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Lithofacies, palynofacies, and sequence stratigraphy of Palaeogene strata in Southeastern Nigeria

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Abstract

Integrated sedimentologic, macrofossil, trace fossil, and palynofacies data from Paleocene-Middle Eocene outcrops document a comprehensive sequence stratigraphy in the Anambra Basin/Afikpo Syncline complex of southeastern Nigeria. Four lithofacies associations occur: (1) lithofacies association I is characterized by fluvial channel and/or tidally influenced fluvial channel sediments; (2) lithofacies association II (*Glossifungites* and *Skolithos* ichnofacies) is estuarine and/or proximal lagoonal in origin; (3) lithofacies association III (*Skolithos* and *Cruziana* ichnofacies) is from the distal lagoon to shallow shelf; and (4) shoreface and foreshore sediments (*Skolithos* ichnofacies) comprise lithofacies association IV. Five depositional sequences, one in the Upper Nsukka Formation (Paleocene), two in the Imo Formation (Paleocene), and one each in the Ameki Group and Ogwashi-Asaba Formation (Eocene), are identified. Each sequence is bounded by a type-1 sequence boundary, and contains a basal fluvio-marine portion representing the transgressive systems tract, which is succeeded by shoreface and foreshore deposits of the highstand systems tract. In the study area, the outcropping Ogwashi-Asaba Formation is composed of non-marine/coastal aggradational deposits representing the early transgressive systems tract. The occurrence of the estuarine cycles in the Palaeogene succession is interpreted as evidence of significant relative sea level fluctuations, and the presence of type-1 sequence boundaries may well be the stratigraphic signature of major drops in relative sea level during the Paleocene and Eocene. Sequence architecture appears to have been tectono-eustatically controlled.

Keywords: Sequence stratigraphy; Lithofacies; Palynofacies; Palaeogene; Anambra basin; Southeastern Nigeria

1. Introduction

Palaeogene rocks outcrop in the region generally referred to as the Southern Nigeria sedimentary basin, which comprises the southern Benue Trough, the Niger Delta, the Benin Embayment (ex-Dahomey), the Anambra Basin, the Abakaliki Fold Belt, the Afikpo Syncline, and the Calabar Flank (Fig. 1). Since the discovery of petroleum resources in the Niger Delta in the late 1950s, the region has attracted numerous studies, but much of the information is confidential to the companies prospecting for oil and gas in the basin. Abstracts on Niger Delta studies abound in the literature, but only a few full papers have been published (e.g., Frankl and Cordry, 1967; Short and Stäuble, 1967; Weber, 1971; Oomkens, 1974; Weber and Daukoru, 1975; Evamy et al., 1978; Petters, 1983; Knox and Omatsola, 1989; Oboh, 1992; Oti and Postma, 1995; Haack et al., 2000; Hooper et al., 2002; Van Heijst et al., 2002; Koledoye et al., 2003). Some studies, such as Doust and Omatsola

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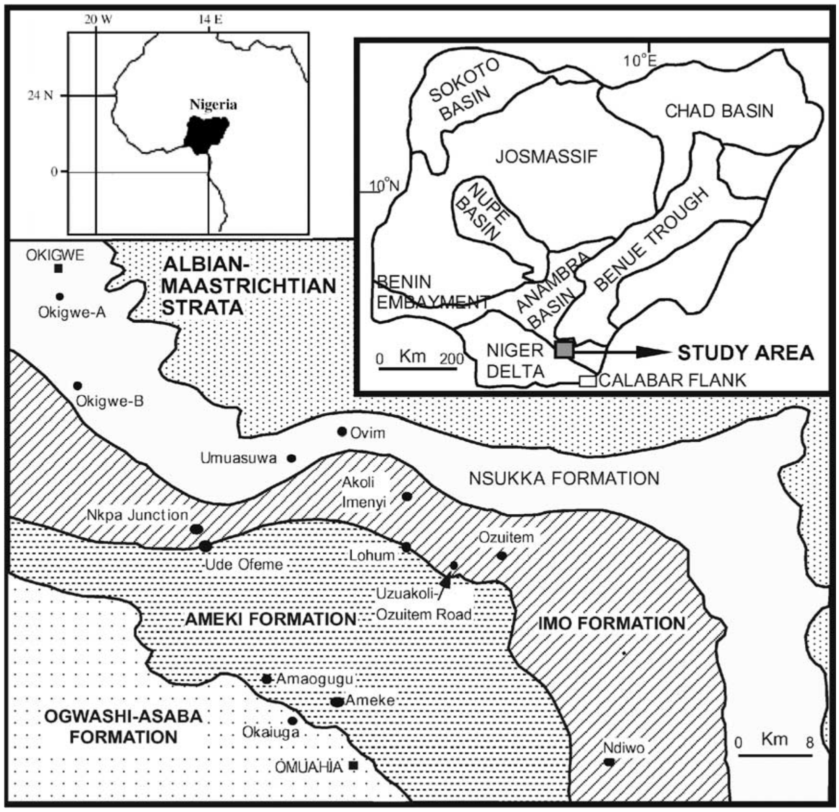

Fig. 1. Map of the study area in the Umuahia-Bende District of Abia State in southeastern Nigeria, showing the locations of outcrop sections. Inset shows the locations of the sub-basins that comprise the general area referred to as the Southern Nigeria sedimentary basin, in addition to the basins in northern Nigeria.

(1990) and Reijers et al. (1997), have related the depositional units of the delta to those of the surrounding basins in southern Nigeria.

This study presents comprehensive sequence stratigraphic interpretations for the Palaeogene sedimentary rocks of the upper Nsukka Formation, Imo Formation, Ameki Formation, and the Ogwashi-Asaba Formation in the Anambra Basin/Afikpo Syncline complex. The study area is located in the Okigwe and Umuahia Districts of Abia State (Fig. 1), where good exposures are accessible in road-cuts, stream channels, and quarry sites. The rocks underlie the a NW-SE oriented, gently undulating plain that marks the southern limit of outcrops of the Albian-Maastrichtian strata in southeastern Nigeria. A detailed outcrop study of the rocks was carried out to establish the spatial distribution and sedimentary characteristics of the various lithofacies, which were integrated with palynofacies to reconstruct a sequence stratigraphic framework for the Palaeogene rocks. An understanding of the sequence stratigraphy of these outcrop equivalents of the lithostratigraphic units in the subsurface of the Niger Delta (Short and Stäuble, 1967), will benefit the companies that use it for deep-water exploration in the delta.

2. Stratigraphic overview

The formation of the Southern Nigerian sedimentary basin followed the break-up of the South American and African continents in the Early Cretaceous (Murat, 1972; Burke, 1996). Various lines of geomorphologic, structural, stratigraphic and palaeontologic evidence have been presented to support a rift model (King, 1950; Bullard et al., 1965; Reyment, 1969; Burke et al., 1971, 1972; Fairhead and Green, 1989; Benkhelil, 1989; Guiraud and Bellion, 1995).

The stratigraphic history of the region is characterized by three sedimentary phases (Short and Stäuble, 1967; Murat, 1972; Obi et al., 2001) during which the axis of the sedimentary basin shifted. These three phases were: (a) the Abakaliki-Benue Phase (Aptian-Santonian), (b) the Anambra-Benin phase (Campanian-Mid Eocene), and (c) the Niger Delta phase (late Eocene-Pliocene). The more than 3000 meters of rocks comprising the Asu River Group and the Ezeaku and Awgu formations, were deposited during the first phase in the Abakaliki-Benue Basin, the Benue Valley and the Calabar Flank (Fig. 2). The second sedimentary phase resulted from the Santonian folding and uplift of the

m.y	AGE	ABAKALIKI – ANAMBRA BASIN	AFIKPO BASIN
30	Oligocene	Ogwashi-Asaba Formation	Ogwashi-Asaba Formation
54.9	Eocene	Ameki/Nanka Formation/ Nsugbe Sandstone (Ameki Group)	Ameki Formation
65	Palaeocene	Imo Formation Nsukka Formation	Imo Formation Nsukka Formation
73	Maastrichtian	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation
83	Campanian	Npkoro Oweli Formation/Enugu Shale	Nkporo Shale/ Afikpo Sandstone
87.5	Santonian	Agbani Sandstone/Awgu Shale	Non-deposition/erosion
88.5	Coniacian	Agbani Sandstone/Awgu Shale	Non-deposition/erosion
93	Turonian	Eze Aku Group	Eze Aku Group (incl. Amasiri Sandstone)
100	Cenomanian – Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Units	Unnamed Units
	Precambrian	Basement Complex	Basement Complex

Fig. 2. Correlation Chart for Early Cretaceous-Tertiary strata in southeastern Nigeria (modified from Nwajide, 1990).

Abakaliki region and dislocation of the depocenter into the Anambra Platform and Afikpo region. The resulting succession comprises the Nkporo Group, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Formation and Ameki Group (Fig. 2). The third sedimentary phase credited for the formation of the petroliferous Niger Delta (Fig. 3), commenced in the Late Eocene as a result of a major earth movement that structurally inverted the Abakaliki region and displaced the depositional axis further to the south of the Anambra Basin (Obi et al., 2001).

Reyment (1965) undertook the first detailed study of the stratigraphy of the Southern Nigerian sedimentary basin, and he proposed many of the lithostratigraphic

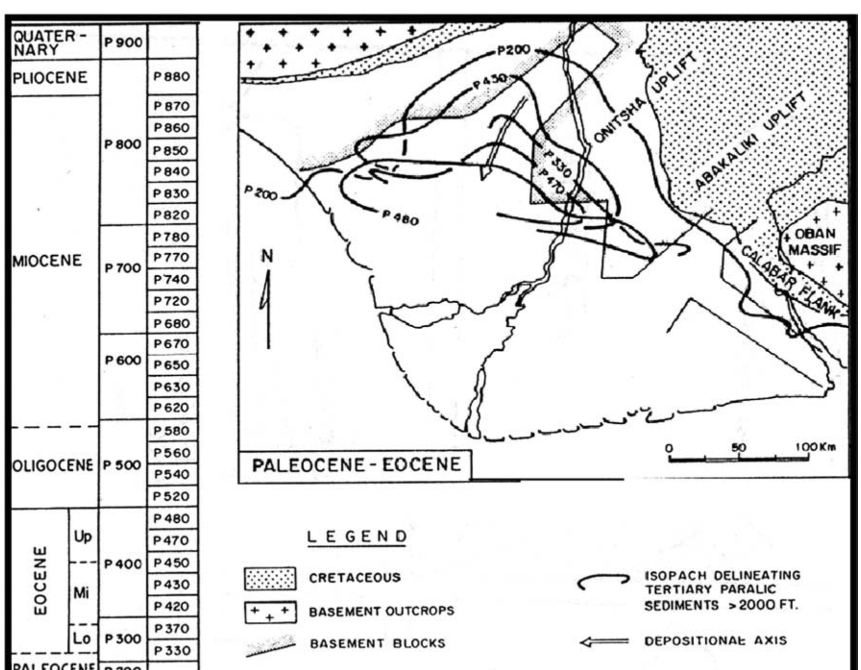

Fig. 3. Stratigraphic evolution of the Niger Delta during the Paleocene-Eocene, showing isopachs of individual pollen zones (from Evamy et al., 1978).

units in the region. Palaeogene time is represented by a sedimentary succession that is thicker than 3500 m (Fig. 4), and consists of the Nsukka Formation (∼350 m), Imo Formation (∼1000 m), Ameki Group (∼1900 m), and Ogwashi-Asaba Formation (∼250 m) (Reyment, 1965; Jan du Chêne et al., 1978; Nwajide, 1979; Arua, 1986; Anyanwu and Arua, 1990).

The Nsukka Formation, which overlies the Ajali Sandstone, begins with coarse- to medium-grained sandstones and passes upward into well-bedded blue clays, fine-grained sandstones, and carbonaceous shales with thin bands of limestone (Reyment, 1965; Obi et al., 2001). Obi et al. (2001) used sedimentological evidence to suggest that the Nsukka Formation represented a phase of fluvio-deltaic sedimentation that began close to the end of the Maastrichtian and continued during the Paleocene (Fig. 4).

The Imo Formation consists of blue-grey clays and shales and black shales with bands of calcareous sandstone, marl, and limestone (Reyment, 1965). Ostracode and foraminiferal biostratigraphy (Reyment, 1965), and microfauna recovered from the basal limestone unit (Adegoke et al., 1980; Arua, 1980) indicate a Paleocene age for the formation. Lithology and trace fossils of the basal sandstone unit reflect foreshore and shoreface (Reijers et al., 1997) or delta front sedimentation (Anyanwu and Arua, 1990; Fig. 4). The Imo Formation is the outcrop lithofacies equivalent of the Akata Formation in the subsurface Niger Delta (Short and Stäuble, 1967; Avbovbo, 1978; Table 1).

