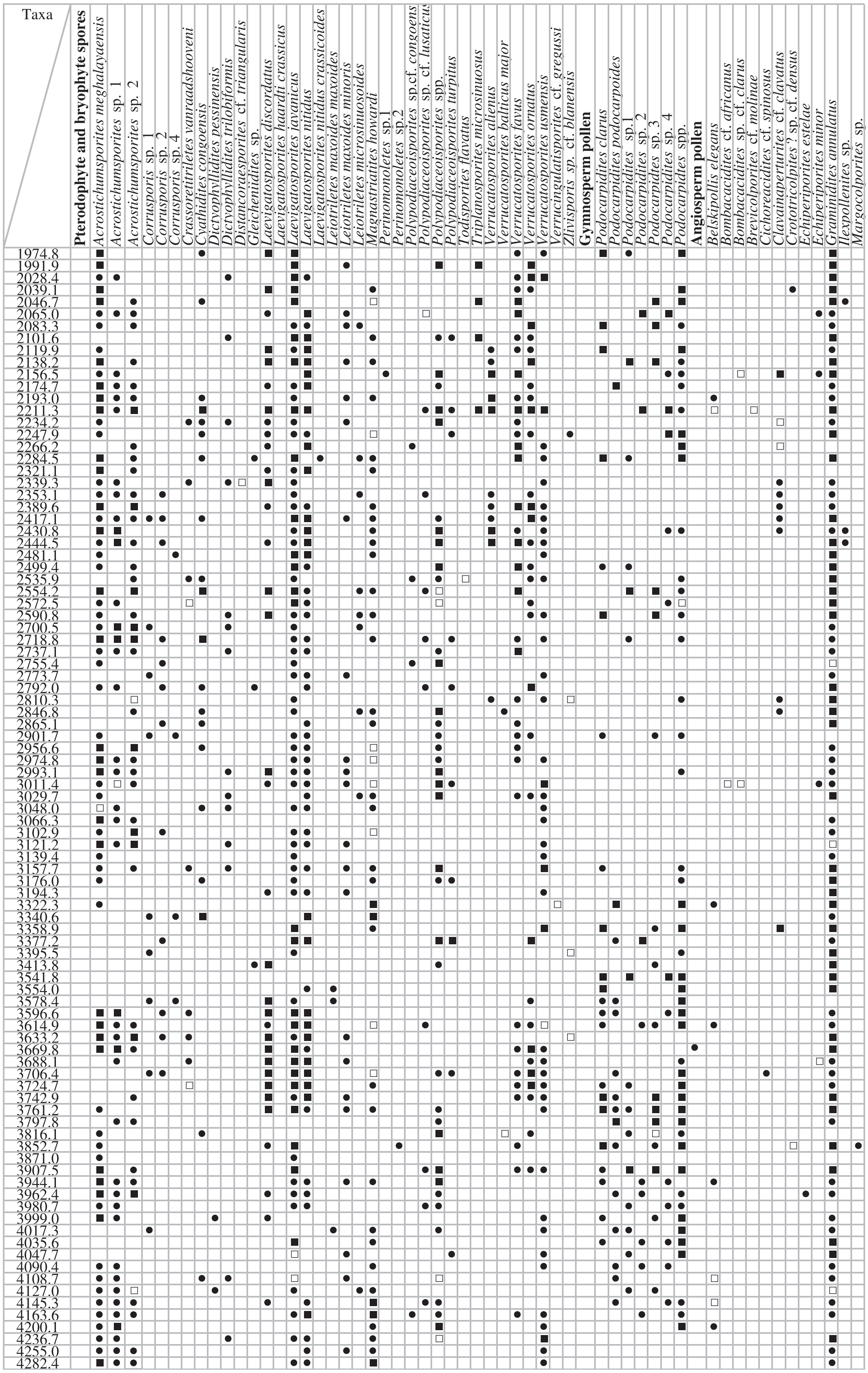

Fig. 9. Vertical distribution of palynomorphs in well 8. *Note:* □ = single specimen; • = 2–9; ■ > 10.

Further, Salard-Cheboldaeff (1978, 1979) reported the ages of *Echiperiporites minor*, *Psilastephanocolporites laevigatus* and *Psilastephanocolporites perforatus* to be Early Miocene. Similar age ranges have been assigned to the following: *Zonocostites ramonae*,

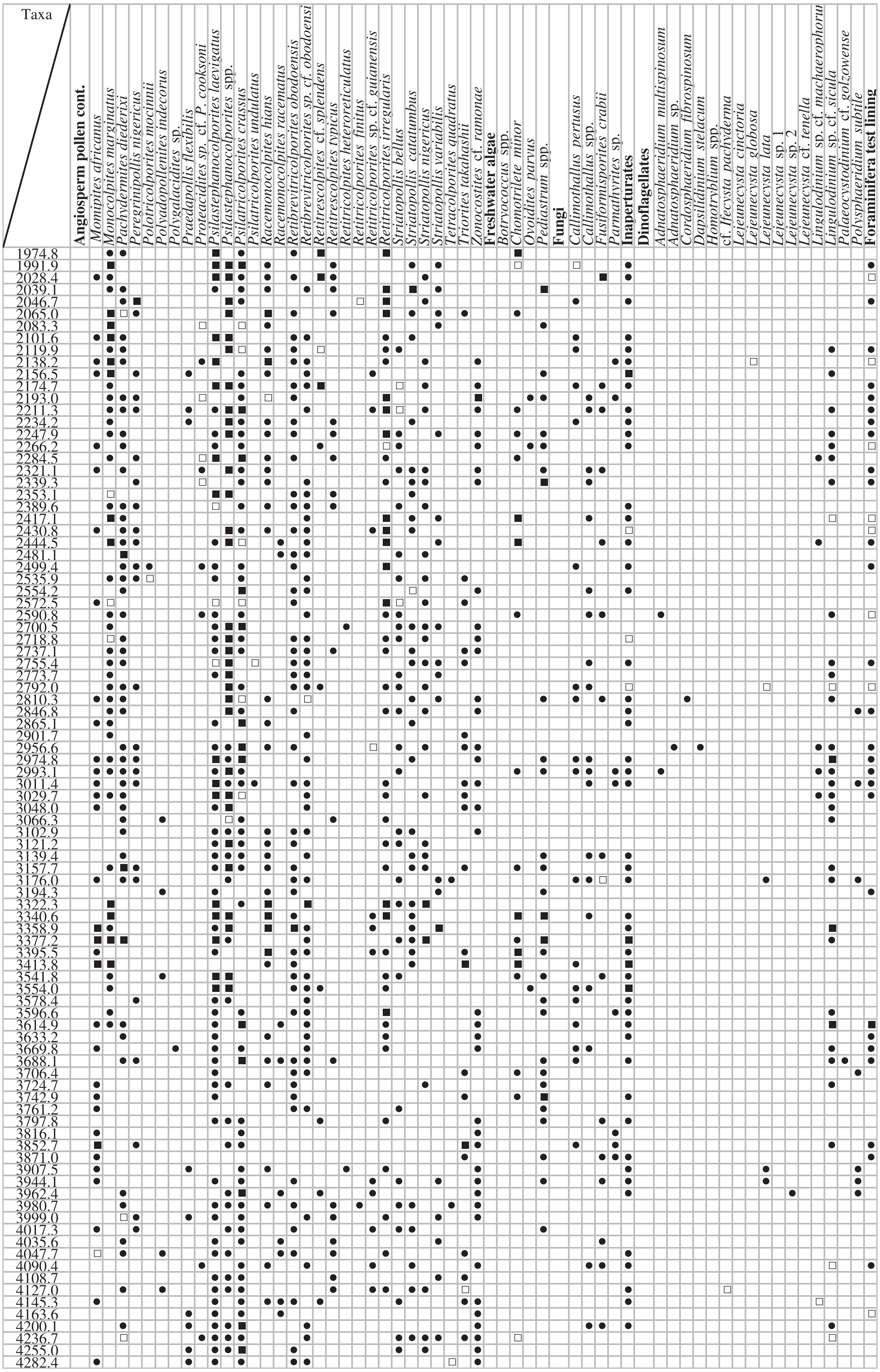

Fig. 9 (*continued*)

Early Miocene to Pleistocene in Nigeria (Germeraad et al., 1968); *Ricciaesporites trandanubicus*, Late Miocene (Karpathian) in Hungary (Nagy, 1985); *Tetracolporites firmus*, *Tiliaepollenites paucus* and *Retitrescolpites geraniaceoides*, Neogene of Burundi (Sah, 1967),

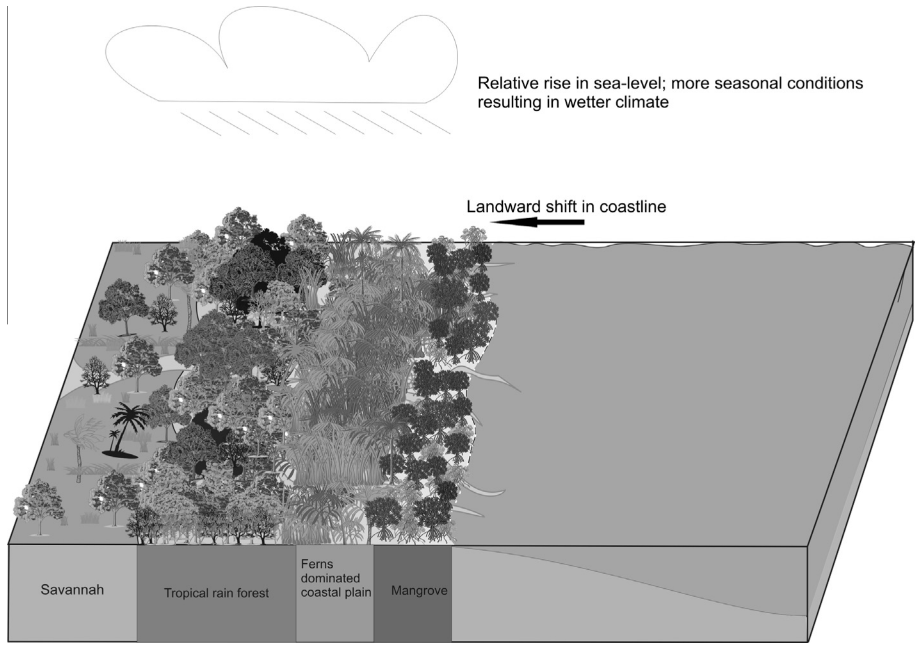

Fig. 10. Vegetation belts during relative rise in sea-level. *Note:* 1. The extension of the mangrove vegetation belt. 2. The decrease of the savanna belt.

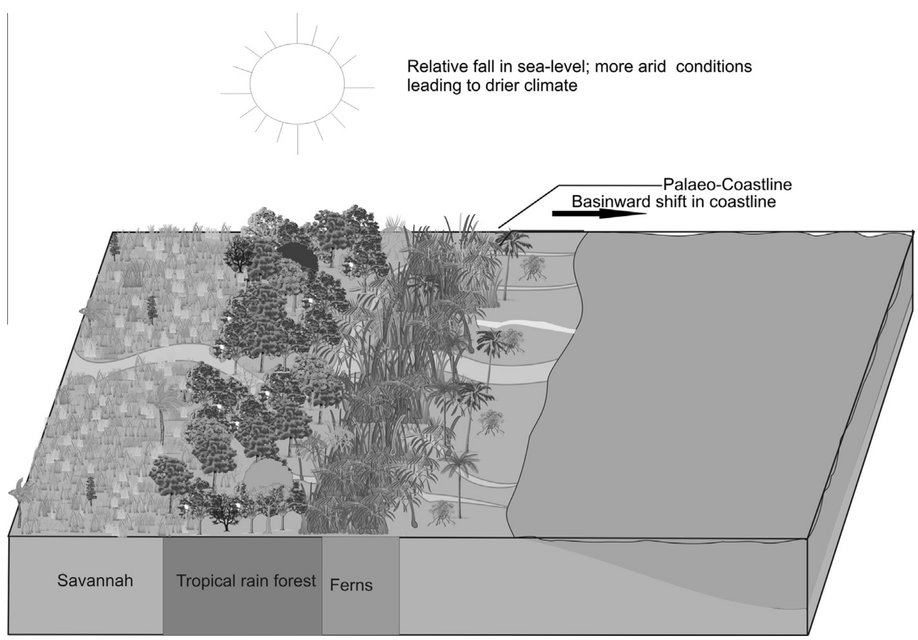

Fig. 11. Vegetation belts during the relative fall in sea-level. *Note:* 1. The basinward shift in coastline leading to increased fluvial activities which may include valley incision. 2. Extension of the savanna vegetation belt. 3. The near disappearance of the mangrove vegetation belt.

and *Tetracolporites quadratus*, Late Miocene to Pliocene age in Burundi and Early Miocene in Sudan (Sah, 1967 and Eisawi and Schrank, 2008 respectively). The abundant presence of the above mentioned palynomorphs at various levels in the three wells is an indication that the stratigraphic interval under investigation was deposited during the Miocene.

Palynostratigraphic evidence from marine dinocysts encountered in the studied wells largely confirms the sporomorph data cited above. Powell (1986) noted the first appearance of *Tuberculodinium vancampoae* in the early Miocene, but also mentioned conflicting earlier reports from the latest Oligocene. Originally this dinoflagellate cyst species was described from the Pleistocene (Fensome and Williams, 2004 and sources therein). The presence of *Tuberculodinium vancampoae* in well 4 (sample 2889) and in well 6 (interval 2279.9–1972.1 m) is thus consistent with an age between Miocene and Pleistocene.

5. Discussions and conclusion

Palynological investigation of the Miocene interval of the Agbada Formation from three deep wells yielded diverse morphological groups, namely: pteridophyte and bryophyte spores, bisaccate and angiosperm pollen, dinoflagellates, foraminiferal test linings,