The Ameki Group consists of the Nanka Sand, Nsugbe Formation, and Ameki Formation (Nwajide, 1979), which are laterally equivalent. The Ameki Formation outcrops in the study area, and is predominantly alternating shale, sandy shale, clayey sandstone, and fine-grained fossiliferous sandstone with thin limestone bands (Reyment, 1965; Arua, 1986). The age of the formation has been considered to be either early Eocene (Reyment, 1965) or early middle Eocene (Berggren, 1960; Adegoke, 1969). The depositional environment (Fig. 3) has been interpreted as estuarine, lagoonal, and open marine, based on the faunal content. White (1926) interpreted an estuarine environment because of the presence of fish species of known estuarine affinity. Adegoke (1969), however, indicated that the fish were probably washed into the Ameki Sea from inland waters, and preferred an open marine depositional environment. Nwajide (1979) and Arua (1986) suggested environments that ranged from nearshore (barrier ridge-lagoonal complex) to intertidal and subtidal zones

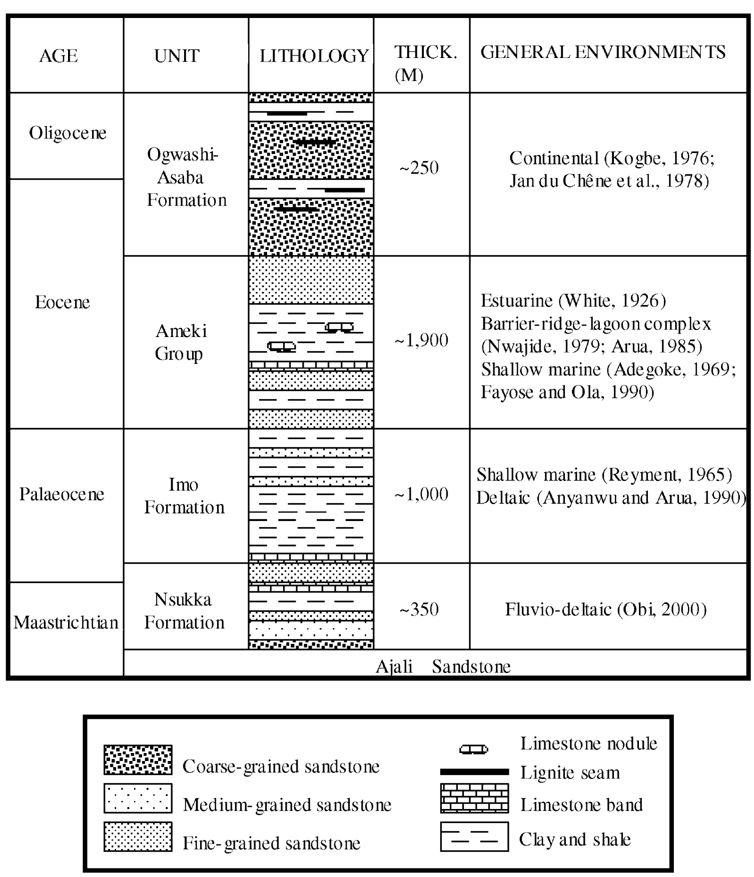

Fig. 4. Summary of stratigraphic data on the Palaeogene succession in southeastern Nigeria.

Table 1
Correlation of subsurface formations in the Niger Delta with outcrops in the study area (modified from Avbovbo, 1978)

Subsurface			Outcrops		
Youngest known age	Formation	Oldest known age	Youngest known age	Formation	Oldest known age
Recent	Benin	Oligocene	Plio-Pleistocene	Benin	Oligocene
Recent	Agbada	Eocene	Miocene Eocene	Ogwashi-Asaba Ameki	Eocene Eocene
Recent Equivalent not known	Akata	Eocene	Eocene Paleocene	Imo Nsukka	Paleocene Maastrichtian

of the shelf environments, whereas Fayose and Ola (1990) suggested that the sediments were deposited in marine waters between the depths of 10 m and 100 m.

The Ogwashi-Asaba Formation comprises alternating coarse-grained sandstone, lignite seams, and light coloured clays of continental origin (Kogbe, 1976; Fig. 3). Although Reyment (1965) suggested an Oligocene-Miocene age for the formation, palynological study by Jan du Chêne et al. (1978) yielded a Middle Eocene age for the basal part. If this palynological interpretation is correct, then the Ameki Group is early to middle Eocene in age. The Ameki Group and the Ogwashi-Asaba Formation are correlative with the Agbada Formation in the Niger Delta (Fig. 4).

3. Methods

Fourteen composite sections of the Palaeogene succession outcropping in the Okigwe, Isiukwuato, Umuahia and Ozuitem areas in Abia State, southeastern Nigeria (Fig. 1) were measured, to gather data on the stratigraphic succession, textural and lithologic variations, and sedimentary structures. These data were used to identify lithofacies associations. Seventy samples from shale and siltstone horizons were collected and processed for palynological contents. Dispersed organic matter and palynomorph groups (Table 2) were used to identify palynofacies assemblages (see Appendix A).

Standard laboratory techniques of digesting sediments in hydrochloric and hydrofluoric acids were used to process the samples (Traverse, 1988). Oxidation stage with nitric acid was omitted for kerogen residues used for palynofacies analysis in order to preserve the colours of the organic debris, which were sometimes critical for identification. Moreover, oxidation along with heavy liquid separation and sieving removes much of the very fine organic matter in the sediment. Several classification schemes for dispersed organic matter can be found in the literature (e.g., Boulter and Riddick, 1986; Van Bergen et al., 1990; Tyson, 1995; Batten, 1996; Oboh-Ikuenobe et al., 1997). In this study, we have used a simplified scheme adapted to the types of organic components and palynomorph groups present in the sediments. Eight types of dispersed organic matter and palynomorph groups were identified (Table 2; Figs. 5 and 6), including spores and pollen, fungal remains, freshwater algae, marine palynomorphs (dinoflagellates, acritarchs, microforaminiferal inner linings), structured phytoclasts (wood, cuticles, parenchyma), unstructured phytoclasts (resins, comminuted and degraded fragments), black debris, and amorphous organic matter. At least 300 particles of organic debris and palynomorph groups were point counted per sample and converted to percentages.

Table 2
Descriptions of palynomorph groups and dispersed organic components identified in this study

Palynomorphs/ organic debris	Description
Sporomorphs	Embryophytic spores and pollen grains derived from land plants (Fig. 5A, C, D, and K)
Fungal remains	Dark brown spores, filamentous hyphae, and mycelia (fruiting bodies of fungal origin) (Fig. 5B, J, and L)
Freshwater algae	Mostly *Pediastrum* and *Azolla* spores with massulae, and rare specimens of *Botryococcus* (Fig. 5E and F)
Marine palynomorphs	Dinoflagellate cysts, acritarchs, and chitinous inner linings of foraminifera (Fig. 5H, I, and M)
Structured phytoclasts	Structured remains of land plants, including lath-shaped or blocky wood particles, parenchyma, and thin cuticle fragments. With the exception of black debris (described below), fragments with some form of cellular structure or definite shape are included in this category (Fig. 6A–E, H, and I)
Unstructured phytoclasts	This category included highly degraded plant remains without much structure with colors ranging from yellow to dark brown and nearly black, comminuted brown debris with sizes <5 μm, and amber-colored, globular to angular particles of resin (Fig. 6F, G, and L)
Black debris	Most particles are opaque and often have shapes similar to wood, although some are rounded and appear to be highly oxidized palynomorphs (Fig. 6J)
Amorphous organic matter	Fluffy, clotted and granular masses with colors ranging from almost colorless to yellow and pale brown. This category is marine in origin, and formed as a result of degradation of algal matter (Fig. 6K)

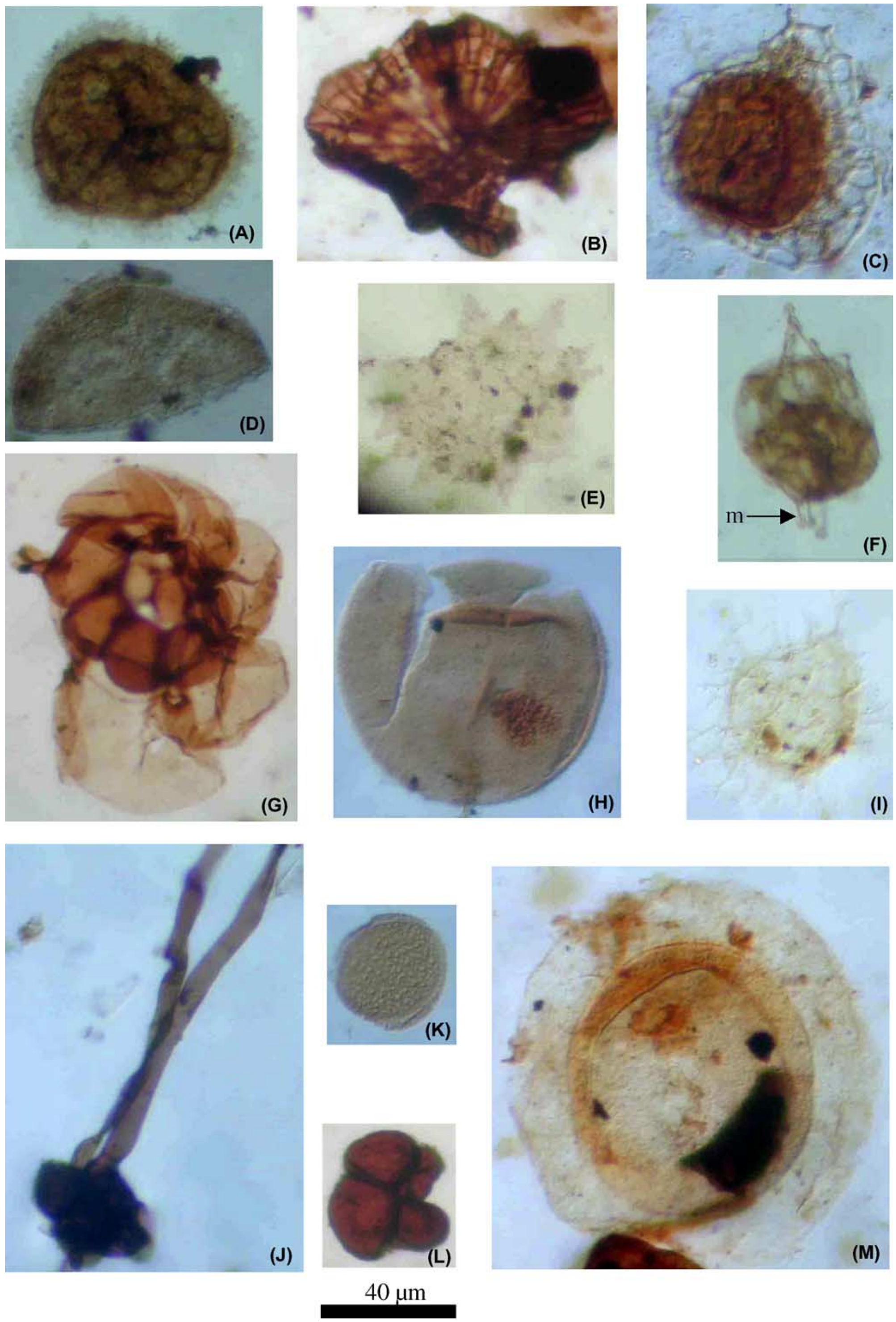

Fig. 5. Photomicrographs of palynomorph groups used for palynofacies analyses: sporomorphs (A, C, D, K), fungal remains (B, J, L), freshwater algae (F, G), and marine palynomorphs (H, I, M). (A) Trilete spore. (B) Fungal fruiting body (mycelium). (C) Tricolpate pollen *Praedapollis africanus*. (D) Monosulcate pollen *Longapertites vaneendenburgi*. (E) *Pediastrum* sp. (F) *Azolla* spore with massulae (m). (G) Inner chitinous lining of foraminifera. (H) Dinoflagellate cyst *Batiacasphaera* sp. (I) Dinoflagellate cyst *Spiniferites mirabilis*. (J) Fungal spore with attached hyphae. (K) Monosulcate pollen *Proxapertites crassus*. (L) Tetracellate fungal spore. (M) Acritarch cyst *Pterospermella* sp.

The percentage data were analyzed using the multivariate statistical techniques of principal components analysis and Euclidean-distance average linkage cluster analysis (Kovach, 2002). The Euclidean distance is designed to work with continuous or ratio scales. In addition, the linkage averages all distances between pairs of