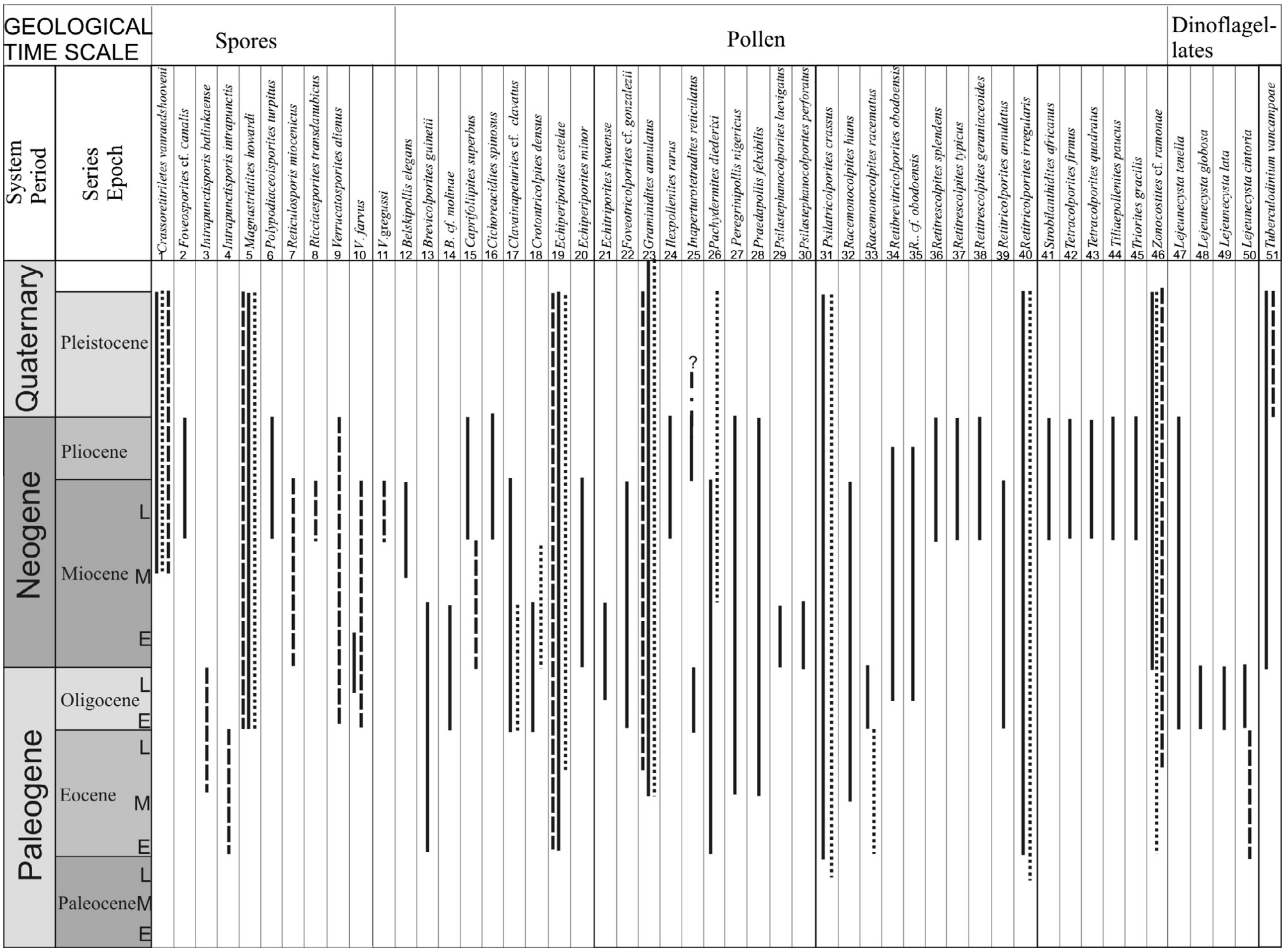

Fig. 12. Previous records of selected palynomorphs from the wells studied. *Note:* ________ = Ranges in Africa, ... = Ranges in South America, – – – – – – = Ranges in other parts of the world. *Sources:* Germeraad et al. (1968) (1, 5, 19, 23, 31, 40, 46); Lorente (1986) (1, 26, 31, 40, 46); Huang (1978) (1); Li and Huang (1990) (1); Sah (1967) (2, 6, 15, 16, 24, 36, 38, 38, 41, 42, 43,44,45); Eisawi and Schrank (2008) (2, 14, 17, 18, 22, 23, 26, 27, 28, 34, 36, 37, 43); Kaska (1989) (27); Clarke (1966) (27); Clarke and Frederiksen (1968) (27); Nagy (1985) (3,8, 11); Krutzsch (1959) (4); Krutzsch (1967) (7); Takahashi and Jux (1989) (9, 10); Legoux (1978) (12, 27, 28, 32, 34, 35); Salard-Cheboldaeff et al. (1992) (12, 21,25, 26); Salard-Cheboldaeff (1978) (13, 14, 18, 22, 25, 39); Salard-Cheboldaeff (1979) (19, 20, 21, 22, 29, 30, 31, 33); Bacchiana et al. (1982) (12, 32, 34, 35); Rao and Ramanujam (1982) (15, 18); Fasola et al. (1985) (17, 26); Oboh et al. (1992) (26, 46); González-Guzmán (1967) (33); El-Beialy (1988) (47); Biffi and Grignani (1983) (47, 48, 49, 50); Bujak et al. (1980) (50);Van der Hammen and Wymstra (1964), (17, 31, 40); Jan du Chêne and Salami (1978) (19, 40); El-Beialy (1990, 1992) (51). Species numbers 1, 5, 6, 9, 10, 16, 19, 20, 23, 26, 27, 29, 31, 32, 33, 34, 35, 40, 46, 47, 48, 49 and 50 occur in wells 4, 6 and 8; species numbers 4, 8, 13, 15, 24, 30, 45 and 51 occur in wells 4 and 6; species number 11 occurs in wells 4 and 8; species numbers 12, 17, 18, 36, 37 and 43 occur in wells 6 and 8; species number 42 occurs only in well 4; species numbers 2, 3, 7, 21, 22, 25, 38, 39, 41 and 44 occur only in well 6; species numbers 14 and 28 occur only in well 8.

freshwater algae, fungi (fungal hyphae) and inaperturate palynomorphs. Of the forms encountered, pteridophyte and bryophyte spores constitute the background assemblage in the three wells. These pteridophytes and bryophytes which include ferns are good indicators of humid tropical climates which might have prevailed in the Niger Delta since the Miocene. The abundance variations of climate-sensitive taxa including *Acrostichumsporites*, *Psilatricolporites crassus* and *Zonocostites ramonae* for the mangrove and *Graminidites annulatus* representing the savanna vegetation indicate interplay between wetter and drier climates.

Sea level oscillation is considered to play an important role in the development of a mangrove ecosystem (Vedel et al., 2006). Mangrove communities have been indicated to flourish during relative sea level rise which corresponds to a wetter climate. Abundance of the savanna taxon, *Graminidites annulatus* is suggested to be associated with a period of relative sea level fall (Poumot, 1989; Morley and Richards, 1993), indicating a possible drier climate. Rarity of cuticles and pollen of Gramineae is interpreted to be related to wetter climatic conditions (Morley, 1981; Morley and Richards, 1993). Intermediate frequencies of the two groups of climate indicators (mangrove and savanna taxa) are taken to represent a condition between wetter and drier climates, possibly temperate conditions.

In the case of *Podocarpidites* (a gymnosperm bisaccate pollen type), its significant recovery in the sections may indicate a contribution even from distant "montane" environments, presumably from the Cameroun mountain range.

Marine-derived components represented by dinoflagellates and foraminiferal test linings are significantly present in the three wells. A relative high population of dinoflagellates in wells 6 and 4 in comparison to well 8 (Figs. 4–6, i.e. the least amount of dinoflagellates was recovered from well 8) is observed. This may suggest an increase of marine-derived components in an offshore direction as expected.

Taxa indicating freshwater contributions including *Botryococcus* spp., *Chomotriletes minor*, *Ovoidites parvus* and *Pediastrum* spp. are significantly represented across the three sections.

Well preserved palynomorphs in the studied well (Plates 1–3) suggest probably rapid burial. The absence of palynomorphs over some extensive sand intervals most especially in well 6 (Fig. 5) may suggest exposure to circulating water leading to oxidation of the palynomorphs.