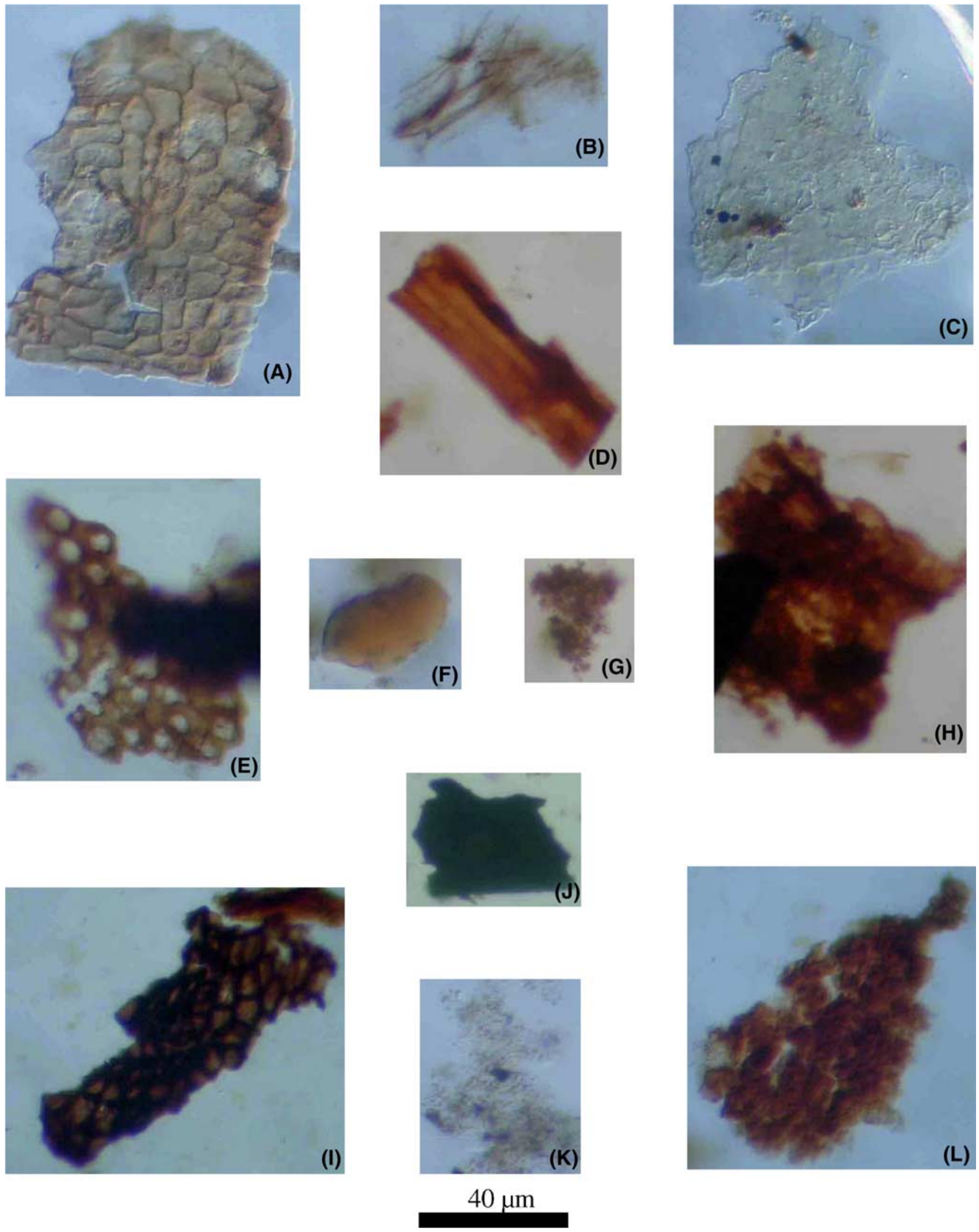

Fig. 6. Photomicrographs of dispersed organic debris used for palynofacies analyses: structured phytoclasts (A–E, H, I), unstructured phytoclasts (F, G, L), black debris (J), and amorphous organic matter (K). Scale bar = 20 μm for Figures A and C. (A) Well preserved parenchyma fragment. (B) Poorly preserved wood. (C) Cuticle. (D) Well preserved wood. (E) Pitted wood. (F) Resin. (G) Degraded and comminuted fragments of wood. (H) Poorly preserved wood, sample Ozuitem-4. (I) Well preserved parenchyma fragment. (J) Black debris. (K) Amorphous organic matter. (L) Degraded wood, sample Ameke-9.

objects in different clusters and decides how far apart they are (Sokal and Michener, 1958). Cluster analysis was used to identify palynofacies assemblages.

Lithofacies associations and palynofacies assemblages were used to interpret depositional environments and reconstruct the sequence stratigraphy of the entire Palaeogene succession. Sequence stratigraphic interpretations followed the methods of Vail et al. (1977) and Van Wagoner et al. (1990).

4. Results

4.1. Lithofacies associations

The Palaeogene strata in the study area are predominantly beds of sandstones, mudrocks (clays, shales, siltstones), heteroliths, and subordinate carbonates, with varied textures and a range of primary sedimentary structures. We have identified four distinct lithofacies associations based on the rock types, their association with one another, their textural characteristics, sedimentary structures, macrofossils, and trace fossils (Table 3; Figs. 7–9). Lithofacies association 1 is commonly stained red and comprises poorly sorted, cross-bedded, coarse-grained, locally conglomeratic, sandstones (Fig. 7A). Association 2 is heterolithic, and consists of alternating shales, siltstones and sandstones. Black shales interbedded with thin sandstones and fossiliferous bands and nodules of limestones (Fig. 7B and Fig. 8A) dominate association 3; the bands appear to be primary layers while the nodules are diagenetic. Association 4 contains well-sorted, fine-grained, trace fossil-rich sandstones (Fig. 9). Lithofacies association 1 is absent in the oldest parts of the succession (upper Nsukka), and it is the only component of the youngest succession (Ogwashi-Asaba). It always disconformably overlies lithofacies association IV. Although the boundaries between lithofacies associations II, III, and IV are generally conformable, reactivation surfaces and disconformities occur within some units. This is more common within lithofacies association I (see section on sequence stratigraphy, sequence 5). Typically, association 2 is succeeded by association 3, which in turn is overlain by association 4.

4.2. Palynofacies assemblages

Visual observations suggest that four groups of dispersed organic matter and palynomorphs are important because they dominate certain samples, and likely influence how the samples group together. The entire percentage point count data were analyzed using principal components analysis, which confirmed that the four components, namely amorphous organic matter, structured phytoclasts, unstructured phytoclasts, and freshwater algae were statistically significant. A second round of analysis was performed using only these four components. Their component loadings (Table 4) indicate that the first two axes constitute 90.2% of the total variance in the sample data. When the component loadings were plotted on a graph, four groups of samples and one outlier (Nkpa-1) emerged (Fig. 10), just as in the earlier round of analysis. However, 30% of the samples within each group are not exactly the same for both analyses. Further analyses were carried out on the two sets of data using average linkage cluster analyses with Euclidean-distance correlation matrix. In this case, both analyses produced five identical groups of samples (Fig. 11), suggesting that the four minor components did not skew the results. Two of these five groups, which are designated palynofacies assemblages A–E, are identical to those defined by principal components analysis: assemblages D and E correlate with groups III and IV, respectively. In addition, 10 samples in assemblage C define group II. Although the minor components are not statistically significant, all eight components are used to discuss the results of the assemblages because some of the minor components appear to be environmentally important. For example, marine palynomorphs, are absent in palynofacies assemblages with a predominantly continental influence.

The characteristics of the five palynofacies assemblages are listed in Table 5 and illustrated in Fig. 12. Samples from the Umuasuwa section dominate palynofacies assemblage A; this assemblage also contains the only sample from the Nkpa section, which has a very high percentage of comminuted unstructured phytoclasts. In general, assemblages A, B, and C have the highest percentages of phytoclasts, but assemblages A and C have the lowest percentages of marine palynomorphs. Amorphous organic matter dominates assemblages D and E, which also record the highest percentage values of marine palynomorphs (up to 13%). With the exception of the three samples from the Okaiuga section (assemblage B) recording the highest percentages of fungal remains (6–9%), this category as well as black debris do not show any significance in their percentages.

5. Discussion

5.1. Depositional environments

Lithofacies interpretation forms the primary tool for identifying the depositional conditions under which the Palaeogene sediments were deposited and preserved. Palynofacies has been used as a secondary tool because palynological samples were obtained only from fine-grained siliciclastic rocks and limestone horizons that were likely to preserve organic material. Generally, sediments in most depositional systems contain dispersed organic matter that have either been transported as clasts or produced in situ. Although continental run-off, oceanic currents, and wind transportation can carry continental components, such as spores and pollen, wood and cuticle fragments, far offshore, their abundance generally decreases seaward (Traverse, 1994). Marine palynomorphs can be carried inshore by storms into brackish environments such as lagoons and estuaries where they can be preserved, but not likely far into fluvial environments. In the area of study, these assumptions likely prevailed, and there was no sedimentologic evidence of gravity deposition (e.g., turbidites). Therefore, the palynofacies model developed from dispersed organic matter distribution has been integrated with lithofacies data and related to depositional environments (see Table 3), and ultimately to tectonics, sediment supply and changes in base level and relative sea level (see section on sequence stratigraphy).

5.1.1. Fluvial channels and tidally influenced channels

Strata of lithofacies association I are interpreted as fluvial channel and/or tidally influenced channel and

Table 3
Characteristics of lithofacies associations and palynofacies assemblages used for inferring depositional environments

Lithofacies association	Lithology	Sedimentary structures/macrofossils/trace fossils	Palynofacies assemblage	Inferred environments
I	Single- and multi-storey sandstones interbedded with siltstones, shales and clays comprises four sub-facies: (1) Fine- to coarse-grained, well to moderately sorted sandstones, which are fine to near symmetrically skewed; units 10–30 m thick	Sub-facies 1 is characterized by planar cross-bedding (Fig. 7A), fining-upward grain size motif, reactivation surfaces, occasional mud drapes and scattered extraformational clasts; no macrofossils or trace fossils	B; no marine palynomorphs in interbedded mudrocks	Fluvial channels
	(2) Fine- to coarse-grained sandstones with pebbles, ferrugenized bands and mud drapes; units up to 20 m thick	Sub-facies 2 has low-angle trough cross-bedding and occasional flaser bedding; contains bivalve shell fragments and disseminated plant matter; no trace fossils	No data	Tidally influenced channels
	(3) Conglomeratic facies consisting of interbedded medium- to coarse-grained, moderately to poorly sorted sandstone and quartz pebble beds; fine to coarse skewed; up to 5 m thick	Planar and tabular cross-bedding; no macrofossils or trace fossils	B (as above)	Fluvial (braided) channels
	(4) Heterolithic facies with regular alternations of thin or thick, fine- to coarse-grained sandstone and mud-rock layers	Sandstone layers have parallel laminations, flaser and lenticular, cross-stratification with occasional reversals; muddy intrtvals intervals may be strongly bioturbated or wavy laminated; undiagnostic ichnofacies with few traces of *Planolites* and unidentified feeding burrows	A dominated by unstructured phytoclasts	Tidally influenced channels
II	Interbedded fine- to medium-grained sandstones, shales, and siltstones; locally gypsiferous	Low-angle trough and planar-tabular cross-bedding, herringbone cross-stratification, lenticular and flaser bedding, wave ripple lamination, bioturbation and ferrugenized concretions; few inoceramid shells, and disseminated plant matter; trace fossils include *Diplocraterion*, *Planolites* and *Thalassinoides* of the *Glossifungites* and *Skolithos* ichnofacies	B (as above) and C with elevated percentages of phytoclasts	Estuarine and/or proximal lagoon
III	Dominantly bluish-gray shales and black shales with thin interbeds and nodules of coquinas, limestones (Fig. 8A), sharp-based micaceous siltstones	Hummocky cross-stratification and wave ripple laminations in the sandstones; abundant casts, molds, and shells of bivalves, gastropods (*Busycon*, *Turritella*; Fig. 7B), nautiloids and fish teeth in the limestones; wood (Fig. 8B) and amber in shales; *Skolithos* and *Cruziana* ichnofacies	Very mixed assemblage A (20–40% freshwater algae) C (as above) D (9–19%) freshwater algae and 40–70% amorphous organic matter E (>70% amorphous organic matter)	Distal lagoon to shallow shelf
IV	Fine-grained, well sorted sandstones, locally medium-grained, with interbeds of siltstones and shales	Hummocky cross-stratification, swaley lamination, wave ripple lamination, lenticular bedding, bioturbation, phosphatic and siderite nodules; contains bivalve and gastropod shells; trace fossil suite of *Arenicolites*, *Teichichnus*, *Ophiomorpha* (Fig. 9), *Planolites*, *Rhizocorallium* and *Diplocraterion* belongs to the *Skolithos* ichnofacies	D (<9% freshwater algae and more phytoclasts than lithofacies association III) E (as above)	Shoreface-foreshore

Refer to Table 4 for detailed characteristics of palynofacies assemblages.

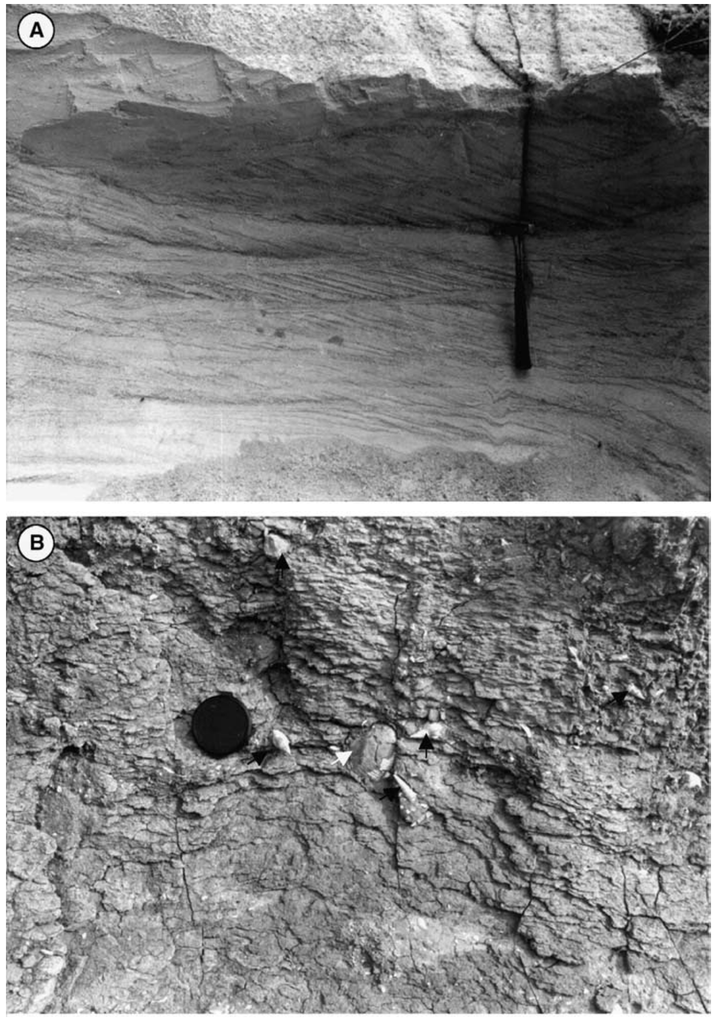

Fig. 7. Photographs of sedimentary structures and fossils in the Imo and Ameki Formations. (A) Planar and tabular cross stratification in sandstones at the Nkpa Junction locality. (B) Whole shells (black arrows) and shell fragment (white arrow) at the type Ameki locality in Ameke.

associated floodplain deposits. Fluvial channel sub-facies 1 and 3 (Table 3) are identified by fining-upward textures and sedimentary structures that thin upward. Lateral accretion surfaces are typically draped with mud. Based on the models of Nilsen (1982) and Miall (1992), thickly bedded, channelized matrix-supported conglomerates exhibiting normal grading (sub-facies 3), and 10–80-cm thick, sandy, white-brown mottled clay are interpreted as braided channel and flood plain sediments, respectively. These sediments do not preserve macrofossils and trace fossils. Three samples from clay layers in the Okaiuga section (palynofacies assemblage B) yields the highest percentages of unstructured phytoclasts in the study area (Table 5; Appendix A) and 14–21% structured phytoclasts. These samples also have the highest percentages (>5%) of fungal remains, are amorphous organic matter-poor (<10%), and have no marine palynomorphs, thus supporting a nonmarine environment of deposition.