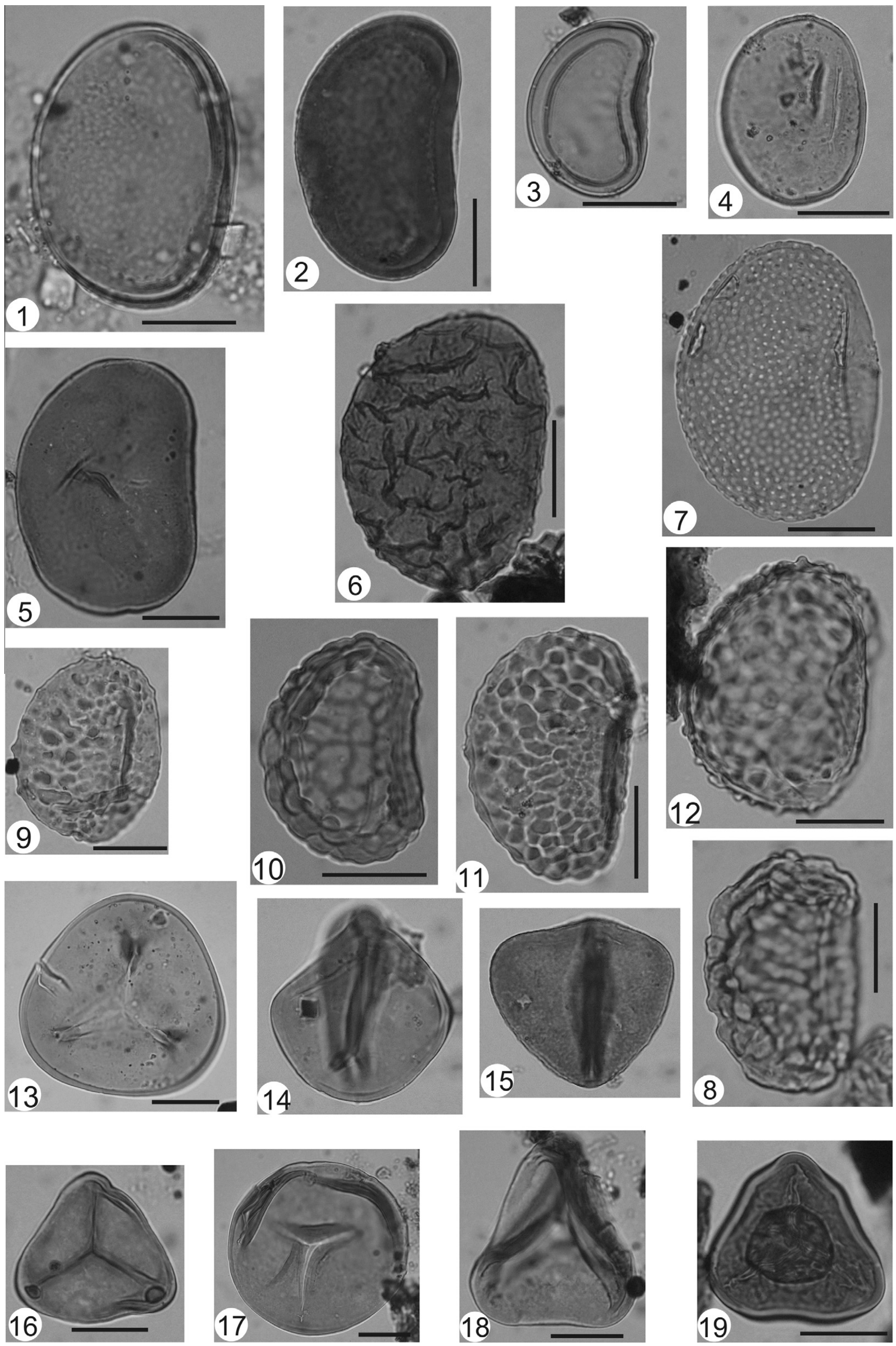

Plate 1. Fig. 1, *Laevigatosporites javanicus* TAKAHASHI, 1982. Fig. 2, *Laevigatosporites nitidus crassicoides* KRUTZSCH, 1967. Fig. 3, *Laevigatosporites haardti* (POTONIÉ & VENITZ) THOMSON & PFLUG, 1953 *crassicus* KRUTZSCH, 1967. Fig. 4, *Laevigatosporites discordatus* PFLUG, 1953. Fig. 5, *Laevigatosporites nitidus* (MAMCZAR, 1960) KRUTZSCH, 1967. Fig. 6, *Perinomonoletes* sp. 1. Fig. 7, *Reticulosporis miocenicus* (SELLING, 1944) KRUTZSCH, 1959. Fig. 8, *Verrucatosporites alienus* (POTONIÈ, 1931) THOMSON and PFLUG, 1953. Fig. 9, *Verrucatosporites favus* (POTONIÈ, 1931c) THOMSON and PFLUG, 1953 subfsp. *favus*. Fig. 10, *Verrucatosporites balticus major* KRUTZSCH, 1967. Fig. 11, *Verrucatosporites ornatus* SAH, 1967. Fig. 12, *Verrucatosporites usmensis* VAN DER HAMMEN, 1956. Fig. 13, *Leiotriletes maxoides maxoides* KRUTZSCH, 1962. Fig. 14, *Leiotriletes microsinuosoides* KRUTZSCH, 1962. Fig. 15, *Triplanosporites microsinuosus* PFLANZL, 1955. Fig. 16, *Cyathidites congoensis* SAH, 1967. Fig. 17, *Todisporites major* COUPER, 1958. Fig. 18, *Dictyophyllidites trilobiformis* SAH, 1967. Fig. 19, cf. *Undulatisporites structuris* KRUTZSCH, 1962.

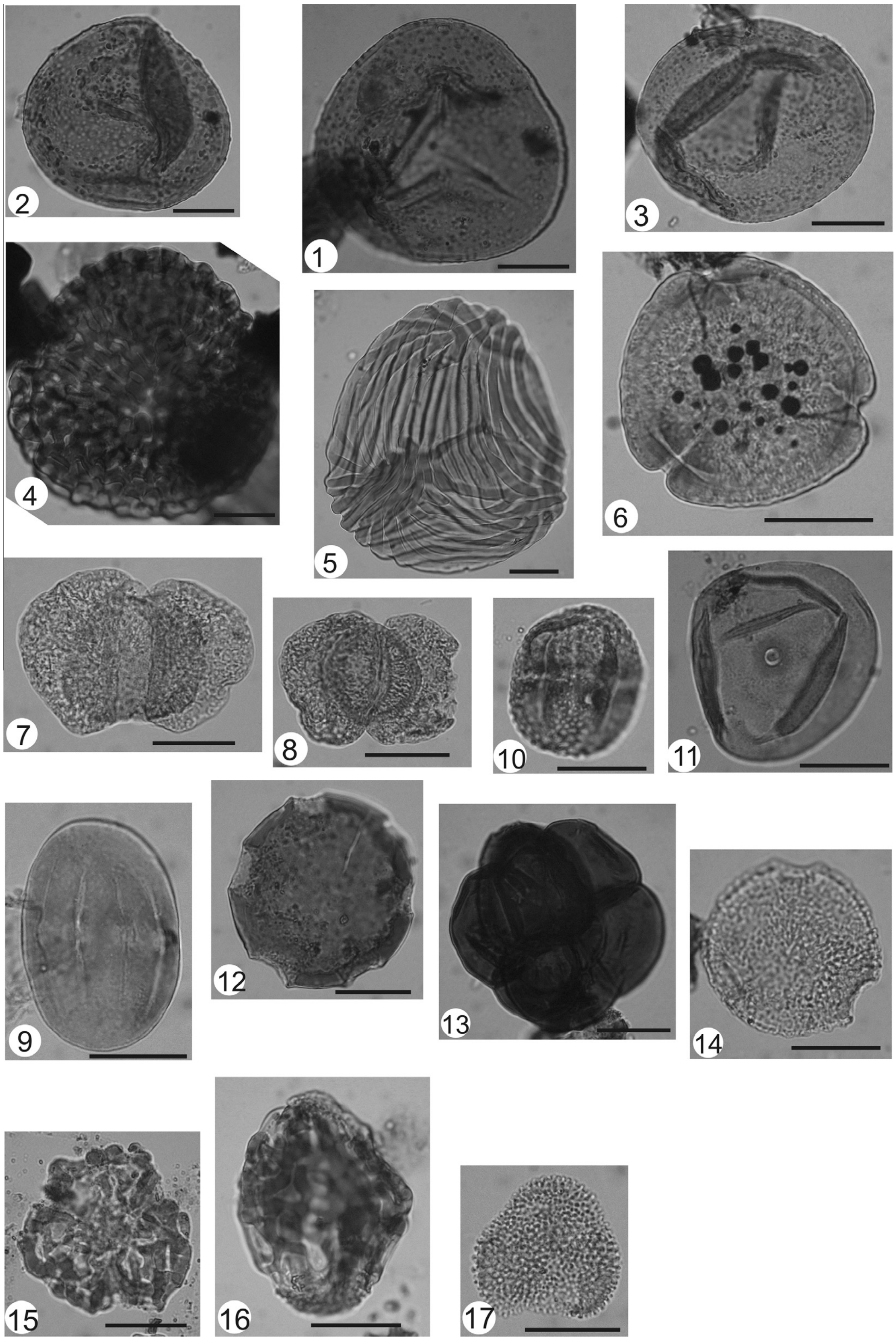

Plate 2. Fig. 1, *Acrostichumsporites meghalayaensis* KAR, 1992. Fig. 2, *Acrostichumsporites* sp. 1. Fig. 3, *Acrostichumsporites* sp. 2. Fig. 4, *Crassoretitriletes vanraadshooveni* GERMERAAD et al., 1968. Fig. 5, *Magnastriatites howardi* GERMERAAD et al. 1968. Fig. 6, *Psilatricolporites crassus* VAN DER HAMMEN and WYMSTRA, 1964. Fig. 7, *Podocarpidites clarus* SAH, 1967. Fig. 8, *Podocarpidites podocarpoides* (THIERGART, 1958) KRUTZSCH, 1971. Fig. 9, *Psilastephanocolporites laevigatus* SALARD-CHEBOLDAEFF, 1978. Fig. 10, *Psilastephanocolporites* cf. *perforatus* SALARD-CHEBOLDAEFF, 1978. Fig. 11, *Graminidites annulatus* (VAN DER HAMMEN) POTONIÉ, 1960. Fig. 12, *Pachydermites diederixi* GERMERAAD, HOPPING & MULLER, 1968. Fig. 13, *Polyadopollenites indecorus* TAKAHASHI and JUX, 1989. Fig. 14, *Caprifoliipites superbus* SAH, 1967. Figs. 15–16, *Peregrinipollis nigericus* CLARKE, 1966. Fig. 17, *Crototricolpites*? sp. cf. *densus* SALARD-CHEBOLDAEFF, 1978.

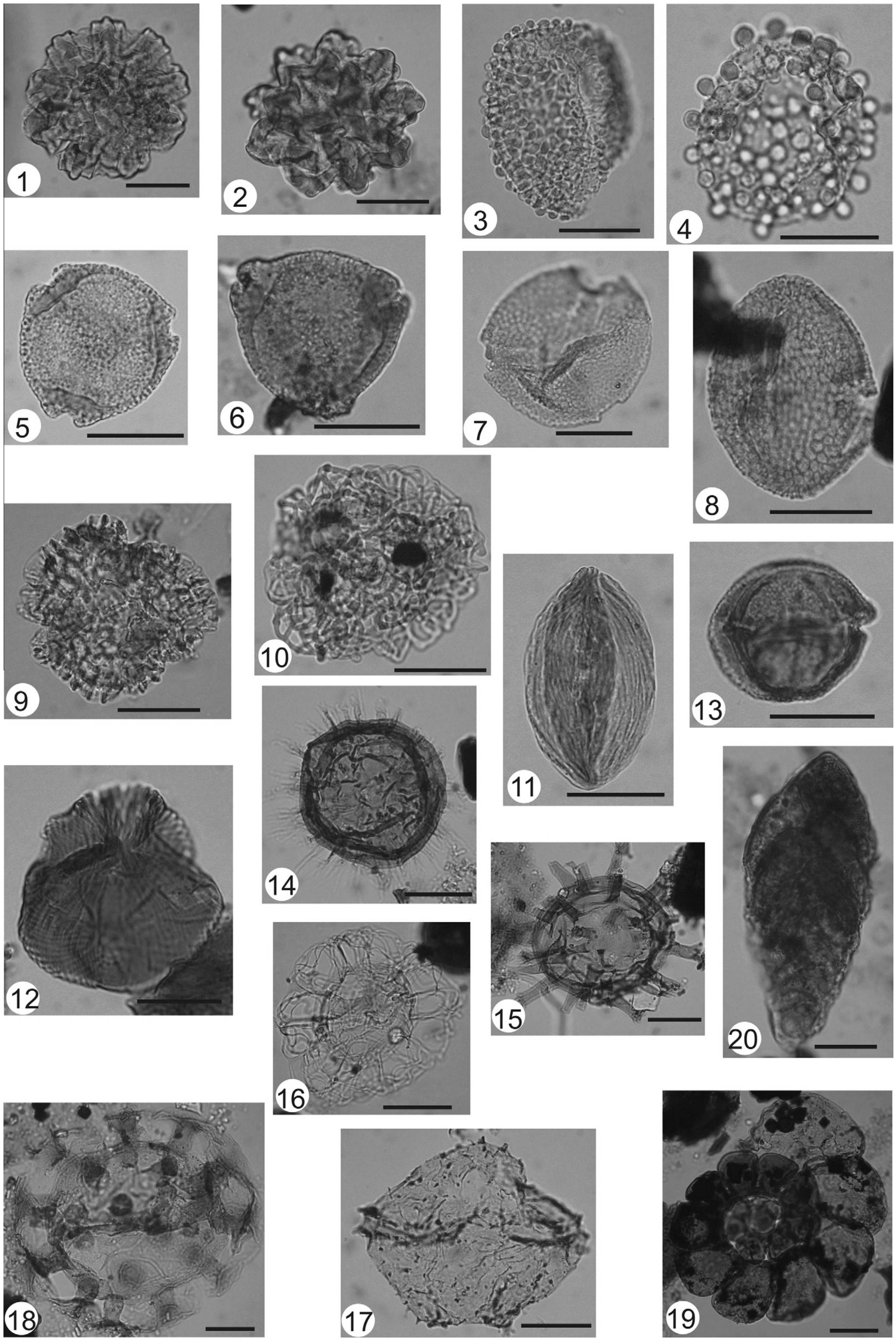

Plate 3. Fig. 1, *Ctenolophonidites costatus* VAN HOEKEN-KLIKENBERG, 1966. Fig. 2, *Ctenolophonidites* sp. Fig. 3, *Racemonocolpites hians* LEGOUX, 1978. Fig. 4, *Racemonocolpites racematus* (VAN DER HAMMEN, 1954a) GONZÁLEZ GUZMÁN, 1967. Fig. 5, *Retibrevitricolporites obodoensis* LEGOUX, 1978. Fig. 6, *Retibrevitricolporites* sp.cf. *obodoensis* LEGOUX, 1978. Fig. 7, *Retitricolporites* cf. *annulatus* SALARD-CHEBOLDAEFF, 1978. Fig. 8, *Retitricolporites* sp. cf. *guianensis* VAN DER HAMMEN and WYMSTRA, 1964. Fig. 9, *Retitrescolpites typicus* SAH, 1967. Fig. 10, *Praedapollis flexibilis* LEGOUX, 1978. Fig. 11, *Striatopollis nigericus* TAKAHASHI and JUX, 1989. Fig. 12, *Striatopollis bellus* SAH, 1967. Fig. 13, *Zonocostites* cf. *ramonae* GERMERAAD, HOPPING & MULLER, 1968. Fig. 14, *Lingulodinium* sp. cf. *machaerophorum* (Deflandre & Cookson) Wall, 1967. Fig. 15, *Dapsilidinium stelacum* Islam,1983a. Fig. 16, *Adnatosphaeridium multispinosum* Williams & Downie, 1966c. Fig. 17, *Lejeunecysta* cf. *tenella* (Morgenroth, 1966) Wilson and Clowes, 1980. Fig. 18, *Tuberculodinium vancampoae* (Rossignol, 1962) Wall, 1967. Figs. 19–20, Foraminifera test linings.

Appendix A. List of species

A.1. Pteridophyte and bryophyte spores

Monolete spores	
Genus	*Laevigatosporites* Ibrahim, 1933.
	Laevigatosporites discordatus Pflug, 1953
	Laevigatosporites haardti (Potonié & Venitz) Thomson & Pflug, 1953
	crassicus Krutzsch, 1967
	Laevigatosporites javanicus Takahashi, 1982
	Laevigatosporites nitidus (Mamczar, 1960) Krutzsch, 1967
	Laevigatosporites nitidus crassicoides Krutzsch, 1967
Genus	*Perinomonoletes* Krutzsch, 1967
	Perinomonoletes sp. 1
	Perinomonoletes sp. 2
Genus	*Reticulosporis* Krutzsch 1959
	Reticulosporis miocenicus (Selling, 1944) Krutzsch, 1959
	Reticulosporis sp. A
	Reticulosporis sp. B
Genus	*Verrucatosporites* Pflug & Thomson in Thomson & Pflug, 1953
	Verrucatosporites alienus (Potonié, 1931) Thomson & Pflug, 1953
	Verrucatosporites balticus major Krutzsch, 1967
	Verrucatosporites favus (R. Potonié, 1931) Thomson & Pflug, 1953 subfsp. *favus*
	Verrucatosporites ornatus Sah, 1967
	Verrucatosporites usmensis Van der Hammen, 1956

Trilete spores	
Genus	*Acrostichumsporites* Kar, 1991
	Acrostichumsporites meghalayaensis Kar, 1991
	Acrostichumsporites sp.1
	Acrostichumsporites sp.2
Genus	*Biretisporites* Delcourt & Sprumont, 1955
	Biretisporites potoniaei Delcourt & Sprumont, 1955
	Biretisporites sp.
Genus	*Crassoretitriletes* Germeraad, Hopping and Muller, 1968
	Crassoretitriletes vanraadshooveni Germeraad, et al., 1968
Genus	*Cyathidites* Couper, 1953
	Cyathidites congoensis Sah, 1967
Genus	*Dictyophyllidites* Couper, 1958
	Dictyophyllidites pessinensis (Krutzsch, 1962) Nagy, 1985
	cf. Dictyophyllidites pliocaenicus (Thiergart, 1940) Nagy, 1985
	Dictyophyllidites trilobiformis Sah, 1967
Genus	*Distancoraesporis* (Krutzsch, 1963) Srivastava, 1973
	Distancoraesporis cf. *triangularis* (Mamczar, 1960 ex Krutzsch, 1963) Grabowska in Stuchlik, 2001
Genus	*Foveosporites* Balme, 1957
	Foveosporites cf. *canalis* Balme, 1957
	Genus *Foveotriletes* (Van der Hammen, 1954) ex R. Potonié, 1956
	Foveotriletes margaritae (Van der Hammen) Germeraad, Hopping & Muller, 1968
	Genus *Gleicheniidites* Ross, 1949
	Gleicheniidites sp. Salard-Cheboldaef, 1992
	Genus *Intrapunctisporits* Krutzsch, 1959
	Intrapunctisporis balinkaënse Kedves, 1973
	cf. *Intrapunctisporis gracilis* Krutzsch, 1967
	Intrapunctisporis intrapunctis Krutzsch, 1959
	Genus *Leiotriletes* (Naumova) ex Potoniè & Kremp, 1954
	Leiotriletes maxoides maxoides Kutzsch, 1962
	Leiotriletes maxoides minoris Krutzsch, 1962
	Leiotriletes microsinuosoides Krutzsch, 1962
	L. spp.,
Genus	*Magnastriatites* Germeraad, Hopping and Muller, 1968
	Magnastriatites howardi Germeraad et al., 1968
Genus	*Matonisporites* Couper, 1958
	Matonisporites rarus Sah, 1967
Genus	*Polypodiaceoisporites* Potoniè, 1951
	Polypodiaceoisporites sp. cf. *congoensis* Sah, 1967
	Polypodiaceoisporites sp. cf. *lusaticus* Krutzsch, 1967
	Polypodiaceoisporites spp.
	Polypodiaceoisporites turpitus Sah, 1967
Genus	*Ricciaesporites* Nagy, 1968
	Ricciaesporites transdanubicus Nagy, 1968
	Ricciaesporites sp.
Genus	*Todisporites* Couper, 1958
	Todisporites major Couper, 1958
	Todisporites flavatus Sah & Kar, 1969
Genus	*Triplanosporites* (Pflug) in Thomson & Pflug, 1953
	Triplanosporites microsinuosus Pflanzl, 1955
Genus	*Undulatisporites* (Pflug) in Thomson & Pflug, 1953
	cf. *Undulatisporites structuris* Krutzsch, 1962
Genus	*Verrucingulatisporites* Kedves, 1961
	Verrucingulatisporites cf. *gregussi* Nagy, 1963
Genus	*Zlivisporis* Pacltova, 1957
	Zlivisporis sp. cf. *blanensis* Pacltova, 1961