Tidal influence is reflected by erosional lower-bounding surfaces with pebble lags, herringbone cross-stratification, flaser bedding, mud drapes, and reactivation surfaces in sub-facies 2 and 4. Some of these features, such as herringbone cross-stratification, reactivation surfaces, and mud drapes also probably relate to ebb-flood tidal cycles (Yang and Nio, 1985; Leckie and Singh, 1991; Shanley et al., 1992). This suite of sedimentary structures is typical of tidally influenced channel deposits that accreted in the transition between the tidal zone and fluvial channels (Archer and Kvale, 1989; Hettinger, 1995). Sub-facies 4 has a few trace fossils (*Planolites* and unidentified feeding burrows), but there is no clear pattern of relationship with the depositional environment due to the paucity of trace fossils. The Nkpa-I sample is dominated by comminuted unstructured phytoclasts, and is very poor (5.7%) in amorphous organic matter, confirming nonmarine deposition for that horizon.

5.1.2. Estuary and/or proximal lagoon

Alternating thin units of sandstones, siltstones and shales of lithofacies association II suggest rhythmic sed-

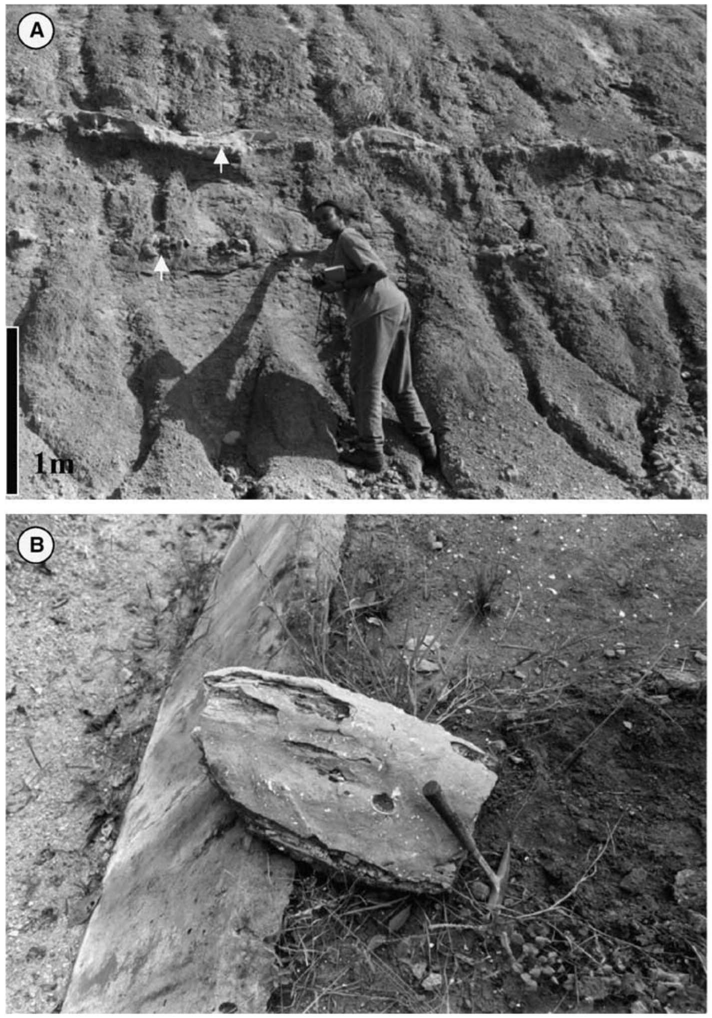

Fig. 8. Photographs of sedimentary structures and fossils in the Ameki Formation at the Ameke section. (A) Limestone bands and nodules (white arrows) interbedded with fossiliferous shale. (B) Petrified wood.

imentation (Boersma and Terwindt, 1981), and the fact that these alternating units have wave ripple laminations, lenticular and flaser bedding indicates that there were frequent fluctuations in current strength. Such conditions are common in subtidal and intertidal settings (Prothero and Schwab, 1996), where the sandstone units may be distributary mouth bars or bay fill deposits (Allen, 1993). We interpret lithofacies association II sediments as estuarine and/or proximal lagoonal in origin, based in part on the models of Dalrymple et al. (1992), Allen (1993) and Allen and Posamentier (1993). The co-existence of disseminated plant material and inoceramid shells records both terrestrial and open marine sources for the sediments. This is supported by the presence of sporomorphs and marine palynomorphs in the palynological samples. Palynofacies data yield high percentages of unstructured and structured phytoclasts, respectively for samples in assemblages B and C. Clays are occasionally gypsiferous and lenticular-bedded, thereby reflecting freshwater to brackish water, low-energy conditions in the coastal plain, either in swamps or proximal lagoons or tidal flats. Brackish water conditions are reflected by the presence of the *Glossifungites* and *Skolithos* ichnofacies (Kamola, 1984; Pieñkowski, 1985; Pemberton et al., 1992).

5.1.3. Distal lagoon to shallow shelf

The fine-grained deposits of lithofacies association III represent suspension sedimentation of siliciclastic and carbonate grains, possibly on an oxygen-deficient sea bottom. Evidence of anoxic conditions is provided by good preservation of original lamination, and abundant macrofossils. Shales are interbedded with hummocky cross-stratified sandstones, which are typical of shallow shelf sedimentation along storm-dominated coastlines (Walker and Plint, 1992), and indicate sudden short-term change from low- to high-energy conditions associated with spasmodic storm events (Brenner and Davies, 1973; Walker and Plint, 1992; Cheel and Leckie, 1993). Hummocky cross-stratification forms below fair

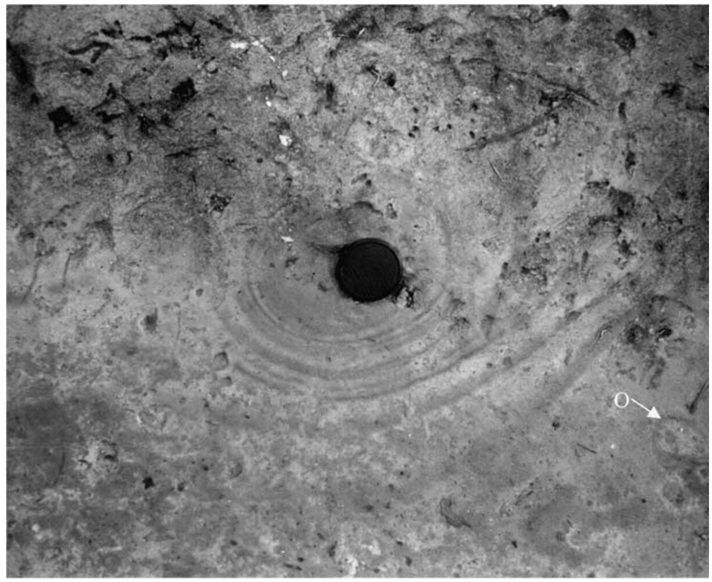

Fig. 9. Bioturbated sandstone of the Imo Formation at Akoli Imenyi. Identifiable trace fossils include *Ophiomorpha* (O) and *Teichichnus* (centered on lens cap).

Table 4
Principal component loadings in which the asterisk indicates absolute values greater than 0.10

Palynodebris component	Axis 1	Axis 2
Freshwater algae	−0.106*	−0.054
Structured phytoclasts	−0.308*	−0.762*
Unstructured phytoclasts	−0.395*	0.645*
Amorphous organic matter	0.859*	0.030

Eigenvalue (Axis) 1 = 906.894 (67.909% of total variance); Axis 2 = 297.677 (22.29%); Cumulative percentage = 90.2%.

weather base by storm-generated waves (Leckie and Walker, 1982; Myrow and Southard, 1996; Cheel and Leckie, 1993; Midtgaard, 1996). The swaley upper surfaces of the limestone bands at Ameke probably reflect late stage waning of the storm event responsible for deposition of the layers. This lithofacies association, therefore, is reflective of distal lagoonal to shallow shelf conditions. Freshwater runoff during the rainy season likely transported elevated percentages of the freshwater alga *Azolla* to the Umuasuwa area (Tables 2 and 4; Appendix A), moderate percentages (generally >4%) of sporomorphs, and high percentages of phytoclasts in assemblages into this environment. The occurrence of palynofacies assemblage E, which, along with assemblage D, has high percentages of amorphous or-

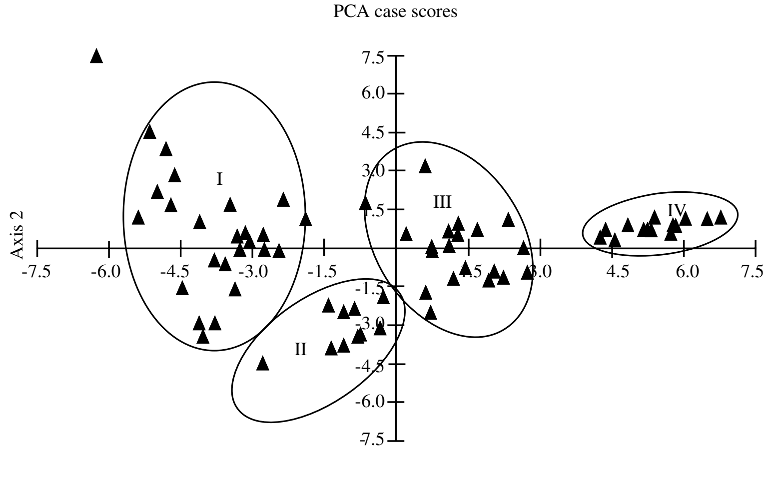

Fig. 10. Graph of samples grouped by principal components analysis (PCA). Four groups (I–IV) are identified. Refer to text for correlation with cluster analysis.

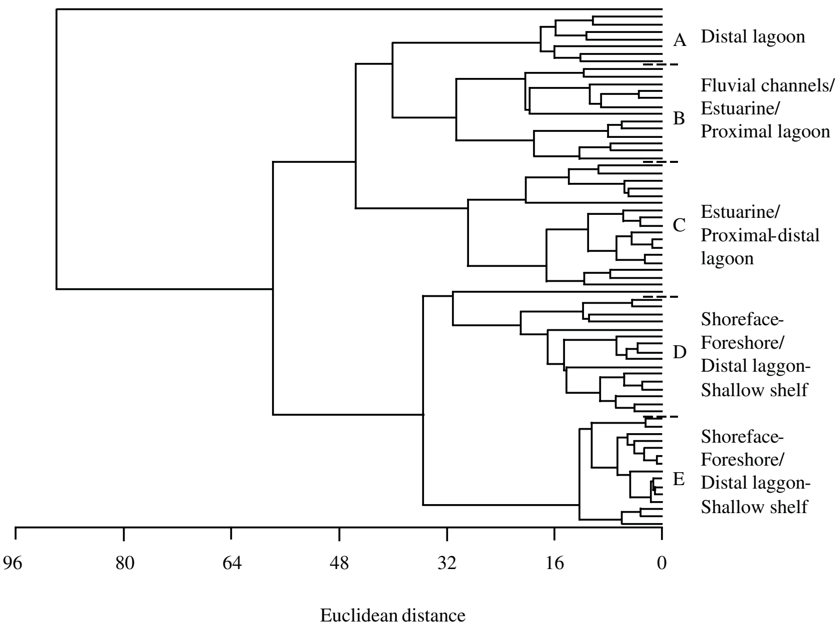

Fig. 11. Dendrogram generated by Euclidean-distance average linkage cluster analysis showing five groups of samples designated palynofacies assemblages A–E. The samples in each assemblage are listed in Appendix.

Table 5
Characteristics of the palynofacies assemblages

Palynofacies	Characteristics
A	Dominated by freshwater algae (mainly *Azolla* spores with massulae, 21–40%) and <20% amorphous organic matter (Fig. 12A); structured phytoclasts range from 17% to 33%, while spores and pollen are generally between 5% and 10%; Nkpa-1 sample dominated by comminuted unstructured phytoclasts
B	Typically 20–60% of unstructured phytoclasts, moderate percentages of structured phytoclasts (14–35%), and 6–42% amorphous organic matter (Fig. 12C and D)
C	Highest percentages of structured phytoclasts, with values ranging from 36% to 65% (Fig. 12E and F); also higher percentages of amorphous organic matter than those of palynofacies assemblage B, and both assemblages have roughly the same percentage of spores and pollen (2–14%)
D	40–63% of amorphous organic matter; some samples have 9–20% freshwater algae (Fig. 12G and H); variable percentages of unstructured phytoclasts is variable (1–34%) as in assemblage C, but spores and pollen are generally fewer (0.3–12%)
E	Samples have >70% amorphous organic matter, and the lowest percentages of structured and unstructured phytoclasts (5–14% and 0.7–7%, respectively) (Fig. 12B)

ganic matter (>40%) and up to 13% marine palynomorphs, suggests that the sediments were derived from the deepest environments in the study area (assemblage E has the least percentage of phytoclasts). The presence of trace fossils of the *Skolithos* and *Cruziana* ichnofacies (e.g., *Arenicolites*, *Teichichnus*, *Plabolites*, *Rhizocorallium*) supports this observation.