Alete spores	
Genus	*Corrusporis* Krutzsch, 1967
	Corrusporis sp. 1
	Corrusporis sp. 2
	Corrusporis sp. 3
	Corrusporis sp. 4

Gymnosperm pollen	
Genus	*Araucariacites* (Cookson) ex Couper, 1953
	Araucariacites sp. cf. *australis* Cookson, 1947
Genus	*Podocarpidites*(Cookson, 1947) Couper, 1953
	Podocarpidites clarus Sah, 1967
	Podocarpidites podocarpoides (Thiergart, 1958) Krutzsch, 1971
	Podocarpidites sp. 1
	Podocarpidites sp.2
	Podocarpidites sp.3
	Podocarpidites sp.4
	Podocarpidites spp

Angiosperm pollen	
Genus	*Annutrisporites* González Guzmán, 1967
	Annutriporites iversenii González Guzmán, 1967
	Genus *Belskipollis* Legoux, 1978
	Belskipollis elegans Legoux, 1978
	Genus *Bombacacidites* Couper, 1960
	Bombacacidites cf. *africanus* Takahashi and Jux, 1989
	Bombacacidites sp. cf. *B. clarus* Sah, 1967
Genus	*Brevicolporites* Anderson, 1960
	Brevicolporites guinetii Salard-Cheboldaeff, 1978
	Brevicolporites cf. *molinae* (Schuler & Doubinger) Salard-Cheboldaeff, 1978
Genus	*Buttinia* Boltenhagen, 1967
	Buttinia cf. *andreevii* Boltenhagen, 1967
Genus	*Caprifoliipites* Wodehouse, 1933
	Caprifoliipites superbus Sah, 1967
Genus	*Cichoreacidites* Sah, 1967
	Cichoreacidites cf. *spinosus* Sah, 1967
Genus	*Clavainaperturites* Van der Hammen and Wymstra, 1964
	Clavainaperturites cf. *clavatus* Van der Hammen and Wymstra, 1964
Genus	*Crototricolpites* (Van Hoeken-Klinkenberg, 1964) Van Hoeken-Klinkenberg, 1966
	Crototricolpites? sp. cf. *densus* Salard-Cheboldaeff, 1978
Genus	*Ctenolophonidites* Van Hoeken-Klinkenberg, 1966
	Ctenolophonidites costatus Van Hoeken-Klinkenberg, 1966
	Ctenolophonidites sp.
Genus	*Echimonocolpites* Van der Hammen & Garcia De Mutis, 1964
	Echimonocolpites sp. cf. *E. minutus* Salard-Cheboldaeff, 1978
Genus	*Echiperiporites* Van der Hammen and Wymstra, 1964
	Echiperiporites estelae Germeraad et al., 1968
	Echiperiporites minor Salard-Cheboldaeff, 1975
Genus	*Echitriporites* (Van der Hammen) ex. Van Hoeken-Klinkenberg, 1964
	Echitriporites kwaense Salard-Cheboldaeff, 1974
	Echitriporites sp.
Genus	*Euphorbiacites* (Zaklinskaja, 1965) ex. Sung & Lee, 1976
	Euphorbiacites africanus Takahashi and Jux, 1989
Genus	*Foveotricolpites* Van der Hammen et Garcia, 1966
	Foveotricolpites sp.
Genus	*Foveotricolporites* Pierce, 1961
	Foveotricolporites cf. *gonzalezii* Salard-Cheboldaeff, 1978
	Foveotricolporites sp.
Genus	*Graminidites* (Van der Hammen) Potonié, 1960
	Graminidites annulatus (Van der Hammen) Potonié, 1960
Genus	*Ilexpollenites* Thiergart 1937
	Ilexpollenites rarus Sah, 1967
	Ilexpollenites sp.
Genus	*Inaperturotetradites* Van Hoeken-Klinkenberg, 1964
	Inaperturotetradites reticulatus Salard-Cheboldaeff, 1978
Genus	*Longapertites* Van Hoeken-Klinkenberg, 1964
	Longapertites marginatus Van Hoeken-Klinkenberg, 1964
Genus	*Margocolporites* Ramnujam, 1966
	Margocolporites sp. Jaramillo et al. 2007
Genus	*Momipites* Wodehouse, 1932
	Momipites africanus Van Hoeken-Klinkenberg, 1966
Genus	*Monocolpites* Van der Hammen, 1954
	Monocolpites marginatus Van der Hammen, 1954
Genus	*Pachydermites* Germeraad, Hopping & Muller, 1968
	Pachydermites diederixi Germeraad, Hopping & Muller, 1968
Genus	*Peregrinipollis* Clarke, 1966
	Peregrinipollis nigericus Clarke, 1966
Genus	*Perfotricolpites* González Guzmàn, 1967
	Perfotricolpites digitatus González Guzmán 1967
Genus	*Polotricolporites* Gonzàlez Guzmán, 1967
	Polotricolporites mocinnii Gonzàlez Guzmán, 1967
Genus	*Polyadopollenites* Pflug & Thomson, 1953
	Polyadopollenites indecorus Takahashi

(*continued on next page*)

	and Jux, 1989
Genus	*Polygalacidites* Sah & Dutta, 1966
	Polygalacidites sp. Takahashi and Jux, 1989
Genus	*Praedapollis* Boltenhagen and Salard, 1973
	Praedapollis flexibilis Legoux, 1978
Genus	*Proteacidites* (Cookson ex Couper, 1953) Martin and Harris, 1974
	Proteacidites sp. cf. *P. cooksoni* Salard-Cheboldaeff, 1978
Genus	*Psilamonocolpites* Puri, 1963
	Psilamonocolpites sp. cf. *medius* (Van der Hammen) Van der Hammen & Garcìa De Mutis,1966
Genus	*Psilastephanocolporites* Leidelmeyer, 1966
	Psilastephanocolporites laevigatus Salard-Cheboldaeff, 1978
	Psilastephanocolporites sp. cf. *perforatus* Salard-Cheboldaeff, 1978
	Psilastephanocolporites spp.
Genus	*Psilatricolpites* Van der Hammen and Wymstra, 1964
	Psilatricolpites hammenii Boltenhagen, 1976
Genus	*Psilatricolporites* (Van der Hammen) ex Pierce, 1961
	Psilatricolporites crassus Van der Hammen and Wymstra, 1964
	Psilatricolporites sp.
Genus	*Racemonocolpites* Gonzalez Guzman, 1967
	Racemonocolpites hians Legoux, 1978
	Racemonocolpites racematus (Van der Hammen, 1954a) Gonzàlez Guzmàn, 1967
	Genus *Retibrevitricolporites*, Legoux, 1978
	Retibrevitricolporites obodoensis Legoux, 1978
	Retibrevitricolporites sp. cf. *obodoensis* Legoux, 1978
Genus	*Retitricolpites* Van der Hammen and Wymstra, 1964
	Retitricolpites heteroreticulatus Boltenhagen, 1976
Genus	*Retitrescolpites* Sah, 1967
	Retitrescolpites cf. *geraniaceoides* Sah, 1967
	Retitrescolpites cf. *splendens* Sah, 1967
	Retitrescolpites typicus Sah, 1967
Genus	*Retitricolporites* (Van der Hammen, 1956) ex. Van der Hammen and Wymstra, 1964
	Retitricolporites cf. *annulatus* Salard-Cheboldaeff, 1978
	Retitricolporites sp. cf. *guianensis* Van der Hammen and Wymstra, 1964
	Retitricolporites irregularis Van der Hammen and Wymstra, 1964
Genus	*Striatopollis* Krutzsch, 1959
	Striatopollis bellus Sah, 1967
	Striatopollis catatumbus (González Guzmán, 1967) Takahashi and Jux, 1989
	Striatopollis nigericus Takahashi and Jux, 1989
	Striatopollis striatellus (Takahashi, 1961) Takahashi in Takahashi and Kim, 1979
	Striatopollis variabilis Takahashi and Jux, 1989
Genus	*Strobilanthidites* Sah, 1967
	Strobilanthidites africanus Sah, 1967
Genus	*Syncolporites* Van der Hammen, 1954
	Syncolporites sp. cf. *marginatus* Van Hoeken-Klinkenberg, 1964
Genus	*Tetracolporites* Couper, 1953
	Tetracolporites firmus Sah, 1967
	Tetracolporites quadratus Sah, 1967
	Tetracolporites sp. Eisawi and Schrank, 2008
Genus	*Tiliaepollenites* (Potoniè) Potoniè & Venitz, 1934
	Tiliaepollenites paucus Sah, 1967
Genus	*Triorites* (Ross) ex. Couper, 1953
	Triorites takahashii Schrank in Bankole et al., 2007
	Triorites gracilis Sah, 1967
Genus	*Zonocostites* Germeraad, Hopping and Muller, 1968
	Zonocostites cf. *ramonae* Germeraad, Hopping and Muller, 1968

A.2. Dinoflagellates

Gonyaulacoids	
Genus	*Adnatosphaeridium* Williams & Downie, 1966c
	Adnatosphaeridium multispinosum Williams & Downie, 1966c
	Adnatosphaeridium sp.
Genus	*Cordosphaeridium* Eisenack, 1963
	Cordosphaeridium fibrospinosum Davey & Williams, 1966
Genus	*Dapsilidinium* Bujak, Downie, Eaton & Williams, 1980c
	Dapsilidinium stelacum Islam, 1983a
Genus	*Homotryblium* Davey and Williams, 1966b
	Homotryblium spp.
Genus	*Ifecysta* Jan Du Chêne & Adediran, 1985
	cf. *Ifecysta pachyderma* Jan Du Chêne & Adediran, 1985
Genus	*Lingulodinium* Wall, 1967
	Lingulodinium sp. cf. *machaerophorum* (Deflandre & Cookson) Wall, 1967
	Lingulodinium sp. cf. *sicula* (Drugg, 1970) Wall & Dale in Wall et al., 1973
Genus	*Polysphaeridium* Davey & Williams, 1966
	Polysphaeridium subtile Davey & Williams, 1966 emend. Bujak et al., 1980
Genus	*Spiniferites*
	Spiniferites spp.
Genus	*Tuberculodinium* Wall, 1967
	Tuberculodinium vancampoae (Rossignol, 1962) Wall, 1967

Peridinioids	
Genus	*Lejeunecysta* Artzner & Dörhöfer, 1978
	Lejeunecysta cinctoria Bujak, 1980
	Lejeunecysta globosa Biffi and Grignani, 1983
	Lejeunecysta lata Biffi and Grignani, 1983
	Lejeunecysta sp. 1
	Lejeunecysta sp. 2
	Lejeunecysta cf. *tenella* (Morgenroth, 1966) Wilson and Clowes, 1980
Genus	*Palaeocystodinium* Alberti, 1961
	Palaeocystodinium cf. *golzowense* Alberti, 1961

Freshwater Algae	
Genus	*Botryococcus*
	Botryococcus spp.
Genus	*Chomotriletes* Naumova, 1953
	Chomotriletes minor (Kedves, 1961) Pocock, 1962
Genus	*Pediastrum* Meyen, 1829
	Pediastrum spp.
Genus	*Ovoidites* (Cookson and Dettman 1959) Nakoman, 1966
	Ovoidites parvus (Cookson and Dettman 1959) Nakoman, 1966

Fungi	
Genus	*Callimothallus* Dilcher ex. Janson & Hill, 1977
	Callimothallus pertusus Dilcher, 1965
	Callimothallus spp.
Genus	*Fusiformisporites*
	Fusiformisporites crabii Rouse, 1962
Genus	*Parmathyrites* Jain and Gupta, 1970
	Parmathyrites sp.

References

Adeniran, B.V., 1997. Quantitative Neogene planktic foraminiferal biostratigraphy of the Western Niger Delta, Nigeria. Nigerian Assoc. Petrol. Explor. 12 (01), 54–69.

Akpoyovbike, A.A., 1978. Tertiary lithostratigraphy of Niger Delta. Am. Assoc. Petrol. Geol. Bull. 62 (2), 295–306.

Armentrout, J.M., Fearn, L.B., Rodgers, K., Root, S., Lyle, W.D., Herrick, D.C., Bloch, R.B., Snedden, J.W., Nwankwo, B., 1999. High-resolution sequence biostratigraphy of a lowstand prograding deltaic wedge: Oso field (Late Miocene), Nigeria. In: Jones, R.W., Simmons, M.D. (Eds.), Biostratigraphy in Production and Development Geology, vol. 152. Geological Society, London, Special Publications, pp. 259–290.

Bacchiana, C., Brancart, R.Y., De Klasz, I., Legoux, O., Paradis, G., 1982. Présence de Miocène inférieur marin dans le ''continental terminal''de la Basse Côte d Ivoire. Rev. Micropaléont. 25, 145–149.

Biffi, U., Grignani, D., 1983. Peridinioid dinoflagellate cysts from the Oligocene of the Niger Delta, Nigeria. Micropaleontology 29 (2), 1–7.

Bujak, J.P., Downie, C., Eaton, G.L., Williams, G.L., 1980. Dinoflagellate cysts and acritarchs from the Eocene of southern England. Spec. Pap. Palaeontol. 24, 100.

Clarke, R.T., 1966. *Peregrinipollis nigericus*, a new palynomorph from the Upper Tertiary of Nigeria. Grana Palynol. 6 (3), 544–546.

Clarke, R.T., Frederiksen, N.O., 1968. Some new sporomorphs from the Upper Tertiary of Nigeria. Grana Palynol. 8 (1), 210–224.

Copestake, P., 1993. Application of micropalaeontology to hydrocarbon exploration in the North Sea Basin. In: Jenkins, D.G. (Ed.), Applied Micropaleontology, pp. 93–152.

Corredor, F., Shaw, J.H., Bilotti, F., 2005. Structural styles in the deep-water fold and thrust belts of the Niger Delta. Am. Assoc. Pet. Geol. Bull. 89 (6), 753–780.

Doust, H., Omatsola, E., 1990. Niger Delta. In: Edwards, J.D., Santogrossi, P.A. (Eds.), Divergent/passive Margin Basins, AAPG Memoir 48: Tulsa. American Association of Petroleum Geologists, pp. 201–238.

Eisawi, A., Schrank, E., 2008. Upper Cretaceous to Neogene palynology of the Melut Basin, southeast Sudan. Palynology 32, 101–129.

El-Beialy, S.Y., 1988. Palynostratigraphy of Late Tertiary sediments in Kafr El-Dawar well No. 1, Nile Delta, Egypt. Rev. Micropaléontol. 30 (4), 249–260.

El-Beialy, S.Y., 1990. Palynology, palaeoecology, and dinocyst stratigraphy of the Oligocene through Pliocene succession in the Qantara-1 well, Eastern Nile Delta, Egypt. J. Afr. Earth Sci. 11 (3/4), 291–307.

El-Beialy, S.Y., 1992. Miocene and Pliocene dinoflagellate cysts and other palynomorphs from the Damanhour South-1 well, western Nile Delta, Egypt. N. Jb. Geol. Paläont. Mh. 1992 (10), 577–594.

Fasola, A., Giffuni, G., Crespo de Gebrera, S., Paredes de Ramos, I., Euribe, A., 1985. Estudios bioestratigraficos del Intervalo Cretacico Superior (Maestrichtiense) a Mioceno Inferior en el Norte del Estrado Guarico, Venezuela. Mem. VI Cong. Geol. Venezolano 1, 588.

Fensome, R.A., Williams, G.L., 2004. The Lentin and Williams index of fossil dinoflagellates, 2004 ed. AASP Contributions Series 42, American Association of Stratigraphic Palynologists Foundation. 909pp.

Germeraad, J.H., Hopping, C.A., Muller, J., 1968. Palynology of Tertiary sediments from tropical areas. Rev. Palaeobot. Palynol. 6, 189–348.

González-Guzmán, A.E., 1967. A Palynological Study on the Upper Los Cuervos and Mirador Formations (Lower and Middle Eocene; Tibú area, Colombia). E.J. Brill, Leiden, Netherlands, 68pp.

Huang, T.-C., 1978. Miocene palynomorphs of Taiwan (III) spores. Taiwania 23, 7–55.

Ige, O.E., 2009. A Late Tertiary pollen record from Niger Delta, Nigeria. Int. J. Bot., 1–13, ISSN 1811-9700.

Jan du Chêne, R.E., Salami, M.B., 1978. Palynology and micropalaeontology of the Upper Eocene of the well Nsukwa 1 (Niger Delta, Nigeria). C. r. des Séances SPHN Gèneve, N.S. 13, 5–9.