5.1.4. Shoreface and foreshore

The well-sorted, cross-bedded sandstones of lithofacies association IV are interpreted as storm- and wave-dominated shoreface and foreshore deposits, based on the model of Walker and Plint (1992). Cross-bedding is attributed to wave-induced unidirectional currents as well as shallow tidal currents developed in the open nearshore environments. Extraformational clasts at the base of the hummocky cross-stratified bedsets are interpreted as transgressive lags deposited over ravinement surfaces (Hettinger, 1995). The presence of sharp-based, graded heteroliths likely reflects deposition from waning storm generated flows, with the muddy portions of each bed representing inter-storm pelagic sedimentation (Walker and Plint, 1992). Palynologic samples from these muddy intervals have high percentages of amorphous organic matter and belong to palynofacies assemblages D and E. Thin-bedded, wave-rippled sandstones with a variety of trace fossils are interpreted as lower to middle shoreface deposits, whereas strongly bioturbated sandstones with abundant *Planolites*, *Thalassinoides*, *Skolithos*, *Arenicolites*, and *Ophiomorpha* traces probably represent the upper shoreface and foreshore (Swift and Niedoroda, 1985; MacEachern and Pemberton, 1992).

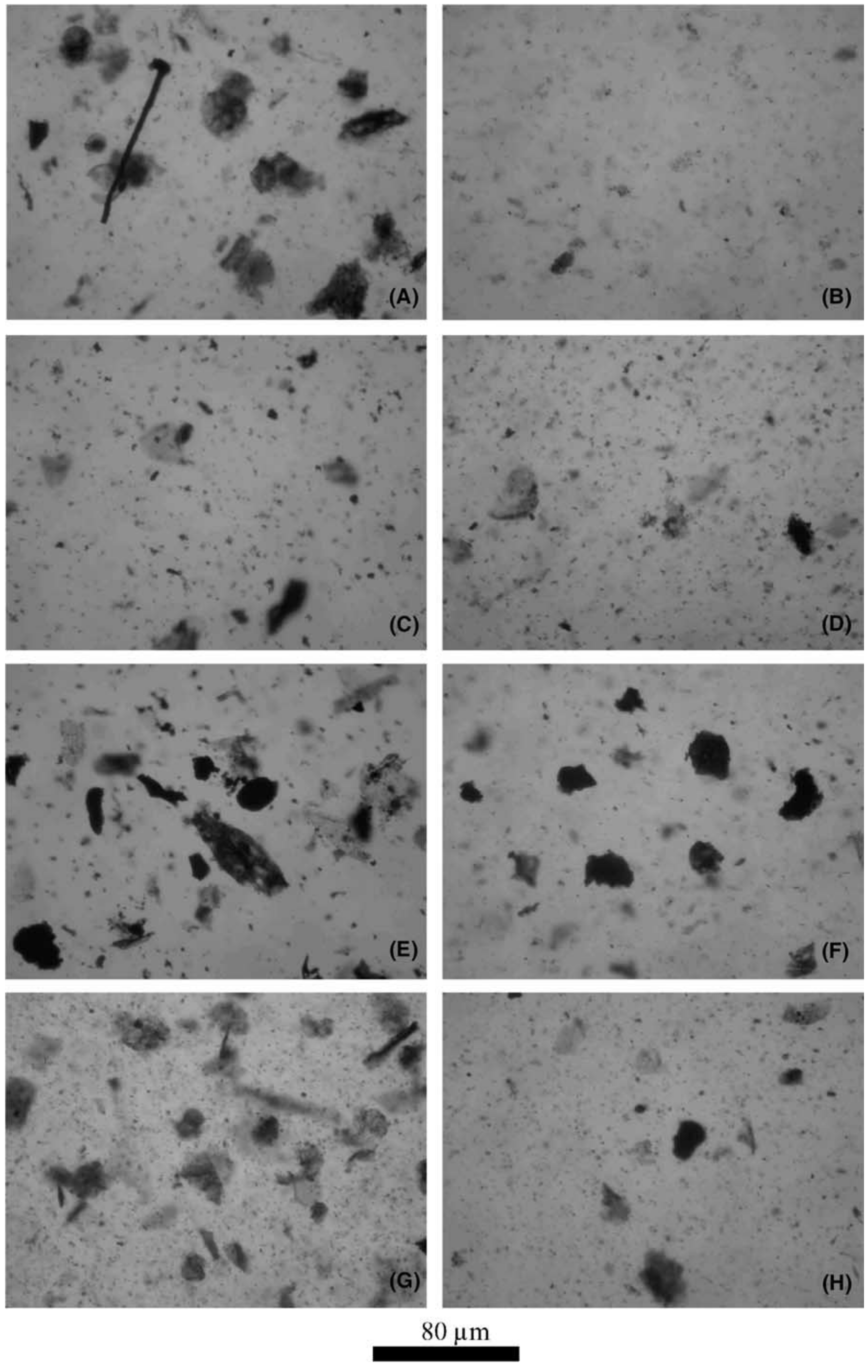

Fig. 12. Photomicrographs of palynofacies assemblages identified from average linkage cluster analysis. (A) Assemblage A, with 20–40% *Azolla* algal spores. (B) Assemblage E has >70% amorphous organic matter. (C, D) Assemblage B has high percentages of unstructured and comminuted phytoclasts. (E, F) Assemblage C is dominated by structured phytoclasts (>40%). (G, H) Assemblage D has 10–40% structured phytoclasts and 40–7% amorphous organic matter. Some samples have moderate percentages (9–19%) of freshwater algae (e.g., Figure G).

5.2. Sequence stratigraphy

The sequence stratigraphic interpretation presented here is based on the vertical relationship of the lithofacies associations, palynofacies assemblages, and the existing stratigraphic framework of the Palaeogene succession in southeastern Nigeria (Petters, 1983; Doust and Omatsola, 1990; Reijers et al., 1997; Obi, 2000). Each formation is analyzed in terms of the main systems tracts, sequence boundaries, transgressive surfaces, and maximum flooding surfaces. Five sequences and four regional or sequence boundaries are recognized in the Palaeogene succession in the study area, rather than the single sequence described by Reijers et al. (1997). Each unconformity is located where a basinward dislocation is indicated by juxtaposition of lithofacies I over lithofacies association IV (fluvial channel over shoreface-foreshore, or tidally influenced channel over shoreface-foreshore) (Hettinger, 1995). These unconformities, therefore, are interpreted as type 1 sequence boundaries (Haq et al., 1987, 1988) formed by falls in relative sea level greater than subsidence at the shelf edge. Local tectonics affected the sedimentation pattern in this passive margin of southern Nigeria, and stratigraphic base level changes probably played an even greater role in the sequence stratigraphy of the non-marine/coastal sediments of the Ogwashi-Asaba Formation. The stratigraphic architecture of the sequences is illustrated in Fig. 13; section locations can be found in Fig. 1.

5.2.1. Sequence 1—upper Nsukka formation

The upper Nsukka Formation crops out at the Ovim, Okigwe-A, and Umuasuwa sections as an incomplete sequence. At the Ovim section (Fig. 13A), about 36 m of distal lagoonal to shallow marine sediments (lithofacies association III) pass upward shoreface-foreshore sediments (lithofacies association IV) characterized by the *Skolithos* ichnofacies. Only the shoreface-foreshore sediments are exposed at Okigwe-A (Fig. 13B). At the Umuasuwa section (Fig. 13C), the distal lagoonal-shallow marine sediments overlie estuarine/proximal lagoonal sediments (lithofacies II). A maximum flooding surface has been identified at approximately 38.5 m where the highest percentage of amorphous organic matter is recorded. Lithofacies associations II and III are interpreted as the transgressive systems tract; lithofacies association IV represents the highstand systems tract.

Up-dip in the Okigwe-Enugu area, Obi (2000) recognized a type 1 sequence boundary at the base of a conglomerate that defines the contact between the Ajali Sandstone and the Nsukka Formation. Our first sequence boundary, ***SB-1***, occurs at the top of the upper Nsukka Formation (Fig. 13B and C), where black carbonaceous shales and siltstones of lithofacies association IV are abruptly overlain by strongly ferrugenized, coarse-grained to pebbly, tidally influenced fluvial sandstone (lithofacies association I). At the Okigwe-A section, the black shale is altered to nodular clay, which is mottled yellow, brown, and purple immediately below the sandstone, while at Umuasuwa, shale is abruptly truncated by a 50-cm thick ironstone. These features may record a palaeosol along the bedrock erosional surfaces of the palaeovalley (Wright, 1986; Retallack, 1988; Kraus and Brown, 1988), suggesting that the basal surface was subaerially exposed to weathering before deposition of the overlying valley-fill sediments. This surface is also considered a transgressive surface of erosion.

5.2.2. Sequence 2—lower Imo formation

Sequence 2 is one of two sequences identified in the Imo Formation. Each cycle is characterized by a tripartite vertical stratigraphic organization consisting of a coarse, river-dominated basal unit (lithofacies association I), a mudrock-dominated esuarine-marine unit (lithofacies associations II and III), and an upper sandstone unit (lithofacies association IV). This pattern was recognized in other areas by Rahamani (1988), Dalrymple (1992), Bhattacharya (1993), and Cotter and Driese (1998). Lithofacies associations I and II (Fig. 13B and C) represent the fining-upward and deepening upward-sequences corresponding to the transgressive systems tract. The erosive base of this sequence is interpreted to be a transgressive surface overprinted on a sequence boundary.

The transgressive facies continues upward into storm-dominated lithofacies association IV and black shale of lithofacies association III (with thin bands of coquinoid limestone) at Okigwe-B (Fig. 13D). At this locality, the shaly interval from 30 m to 34 m records a very high percentage of amorphous organic matter (palynofacies E) and probably represents a condensed section associated with a maximum flooding surface. The transgressive systems tract is estimated to be well over 60 m thick. The overlying fossiliferous shoreface succession is poorly exposed and gives way upward to mottled clays of foreshore origin. These shoreface-foreshore deposits (lithofacies IV) constitute the highstand systems tract, and terminate at the second sequence boundary, ***SB-2***. This sequence boundary 2 is overlain by ferrugenized clayey conglomerate (lithofacies association I) interpreted as a part of a palaeosol profile (Retallack, 1986; Ye, 1995). The basal contact of the clayey conglomerate is thus a type 1 unconformity, with the abrupt vertical facies change from foreshore to fluvial facies recording a basinward shift of facies, and is consistent with a fall in relative sea level (Posamentier and Vail, 1988; Van Wagoner et al., 1990; Ye and Kerr, 2000).

5.2.3. Sequence 3—upper Imo formation

The upper Imo Formation represents a complete sequence, and preserves an up-section variation from fluvial channel to tidally influenced fluvial channel sediments (lithofacies association I) through estuarine and shallow shelf deposits (lithofacies associations II and III) to shoreface-foreshore sediments (lithofacies association IV). At Okigwe-B, ***SB-2*** is overlain by some 50 cm of clayey conglomerate of braided fluvial channel origin (Fig. 13C), much of which is eroded and succeeded by estuarine sediments. Up-section at Nkpa Junction (Fig. 13E), there is a transition into tidally influenced fluvial channel and floodplain deposits. The Nkpa-1 palynological sample from a floodplain horizon (palynofacies assemblage A) has a very high percentage of comminuted unstructured phytoclasts. The basal units of lithofacies association I are interpreted channel deposits on the shelf, representing the early transgressive systems tract. The top of the tidally influenced fluvial

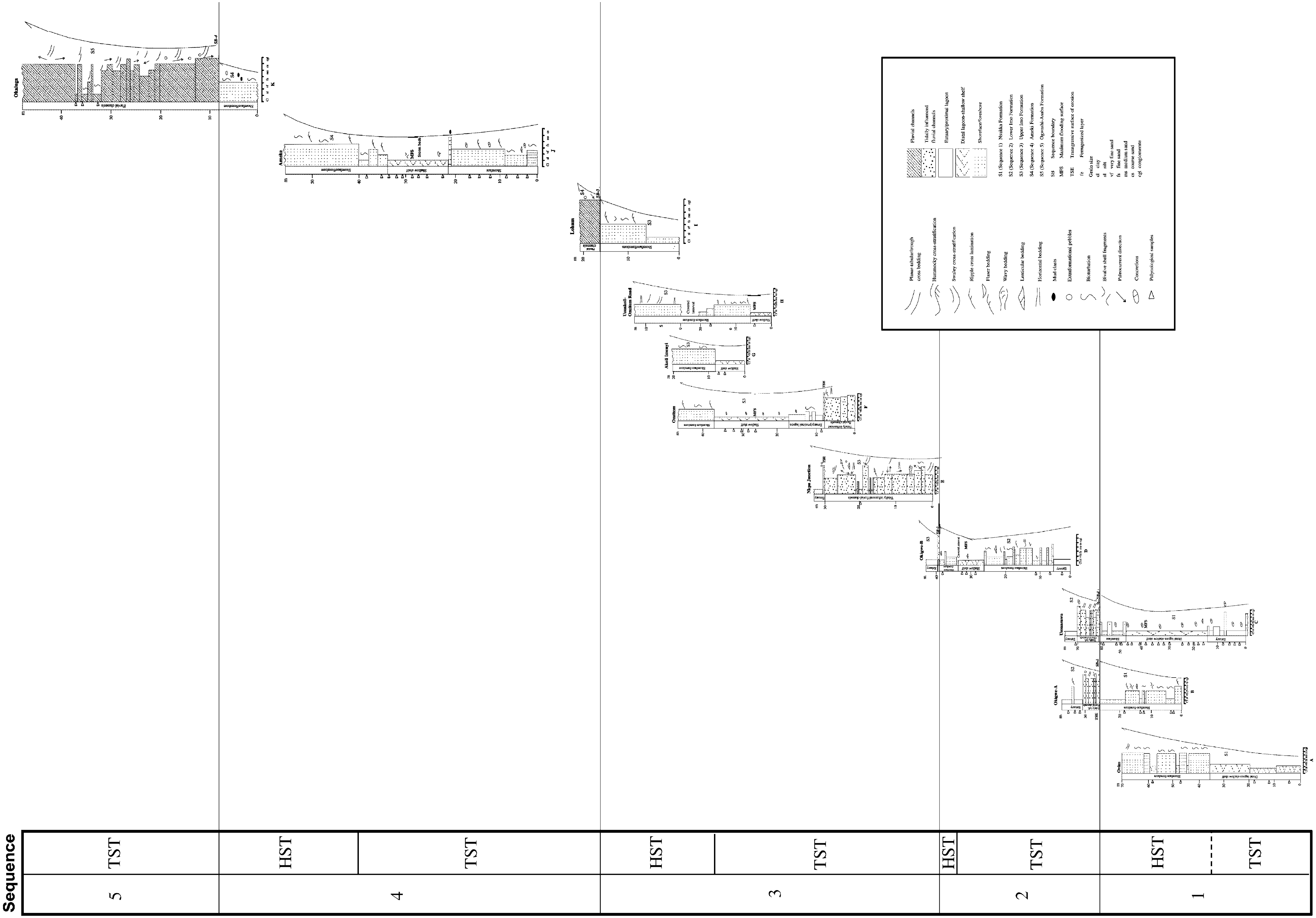

Fig. 13. Correlation of the sequence stratigraphic units in key sections in the study area. Refer to Fig. 1 for the locations of each stratigraphic section. TST = transgressive systems tract, and HST = highstand systems tract.

channel facies at Nkpa Junction and Ozuitem is truncated by a surface that is characterized by the *Glossifungites* ichnofacies and overlain by a thin, strongly ferrugenized, pebbly to coarse-grained sandstone (Fig. 13E and F). This ferrugenized sandstone is a transgressive lag, the basal contact of which is interpreted as a transgressive surface of erosion (TSE).