Kar, R.K., Jain, K.P., 1981. Palynology of Neogene sediments around Quilon and Varkala⁎ Kerala coast, South India – 2. Spores and pollen grains. Palaeobotanist 27, 113–131.

Kaska, H.V., 1989. A spore and pollen zonation of Early Cretaceous to Tertiary non marine sediments of central Sudan. Palynology 13, 79–90.

Knox, G.J., Omatsola, E.M., 1989. Development of the Cenozoic Niger Delta in terms of the Escalator Regression model and impact on hydrocarbon distribution. In: Proceedings KNGMG Symposium Coastal Lowlands, Geology and Geotechnology, pp. 181–202.

Krutzsch, W., 1959. Mikropaläontologische (*sporenpaläontologische*) Untersuchungen in der Braunkohle des Geiseltales. Geologie, Jahrgang 8, Beiheft (21/22), 1–425.

Krutzsch, W., 1967. Atlas der mittel- und jungtertiären dispersen Sporen- und Pollen- sowie. der Mikroplanktonformen des nördlichen Mitteleuropas. Lieferung IV und V. VEB Gustav Fischer Verlag Jena, 232pp.

Kulke, H., 1995. Nigeria. In: Kulke, H. (Ed.), Regional Petroleum Geology of the World. Part II: Africa, America, Australia, and Antarctica, Berlin, Gebrüder Borntraeger, pp. 143–172.

Lawrence, S.R., Munday, S., Bray, R., 2002. Regional geology and geophysics of the eastern Gulf of Guinea (Niger Delta to Rio Muni). Lead. Edge 21 (11), 1112–1117.

Legoux, O., 1978. Quelques espèces de pollen caractéristiques du Néogéne du Nigéria. Bull. Cent. Rech. Explor. – Prod. Elf-Aquitaine 2 (2), 265–317.

Li, L.C., Huang, T.S., 1990. The Early Pliocene pollen flora of the lower Erhchiu Formation, Sanhsia, northern Taiwan. Taiwania 35, 143–147.

Lorente, M., 1986. Palynology and palynofacies of the Upper Tertiary in Venezuela. Dissert. Bot. (Gebrüder Borntraeger, Berlin) 99, 1–222.

Morley, R.J., 1981. Development and vegetation dynamics of a lowland ombrogenous peat swamp in Kalimanan Tengah, Indonesia. J. Biogeogr. 8, 383–404.

Morley, R.J., Richards, K., 1993. Gramineae cuticles: a key indicator of Late Cenozoic climatic change in the Niger Delta. Rev. Palaeobot. Palynol. 77, 119–127.

Nagy, E., 1985. Sporomorphs of the Neogene in Hungary. Geologica Hungarica; Series Palaeontologica, Fasciculus 47, 471pp.

Oboh, F.E., 1992. Middle Miocene palaeoenvironments of the Niger Delta. Palaeogeogr. Palaeoclimatol. Palaeoecol. 92, 55–84.

Oboh, F.E., 1995. Sedimentological and palynological characteristics of the E2.0 reservoire (Middle Miocene) in the Kolo Creek Field, Niger Delta. In: Oti, M.N., Postuma, G. (Eds.), Geology of Deltas. A.A. Balkema, Rotterdam, pp. 243–256.

Oboh, F.E., Salami, M.B., Chapman, J.L., 1992. Palynological interpretation of the palaeoenvironments of Miocene strata of the well Igbomotoru-1, Niger Delta. J. Micropalaeont. 11, 1–6.

Oloto, I.N., 1992. Succession of palynomorphs from the Early Eocene of Gbekebo-1 well in S.W., Nigeria. J. Afr. Earth Sci. 15, 441–452.

Ozumba, M.B., 1994. Late Miocene – Pliocene Biostratigraphy, Offshore Niger Delta. 12 Ann. Int. Conf., NAPE, Lagos, Nigeria, p. 42.

Petters, S.W., 1979. Some Later Tertiary foraminifera from Parabe-1 western Niger Delta. Rev. Esp. Micropaleontol. 11, 119–133.

Petters, S.W., 1983. Gulf of Guinea planktonic foraminiferal biochronology and geological history of the South Atlantic. J. Foram. Res. 13 (1), 32–59.

Poumot, C., 1989. Palynological evidence for eustatic events in the tropical Neogene. Bull. Centres Rech. Explor. – Prod. Elf-Aquitaine 13 (2), 437–453.

Powell, A.J., 1986. Latest Paleogene and earliest Neogene dinoflagellate cysts from the Lemme section, northwest Italy. In: Wrenn, J.H., Duffield, S.L., Stein, J.A.

(Eds.), Papers from the First Symposium on Neogene Dinoflagellate Cyst Biostratigraphy. Contributions Series, vol. 17. American Association of Stratigraphic Palynologists, pp. 83–104.
Rao, K.P., Ramanujam, C.G.K., 1982. Palynology of the Neogene Quilon beds of Kerala State in South India, 2: Pollen of dicotyledons and discussions. Palaeobotanist 30, 68–100.
Reijers, T.J.A., Petters, S.W., Nwajide, C.S., 1997. The Niger Delta Basin. In: Selley, R.C. (Ed.), African Basins. Hsü, K.J. (Series Editor), Sedimentary Basins of the World, vol. 3, pp. 151–172.
Rull, V., 1998. Middle Eocene mangroves and vegetation changes in the Maracaibo basin. Palaios 13, 287–296.
Rull, V., 2001. A quantitative palynological record from the Early Miocene of western Venezuela, with emphasis on mangroves. Palynology 25, 109–126.
Sah, S.C.D., 1967. Palynology of an Upper Neogene profile from Rusizi Valley (Burundi). Koninklijk Museum voor Midden-Afrika—Tervuren, Belgie Annalen—Reeks in -8°—Geologische Wetenschappen, vol. 57, 173pp.
Salard-Cheboldaeff, M., 1978. Sur la palynoflore Maestrichtienne et Tertiaire du basin sédimentaire littoral du Cameroun. Pollen Spores 20 (2), 218–260.
Salard-Cheboldaeff, M., 1979. Palynologie maestrichtienne et tertiaire du Cameroun. Etude qualitative et répartition verticale des principales espèces. Rev. Palaeobot. Palynol. 28, 365–388.
Salard-Cheboldaeff, M., Mouton, J., Brunet, M., 1992. Paléoflore Tertiaire du Basin d'Anloua plateau de l'Adamaoua, Cameroun. Rev. Españ. Micropaleontol. 24 (2), 131–162.
Samant, B., Phadtare, N.R., 1997. Stratigraphic palynoflora of the early Eocene Rajpardi lignite, Gujarat and the lower age limit of the Tareswar Formation of south Cambay Basin, India. Palaeontographica Abt. B, 245, Lfg., 1–6, 1–108.
Short, K.C., Stäuble, A.J., 1967. Outline of geology of Niger Delta. Am. Assoc. Petrol. Geol. Bull. 51 (5), 761–779.
Stacher, P., 1995. Present understanding of the Niger Delta hydrocarbon habitat. In: Oti, M.N., Postma, G. (Eds.), Geology of Deltas. A.A. Balkema, Rotterdam, pp. 257–267.
Takahashi, K., Jux, U., 1989. Palynology of Middle Tertiary lacustrine deposits from the Jos Plateau, Nigeria. Bull. Fac. Liberal Arts, Nagasaki Univ. (Nat. Sci.) 29(2), 181–367.
Van der Hammen, T., Wymstra, T.A., 1964. A palynology study on the Tertiary and Upper Cretaceous of British Guiana. Leidse. Geol. Meded. D1 (30), 183–241.
Van der Zwan, C.J., Brugman, W.A., 1999. Biosignals from the EA Field, Nigeria. In: Jones, R.W., Simmons, M.D. (Eds.), Biostratigraphy in Production and Development Geology, vol. 152. Geological Society, London, Special Publications, pp. 291–301.
Van Hoeken-Klinkenberg, P.M.J., 1966. Maastrichtian Paleocene and Eocene pollen and spores from Nigeria. Leidse. Geol. Meded. 38, 37–48.
Vedel, V., Behling, H., Cohen, M., Lara, R., 2006. Holocene mangrove dynamics and sea-level changes in northern Brazil, inferences from the Taperebal core in northeastern Paraná State. Veget Hist Archaeobot. 15, 115–123.
Weber, K.J., 1971. Sedimentological aspects of oil fields in the Niger Delta. Gel. Mijnbouw 50 (3), 559–576.
Weber, K.J., Daukoru, E., 1975. Petroleum geology of the Niger Delta. Proc. World Petrl. Cong. 9, 209–221.