The overlying estuarine/proximal lagoonal facies (lithofacies II) contain trace fossils of the *Skolithos* ichnofacies. These sediments are in turn overlain by a succession of black shale that has higher percentages of sporomorphs and marine palynomorphs, and a mixed suite of *Cruziana* and *Skolithos* ichnofacies (lithofacies III). At Ozuitem (Fig. 13F) and Uzuakoli-Ozuitem Road (Fig. 13H), the maximum flooding surface occurs around 26.5 m and 4.2 m, respectively where samples record more than 13% of marine palynomorphs. The transition from the *Glossifungites* ichnofacies below to mixed suite of *Cruziana* and *Skolithos* ichnofacies, coupled with the change from sandy lithofacies to dark grey and black shales, indicates progressive deepening-upward parasequences interpreted as the transgressive systems tract.

Lithofacies association III passes upward into very fine-grained, shelly shoreface sandstones of lithofacies association IV, which represent the early progradational phase of sequence 3. Foreshore sediments succeed the shoreface sandstones, and both sets of deposits are parasequences of the highstand systems tract. The exposed thickness of the shoreface-foreshore sediments varies from about 12 m at the Akoli Imenyi (Fig. 13G) to over 20 m at Uzuakoli-Ozuitem Road (Fig. 13H).

Sequence boundary 3, ***SB-3***, is identified at the top of the Imo Formation. This erosive contact is at the Lohum section (Fig. 13I), where it separates micaceous and fossiliferous shoreface sandstone of lithofacies association IV from >5 m-thick conglomeratic sandstone of lithofacies association I. The trace fossils *Thalassinoides*, *Diplocraterion*, *Monocraterion*, and *Planolites* occur in the shoreface sandstone and they can be found about 5 m below the conglomeratic sandstone, which has quartz pebbles imbricated seaward at 250°. The juxtaposition of shoreface and fluvial deposits indicates that a moderately high-energy erosional event was followed by seaward-directed (prograding) deposition.

5.2.4. Sequence 4—Ameki formation

Sequence 4 has an exposed thickness over 70 m and is a mixed siliciclastic-carbonate system containing the most extensive limestone deposit in the study area. The sequence begins with conglomeratic sandstone at the Lohum section (Fig. 13I), which grades upward into multi-storey, channelized sandstone, which is exposed in areas to the south of the section. Each single storey begins on an irregular pebbly base with sole marks and grades into a finer grained top that is capped by a thin ironstone layer. These sandstones are non-marine aggradational deposits (braided river) on the shelf and represent the early transgressive systems tract; they have an overall exposed thickness in excess of 40 m. The braided river deposits are overlain by poorly exposed estuarine sediments (lithofacies II), which crop out in the area around Ude-Ofome and parts of Amaogugu. The contact is considered to be a transgressive surface.

At the type locality in Ameke (Fig. 13J), the section begins with over 20 m of trace fossil-rich shoreface sediments (lithofacies IV), which grade upward into fossiliferous shale and limestone bands (lithofacies III) of storm-dominated shelf origin. The estuarine, shoreface and shelf facies constitute the transgressive systems tract. A maximum flooding surface can be inferred at the Ameke section, where a coquinoid storm-bed overlies the black shale (interval 28.5 m). Above this interval at Ameke and in the lower part of the Okaiuga section (Fig. 13K), trace fossil-rich shoreface deposits (lithofacies IV) are present. Extraformational clasts, wood fragments, and amber that are typical of the Ameki Formation (Arua, 1986) occur in these shoreface sediments, which represent the highstand systems tract.

The fourth sequence boundary, ***SB-4***, is exposed at Okaiuga (Fig. 13K), where a thin ironstone layer separates shoreface deposits of the Ameki Formation from the conglomerate bed of the Ogwashi-Asaba Formation. The sharp, erosive base of the conglomerate bed is interpreted as the stratigraphic signature of a major drop in relative sea level that was marked by down cutting of incised valleys onto the shoreface.

5.2.5. Sequence 5—Ogwashi-Asaba formation

Fluvial channel deposits belonging to the Ogwashi-Asaba Formation dominate this incomplete sequence in the study area (Fig. 13K). The lower part of the formation is composed of alternating, thickly bedded, matrix-supported conglomerate and coarse-grained sandstone units interpreted as a braided river deposit (lithofacies I). Each unit begins on a scour surface with randomly oriented pebbles, and grades upward into coarse- to medium-grained sandstone containing pebbles with palaeocurrent direction of approximately 150° (Fig. 14). Parts of the formation contain channel-fill deposits consisting of planar-tabular cross-bedded sandstones interbedded with lignite seams and thin, light-coloured over-bank mudrocks. These are interpreted to be the non-marine/coastal aggradational portion of the transgressive systems tract (Posamentier and Vail, 1988; Ye and Kerr, 2000). The fluvial architecture was probably also affected by changes in base level (Schumm, 1993; Martinsen et al., 1999).

5.3. Controls on sedimentation and sequence development

The tectono-sedimentological history of the Late Campanian-Maastrichtian Anambra Basin holds the

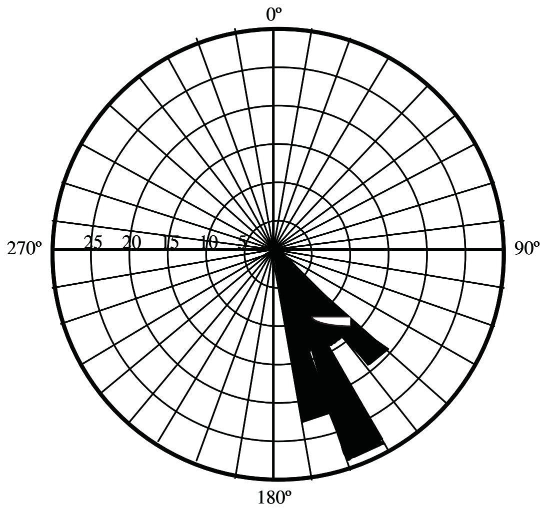

Fig. 14. Rose diagram illustrating palaeocurrent direction in the Ogwashi-Asaba Formation near Umuahia.

key to a better understanding of the origin and evolution of Palaeogene sedimentary sequences and the oil-rich Tertiary-Quaternary Niger Delta. Sedimentation in the post-Santonian Anambra Basin provides a good example of the interrelationship between relative sea level change (eustacy) and tectonics.

Previous workers (Agagu et al., 1985; Obi, 2000; Obi et al., 2001; Obi and Okogbue, 2004) demonstrated this relationship by linking the origin and evolution of the Anambra Basin to the Santonian tectonics that created the Abakaliki Anticlinorium (Olivet et al., 1984; Maluski et al., 1995; Burke, 1996). Before the Santonian deformation, the Anambra Basin was a stable platform, thinly covered by sediments. The formation of the anticlinorium dislocated the depositional axis from the Benue Trough to the Anambra Platform (Murat, 1972; Hoque and Nwajide, 1985; Amajor, 1987). As sediment accumulated on the platform, it gradually subsided asymmetrically and Cretaceous deltaic systems of the palaeo-Benue River prograded toward the southwest (Obi et al., 2001). Evidence from tectono-geomorphologic analysis of the Anambra Basin, facies sequence and architecture, and distribution of seismically induced soft sediment deformation structures within the Campanian-Paleocene succession in the Anambra Basin, suggest that the basin subsided asymmetrically at least three times during the Campanian-Maastrictian period (Obi et al., 2001; Obi and Okogbue, 2004). Asymmetric subsidence along the landward extension of the Atlantic Chain fracture controlled the initial opening of the Benue Trough (Benkhelil, 1986; Ojoh, 1988). The subsidence was in response to post-Benue rift thermal relaxation of the lithosphere (Popoff, 1990; Binks and Fairhead, 1992).

Apart from tectonics and sea level variation, other processes involved in sequence development potentially include climate and sediment supply. Today's humid tropical climate in southeastern Nigeria is similar to that in the Late Cretaceous and Paleogene times (Hoque, 1977; Obi, 2000); hence climate does not appear to have played a major role in the sequence variations in the Paleogene succession. Changes in subsidence rates influence the geometry of resulting sequences, especially in basins with a relatively high sediment input, such as in the Anambra Basin/Afikpo Syncline Complex. A complex architecture of alternating progradational sets with different geometries (reflecting a variation in accommodation), which would be expected if smaller variations in subsidence rates were solely responsible for the formation of individual sequences, was not observed in the present study. Thus, vertical movement was not likely the sole cause for the formation of the sequences. The erosional unconformities identified in the Late Paleocene Imo Shale and the mid-Eocene Ameki Group, which correlate well with major drops in sea level reflected in the global cycle chart of Hardenbol et al. (1998), can be attributed to eustatic control.

The development of other sequence boundaries in the Palaeogene succession that do not correlate with the major sea level drops reflected in the global cycle charts, can be attributed to sea level changes amplified by local tectonics. The cycles of fluvio-marine to shallow marine strata identified in the study area provide a strong indication of the interplay between tectonics and relative sea level changes. The overall similarity recorded in lithofacies organization and distribution of the Campanian-Maastrictian and Palaeogene sequences in the Anambra Basin, and the progressive southward migration of depositional systems, suggest that the episodic and asymmetrical subsidence of the Anambra Basin described by Obi and Okogbue (2004), progressed into the Tertiary and Quaternary periods. Accumulation of the marine strata of the Imo Shale and Ameki Group (sequences 2, 3, 4) and their lateral equivalents in the Niger Delta is consistent with marine transgression and progressive southwestward migration of deltaic systems into the Equatorial Atlantic Ocean (Ekweozor and Daukoru, 1994). Therefore, a tectono-eustatic control is proposed for the development of stratigraphic sequence of the Palaeogene strata in the Anambra Basin/Afikpo Syncline complex.

6. Conclusions

Detailed sedimentological and palynofacies analyses show that the Palaeogene strata in the Okigwe-Umuahia area of the Anambra Basin/Afikpo Syncline complex consist of five depositional sequences (Fig. 15): (1) Nsukka Formation, (2) Lower Imo Formation, (3) Upper Imo Formation, (4) Ameki Formation and (5) Ogwashi-Asaba Formation. A typical sequence begins

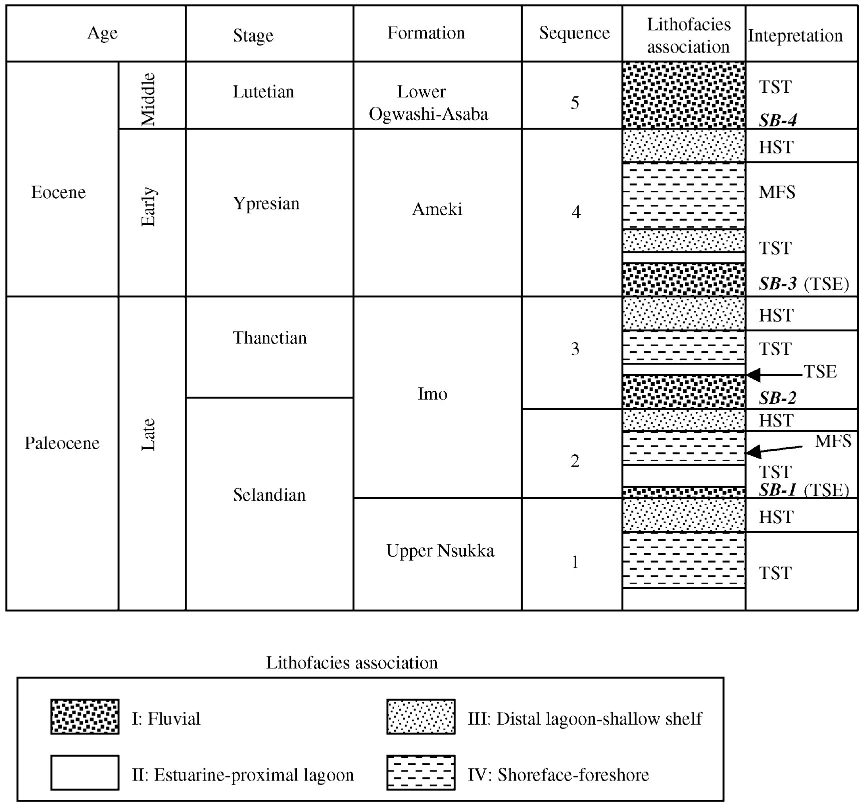

Fig. 15. Sequence stratigraphic model for the Palaeogene sequences in southeastern Nigeria. SB = sequence boundary, MFS = maximum flooding surface, TSE = transgressive surface of erosion, TST = transgressive systems tract, and HST = highstand systems tract.

with accumulation of coarse fluvial channel and/or tidally influenced fluvial channel deposits (lithofacies I), which are overlain by estuarine and/or proximal lagoonal sediments (lithofacies II). Next in the sequence are fossiliferous distal lagoonal to shallow shelf deposits (lithofacies III), which in turn pass upward into wave-dominated shoreface and foreshore sediments (lithofacies IV). A similar pattern was identified by Obi (2000) in Upper Cretaceous strata in the Okigwe-Enugu area, which is up-dip of the study area. He interpreted the sediments as ancient estuarine-fills. The Palaeogene sequences of the present study appear to represent analogous deposition, with the fluvial sandstones and/or tidally influenced fluvial facies filling the incised valleys that formed when sea level fell. Onset of transgression resulted in the deposition of estuarine and/or proximal lagoonal deposits. The succeeding distal lagoonal to shallow shelf deposits accumulated in the central part of the estuary, following maximum marine transgression, while the overlying wave dominated sandstones at the top of each sequence represent the progradational filling of the bay-head of the estuary (Fig. 15).

Each sequence is bounded by a type-1 sequence boundary, and contains basal fluvio-marine sediments representing the transgressive systems tract, which are succeeded by shoreface and foreshore strata of the highstand systems tract. Only the non-marine/coastal aggradational deposits of the transgressive systems tract of the Ogwashi-Asaba Formation are exposed in the study area. The occurrence of the estuarine cycles in the Palaeogene succession is interpreted as evidence of significant relative sea level fluctuations, and the presence of type-1 sequence boundaries may well be the stratigraphic signature of major drops in relative sea level during Paleocene and Eocene.

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Appendix A

Sample numbers, depths, percentage data for palynofacies analysis, and palynofacies assemblage to which each sample belongs. SPORO = sporomorphs, FUN = fungal remains, MAR = marine palynomorphs, FWG = freshwater algae, STRP = structured phytoclasts, UNSTRP = unstructured phytoclasts, BDB = black debris, AOM = amorphous organic matter.

Sample	Depth (m)	SPORO	FUN	MAR	FWG	STRP	UNSTRP	BDB	AOM	Palynofacies
Akoli-1	15.0	2.7	0.0	13.3	0.0	8.0	0.7	4.7	70.7	E
Akoli-2	17.0	3.0	0.7	4.7	0.3	8.0	0.7	3.3	79.3	E
Uzuakoli-1	4.2	2.7	3.3	2.0	0.0	9.0	0.7	1.7	80.6	E
Uzuakoli-2	17.5	2.7	1.3	1.7	0.0	7.6	1.0	0.7	85.0	E
Ameke-1	2.8	9.7	1.3	3.7	0.3	30.7	4.0	0.3	50.0	D
Ameke-2	5.0	3.7	0.3	3.0	0.0	32.0	3.7	0.0	57.3	D
Ameke-3	8.7	4.0	0.0	3.3	0.0	30.0	3.3	0.0	59.4	D
Ameke-4	12.5	2.3	0.7	2.3	0.3	43.4	2.0	0.3	48.7	C
Ameke-5	15.0	3.0	0.7	1.7	0.0	56.6	1.7	0.7	35.6	C
Ameke-6	17.1	2.7	1.0	1.6	0.0	53.0	2.7	0.7	38.3	C
Ameke-7	22.8	2.0	0.3	1.0	0.0	58.7	2.7	1.0	34.3	C
Ameke-8	26.0	1.7	1.0	1.3	0.0	49.0	9.7	0.7	36.6	C
Ameke-9	27.8	5.0	1.0	2.3	0.0	46.4	8.0	0.0	37.3	C
Ameke-10	28.5	1.0	0.0	5.0	0.0	7.3	1.7	0.3	84.7	E
Ameke-11	30.7	4.0	1.0	2.0	0.0	53.3	1.7	0.7	37.3	C
Ameke-12	32.0	6.3	1.7	2.3	0.0	64.7	2.0	0.7	22.3	C
Ameke-13	33.5	2.7	0.3	2.3	0.0	28.4	3.0	0.0	63.3	D
Ameke-14	34.9	3.7	0.7	2.0	0.3	50.0	2.3	0.0	41.0	C
Ameke-15	38.4	1.0	1.3	1.0	0.0	5.0	1.0	0.3	90.4	E
Nkpa-1	19.7	1.3	0.7	0.0	0.0	4.3	86.6	1.0	5.7	A
Okaiuga-1	32.5	9.7	8.7	0.0	0.0	20.7	45.3	7.7	9.0	B
Okaiuga-2	35.6	7.0	5.0	0.0	0.0	14.3	59.7	6.0	8.0	B
Okaiuga-3	37.8	8.0	6.0	0.0	0.0	15.0	52.0	10.7	8.3	B
Okigwe A-1	2.0	13.7	1.7	5.0	2.0	15.0	26.0	6.0	20.6	B
Okigwe A-2	3.0	3.3	1.3	0.7	0.0	28.0	14.3	3.0	49.3	D
Okigwe A-3	12.0	0.7	0.3	0.0	0.0	9.0	33.3	9.3	49.7	D
Okigwe A-4	13.5	2.3	0.7	1.0	1.0	24.7	11.3	12.3	46.7	D
Okigwe A-5	18.2	3.0	0.7	3.0	0.3	37.3	44.3	4.7	6.7	B
Okigwe A-6	31.5	3.7	0.7	9.6	0.7	33.0	22.0	9.6	20.7	B
Okigwe A-7	33.0	6.0	1.3	7.7	0.7	19.7	15.0	1.0	50.0	D
Okigwe A-8	35.0	1.3	0.7	0.3	0.0	6.0	3.0	1.3	87.4	E
Okigwe B-1	2.5	10.3	1.0	4.0	9.0	32.6	21.7	4.7	16.7	B
Okigwe B-2	6.0	5.0	1.0	5.3	1.3	23.4	12.0	2.0	50.0	D
Okigwe B-3	11.0	9.7	0.7	3.3	1.7	56.0	13.3	3.3	12.0	C
Okigwe B-4	28.5	7.3	3.0	2.3	1.7	27.3	4.7	2.0	51.7	D
Okigwe B-5	31.0	2.0	0.3	1.0	0.0	7.7	5.3	1.0	82.7	E
Okigwe B-6	32.5	2.3	0.3	2.0	1.7	31.0	49.3	2.7	10.7	B
Okigwe B-7	38.0	3.7	1.0	5.0	1.7	32.0	43.3	2.3	11.0	B
Ozuitem-1	8.2	8.0	5.0	1.3	1.0	7.0	1.3	0.7	75.7	E
Ozuitem-2	26.5	0.3	0.3	1.7	0.0	4.0	0.7	0.3	92.7	E
Ozuitem-3	28.2	9.3	1.0	13.7	0.0	15.7	1.7	1.0	57.6	D
Ozuitem-4	31.0	14.3	1.7	4.7	0.3	36.7	2.7	2.0	37.6	C
Ozuitem-5	33.0	12.0	0.7	5.0	0.3	25.0	1.0	1.0	55.0	D
Ozuitem-6	35.0	13.0	1.7	4.0	0.0	34.0	1.7	1.0	44.7	C
Umuasuwa-1	1.8	6.3	1.0	2.3	4.0	33.3	31.0	0.7	21.4	B
Umuasuwa-2	3.5	2.0	0.3	2.0	0.3	17.0	16.0	0.7	61.4	D
Umuasuwa-3	5.5	5.7	1.7	5.3	0.3	45.3	9.0	0.7	32.0	C

Appendix A (*continued*)

Sample	Depth (m)	SPORO	FUN	MAR	FWG	STRP	UNSTRP	BDB	AOM	Palynofacies
Umuasuwa-4	8.0	6.0	0.7	4.0	0.3	57.7	15.0	0.0	16.3	C
Umuasuwa-6	16.0	4.7	0.0	0.7	31.3	28.0	13.3	0.3	21.7	A
Umuasuwa-7	18.0	5.0	0.0	0.0	40.0	24.3	15.7	1.0	14.0	A
Umuasuwa-8	20.0	4.7	0.0	1.0	38.0	17.7	24.6	0.0	14.0	A
Umuasuwa-9	22.0	9.3	0.7	0.7	38.0	29.0	7.7	5.0	9.6	A
Umuasuwa-10	24.5	1.7	0.0	0.7	4.0	21.3	31.0	0.0	41.3	B
Umuasuwa-11	30.0	7.7	1.7	0.7	31.0	32.3	14.3	1.7	10.6	A
Umuasuwa-12	32.0	7.0	2.3	0.0	23.8	27.0	28.3	2.3	11.3	A
Umuasuwa-13	34.0	2.0	0.3	0.3	3.7	28.7	32.0	0.7	32.3	B
Umuasuwa-14	36.2	10.7	1.3	1.0	14.0	18.3	11.0	2.7	41.0	D
Umuasuwa-15	38.5	5.0	0.7	2.7	9.6	19.0	11.3	0.7	51.0	D
Umuasuwa-16	40.7	2.7	0.7	1.7	19.3	13.0	9.3	4.0	49.3	D
Umuasuwa-18	44.7	2.3	0.7	0.3	18.4	15.0	8.0	2.3	53.0	D
Umuasuwa-19	46.7	8.3	0.7	4.0	21.3	25.4	19.3	1.7	19.3	A
Umuasuwa-20	49.5	6.0	1.0	1.7	4.0	50.0	23.7	2.3	11.3	C
Umuasuwa-21	51.5	6.6	1.7	1.7	3.0	60.0	11.0	2.7	13.3	C
Umuasuwa-22	59.2	2.7	1.0	1.0	2.0	49.3	21.3	2.4	20.3	C
Umuasuwa-23	70.8	4.0	1.3	0.7	3.3	36.0	29.3	3.0	22.4	B
Ovim-1	4.0	4.0	1.7	1.0	0.0	12.6	1.7	7.0	72.0	E
Ovim-2	12.0	3.3	2.7	1.7	0.0	9.3	0.7	3.0	79.3	E
Ovim-3	18.0	3.0	1.3	1.0	0.0	9.7	1.3	3.3	80.4	E
Ovim-4	47.0	1.3	1.0	0.7	0.0	10.0	0.3	2.0	84.7	E
Ovim-5	58.2	1.3	1.3	0.7	0.0	13.7	1.0	7.0	75.0	E

References

Adegoke, O.S., 1969. Eocene stratigraphy of southern Nigeria. Colloque sur l' Eocene, III. Bureau de Recherches Geologiques et Minieres 69, 22–48.

Adegoke, O.S., Arua, I., Oyegoke, O., 1980. Two new nautiloids from the Imo Shale, (Paleocene) and Ameki Formation (Middle Eocene), Anambra State, Nigeria. Journal of Mining and Geology 17, 85–89.

Agagu, O.K., Fayose, E.A., Petters, S.W., 1985. Stratigraphy and sedimentation in the Senonian Anambra Basin of Eastern Nigeria. Journal of Mining and Geology 22, 25–36.

Allen, G.P., 1993. An introduction to estuarine lithosomes and their controls. In: Wright, V.P. (Ed.), Sedimentology Review, vol. 1. Blackwell Scientific Publications, Oxford, pp. 123–138.

Allen, G.P., Posamentier, H.W., 1993. Sequence stratigraphy and facies model of an incised valley fill: the Gironde estuary, France. Journal of Sedimentary Petrology 63, 378–391.

Amajor, L.C., 1987. Paleocurrent, petrography and provenance analyses of the Ajali Sandstone (Upper Cretaceous), Southeastern Benue Trough, Nigeria. Sedimentary Geology 54, 47–60.

Anyanwu, N.P.C., Arua, I., 1990. Ichnofossils from the Imo Formation and their palaeoenvironmnental significance. Journal of Mining and Geology 26, 1–4.

Archer, A.W., Kvale, E.P., 1989. Seasonal and yearly cycles within tidally laminated sediments; an example from the Pennsylvanian in Kentucky, Indiana, and Illinois. Indiana Geological Survey, Illinois Basin Consortium 1, 45–46.

Arua, I., 1980. Palaeocene Macrofossils from the Imo Shale in Anambra State, Nigeria. Journal of Mining and Geology 17, 81–84.

Arua, I., 1986. Paleoenvironment of Eocene deposits in the Afikpo syncline, southern Nigeria. Journal of African Earth Sciences 5, 279–284.

Avbovbo, A.A., 1978. Tertiary lithostratigraphy of the Niger Delta. American Association of Petroleum Geologists Bulletin 62, 295–306.

Batten, D.J., 1996. Palynofacies. In: Jansonius, J., McGregor, D.J. (Eds.), Palynology: Principles and Applications. American Association of Stratigraphic Palynologists Foundation, Dallas, Texas, pp. 1011–1064.

Benkhelil, J., 1986. Caracteristiques structurales et evolution geodynamique du basin intracontinentale de la Benoue (Nigeria). Thesis d'etat, Nice, 275 pp.

Benkhelil, J., 1989. The origin and evolution of the Cretaceous Benue Trough (Nigeria). Journal of African Earth Sciences 8, 251–282.

Berggren, W.A., 1960. Paleocene biostratigraphy and planktonic foraminifera of Nigeria (West Africa). International Geological Congress, Copenhagen, Report 21 (6), 41–55.

Bhattacharya, J.P., 1993. The expression and interpretation of marine flooding surfaces and erosional surfaces in cores; example from the Upper Cretaceous Dunvegan Formation, Alberta foreland basin, Canada. In: Posamentier, H.W., Summerhayes, C.P., Haq, B.U., Allen, G.P. (Eds.), Sequence Stratigraphy and Facies Associations, vol. 18. International Association of Sedimentologists, Special Publication, pp. 125–160.

Binks, R.M., Fairhead, J.D., 1992. A plate tectonic setting for Mesozoic rifts of West and Central Africa. Tectonophysics 213, 141–151.

Boersma, J.R., Terwindt, J.H.J., 1981. Neap-spring tide sequences of intertidal shoal deposits in a mesotidal estuary. Sedimentology 28, 151–170.

Boulter, M.C., Riddick, A., 1986. Classification and analysis of palynodebris from the Paleocene sediments of the Forties Field. Sedimentology 33, 871–886.

Brenner, R.L, Davies, D.K., 1973. Storm-generated coquinoid sandstone: genesis of high energy marine sediments from the upper

Jurassic of Wyoming and Montana. Geological Society of America Bulletin 84, 1685–1698.

Bullard, E.C., Everett, J.E., Smith, A.G., 1965. Fit of the continents around the Atlantic. Philosophical Transactions of the Royal Society London A 258, 41–51.

Burke, K.C., 1996. The African Plate. South African Journal of Geology 99, 341–409.

Burke, K.C., Dessauvagie, T.F.J., Whiteman, A.J., 1971. The opening of the Gulf of Guinea and the geological history of the Benue depression and Niger delta. Nature Physical Science 233, 51–55.

Burke, K.C., Dessauvagie, T.F.J., Whiteman, A.J., 1972. Geological history of the Benue valley and adjacent areas. In: Dessauvagie, T.F.J., Whiteman, A.J. (Eds.), African Geology. University of Ibadan Press, Nigeria, pp. 187–218.

Cheel, R.J., Leckie, D.A., 1993. Hummocky cross-stratification. In: Wright, V.P. (Ed.), Sedimentology Review, vol. 1. Blackwell Scientific Publishers, London, pp. 103–122.

Cotter, E., Driese, S.G., 1998. Incised valley fills and other evidence of sea level fluctuations affecting deposition of the Catskill Formation (Upper Devonian) Appalachian Foreland Basin, Pennsylvania. Journal of Sedimentary Research 68, 347–361.

Dalrymple, R.W., 1992. Tidal depositional systems. In: Walker, R.G., James, N.P. (Eds.), Facies Models: Response to Sea Level Change. Geological Association of Canada, pp. 195–218.

Dalrymple, R.W., Zaitlin, B.A., Boyd, R., 1992. Estuarine models: conceptual basis and stratigraphic implications. Journal of Sedimentary Petrology 62, 1130–1146.

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

Ekweozor, C.M., Daukoru, E.M., 1994. The northern delta depobelt portion of the Akata-Agbada (!) petroleum system, Niger Delta, Nigeria. In: Magoon, L.B., Dow, W.G. (Eds.), The Petroleum Systems; From Source to Trap. American Association of Petroleum Geologists Memoir, vol. 60, pp. 599–613.

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

Fairhead, J.D., Green, C.M., 1989. Controls on rifting in Africa and the regional tectonic model for the Nigeria and East Niger rift basins. Journal of African Earth Sciences 8, 231–249.

Fayose, E.A., Ola, P.S., 1990. Radiolarian occurrences in the Ameki type section, eastern Nigeria. Journal of Mining and Geology 26, 75–80.

Frankl, E.J., Cordry, E.A., 1967. The Niger delta oil province—recent developments onshore and offshore. In: 7th World Petroleum Congress Proceedings, Mexico City, vol. 1B, pp. 195–209.

Guiraud, R., Bellion, Y., 1995. Late Carboniferous to Recent geodynamic evolution of the West Gondwanian, Cratonic, Tethyan margins. In: Nairn, A.E.M. et al. (Eds.), The Ocean Basins and Margins (vol. 8), The Tethys Ocean, pp. 101–124.

Haack, R.C., Sundaraman, P., Diedjomahor, J.O., Xiao, H., Gant, N.J., May, E.D., Kelsch, K., 2000. The Niger Delta petroleum systems, Nigeria. In: Mello, M.R., Katz, B.J. (Eds.), Petroleum Systems of South Atlantic Margins. American Association of Petroleum Geologists Memoir, vol. 73, pp. 213–231.

Haq, B.U., Hardenbol, J., Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. Science 235, 1156–1167.

Haq, B.U., Hardenbol, J., Vail, P.R., 1988. Mesozoic and Cenozoic Chronostratigraphy and cycles of sea-level change. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C.. Posamentier, H.W., Ross, C.A., Van Wagoner, J.C. (Eds.), Sea-level Changes: An Integrated Approach. SEPM Special Publication, vol. 42, pp. 72–108.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., De Graciansky, P.-C., Vail, P.R., 1998. Meozoic-Cenozoic sequence chronostratigraphic framework of European basins. In: De Graciansky, P.-C., Hardenbol, J., Jacquin, T., Jacquin Vail, P.R. (Eds.), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins, vol. 60. SEPM Special Publication, pp. 3–13.

Hettinger, R.D., 1995. Sedimentological descriptions and depositional interpretation in sequence stratigraphic context of two 300-meter cores from Upper Cretaceous Straight Cliffs Formation, Kaiparowits Plateau, Kane County, Utah, U.S.. Geological Survey Bulletin 2115-A, 1–32.

Hooper, R.J., Fitzsimmons, R.J., Grant, N., Vendeville, B.C., 2002. The role of deformation in controlling depositional patterns in the south-central Niger Delta, West Africa. Journal of Structural Geology 24, 847–859.

Hoque, M., 1977. Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, southeastern Nigeria. Sedimentary Geology 17, 235–245.

Hoque, M., Nwajide, C.S., 1985. Tectono-sedimentological evolution of an elongate intracratonic basin (aulacogen): The case of the Benue Trough of Nigeria. Journal of Mining and Geology 21, 19–26.

Jan du Chêne, R., Onyike, M.S., Sowumi, M.A., 1978. Some new Eocene pollen of the Ogwashi-Asaba Formation, Southeastern Nigeria. Revista de Espanol Micropaleontologie 10, 285–322.

Kamola, D.L., 1984. Trace fossils from the marginal-marine facies of the Spring Canyon Member, Blackhawk Formation (Upper Cretaceous), east-central Utah. Journal of Paleontology 58, 529–541.

King, L.C., 1950. Outline and disruption of Gondwanaland. Geological Magazine 87, 353–359.

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: Van der Linden, W.J.M., Cloetingh, S.A.P., Kaasschieter, J.P.K., Van der Graaf, W.J.E., Vandenberghe, J., Van der Gun, J.A.M. (Eds.), Coastal Lowlands, Geology and Geotechnology. Royal Geological and Mining Society of the Netherlands (K.N.G.M.G.) Symposium, Dordrecht, Kluwer Academic Publishers, pp. 181–202.

Kogbe, C.A., 1976. Paleogeographic history of Nigeria from Albian times. In: Kogbe, C.A. (Ed.), Geology of Nigeria. Elizabethan Publishers, Lagos, pp. 237–252.

Koledoye, B.A., Aydin, A., May, E., 2003. A new process-based methodology for analysis of shale smear along normal faults in the Niger Delta. American Association of Petroleum Geologists Bulletin 87, 445–463.

Kovach, W.L., 2002. Multivariate Statistical Package Plus, Versions 3.0 and 3.1 Users' Manual. Kovach Computing Services, Pentraeth, Wales, UK, 127 pp.

Kraus, M.J., Brown, T.M., 1988. Pedofacies analysis: a new approach to reconstructing ancient fluvial sequences. In: Reinhardt, J., Sigleo, W.R. (Eds.), Paleosols and Weathering through Geological Time: Principles and Applications, vol. 216. Geological Society of America, Special Paper, pp. 143–152.

Leckie, D.A., Singh, C., 1991. Estuarine deposits of the Albian Paddy Member (Peace River Formation) and Lowermost Shaftesbury Formation, Alberta, Canada. Journal of Sedimentary Petrology 61, 825–849.

Leckie, D.A., Walker, R.G., 1982. Storm- and tide-dominated shorelines in Late Cretaceous Moosebar-Lower Gates interval–outcrop equivalents of deep basin gas trap in western Canada. American Association of Petroleum Geologists Bulletin 66, 138–157.

MacEachern, J.A., Pemberton, S.G., 1992. Ichnological aspects of Cretaceous shoreface successions and shoreface variability in the Western Interior seaway of North America. In: Pemberton, S.G. (Ed.), Applications of Ichnology to Petroleum Exploration, vol. 17. SEPM Core Workshop, pp. 57–84.

Maluski, H., Coulon, C., Popoff, M., Baudin, P., 1995. $^{40}Ar/^{39}$Archronology, petrology, and geodynamic setting of Mesozoic to early

Cenozoic magmatism from the Benue Trough, Nigeria. Journal of the Geological Society, London 152, 311–326.

Martinsen, O.J., Ryseth, A., Helland-Hansen, W., Flesche, H., Torkildsen, G., Idil, S., 1999. Stratigraphic base level and fluvial architecture: Ericson Sandstone (Campanian), Rock Springs Uplift, SW Wyoming, USA. Sedimentology 46, 235–259.

Miall, A.D., 1992. Alluvial deposits. In: Walker, R.G., James, N.P. (Eds.), Facies Models: Response to Sea Level Change. Geological Association of Canada, pp. 119–142.

Midtgaard, H.H., 1996. Inner-shelf to lower-shoreface hummocky sandstone bodies with evidence for geostrophic influenced combined flow, Lower Cretaceous, West Greenland. Journal of Sedimentary Research 66, 343–353.

Murat, R.C., 1972. Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in southern Nigeria. In: Dessauvagie, T.F.J., Whiteman, A.J. (Eds.), African Geology. University of Ibadan Press, Nigeria, pp. 251–266.

Myrow, P.M., Southard, J.B., 1996. Template deposition. Journal of Sedimentary Research 66, 875–877.

Nilsen, T.H., (Ed.), 1982. Fluvial sedimentation and related tectonic framework, western North America. Sedimentary Geology, vol. 36, pp. 1–523.

Nwajide, C.S., 1979. A lithostratigraphic analysis of the Nanka Sands, southeastern Nigeria. Journal of Mining and Geology 16, 103–109.

Nwajide, C.S., 1990. Cretaceous sedimentation and palaeogeography of the Central Benue Trough. In: Ofoegbu, C.O. (Ed.), The Benue Trough Structure and Evolution. Friedr. Vieweg and Sohn, Braunchweig/Wiesbaden, pp. 19–38.

Obi, G.C., 2000. Depositional Model for the Campanian-Maastrichtian Anambra Basin, Southern Nigeria. Unpublished Ph.D. Thesis, University of Nigeria, Nsukka, 291 pp.

Obi, G.C., Okogbue, C.O., 2004. Sedimentary response to tectonism in the Campanian-Maastrichtian succession, Anambra Basin, Southeastern Nigerian. Journal Africa Earth Sciences 38, 99–108.

Obi, G.C., Okogbue, C.O., Nwajide, C.S., 2001. Evolution of the Enugu Cuesta: A tectonically driven erosional process. Global Journal of Pure Applied Sciences 7, 321–330.

Oboh, F.E., 1992. Middle Miocene palaeoenvironments of the Niger Delta. Palaeogeography, Palaeoclimatology, Palaeoecology 92, 55–84.

Oboh-Ikuenobe, F.E., Yepes, O., ODP Leg 159 Scientific Party, 1997. Palynofacies analysis of sediments from the Côte d'Ivoire-Ghana transform margin: preliminary correlation with some regional events in the Equatorial Atlantic. Palaeogeography, Palaeoclimatology, Palaeoecology 129, 291–314.

Ojoh, K.A., 1988. Evolution des basins albo-santoniens du sud—Quest du fossé de labénoue (Nigeria). Apports à la connaissance du domaine Equatorial de l' Atlantique Sud. Thése Doctorat Université Aix-Marseille III.

Olivet, J.L., Bonnin, J., Beuzart, P., Auzende, J.M., 1984. Cinematique de l'Atlantic nord et central. Publication CNEXO Rapport Scientific et technique, 54.

Oomkens, E., 1974. Lithofacies relations in the Quaternary Niger delta complex. Sedimentology 21, 195–222.

Oti, M.N., Postma, G. (Eds.), 1995. Geology of Deltas. A.A. Balkema, Rotterdam, p. 315.

Pemberton, S.G., MacEachern, J.A., Frey, R.W., 1992. Trace fossil facies models: environmental and allostratigraphic significance. In: Walker, R.G., James, N.P. (Eds.), Facies Models: Response to Sea Level Change. Geological Association of Canada, pp. 47–72.

Petters, S.W., 1983. Gulf of Guinea planktonic foraminiferal biochronology and geological history of the South Atlantic. Journal of Foraminiferal Research 13, 32–59.

Pieñkowski, G., 1985. Early Liassic trace fossil assemblages from the Holy Cross Mountains, Poland: their distribution in continental and marginal marine environments. In: Curran, H.A. (Ed.), Biogenic Structures: Their Use in Interpreting Depositional Environments, vol. 35. SEPM Special Publication, pp. 37–51.

Popoff, M., 1990. Deformation intracontinental gondwanienne—Rifting mesozoique en Afrique (Evolution meso-cenozoique du fosse de la Benue, Nigeria)—Relations de líocean Atlantique sud. These de Etat, University Aix-Marseillea III.

Posamentier, H.W., Vail, P.R., 1988. Eustatic controls on clastic deposition II—sequence and systems tracts models. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A., Van Wagoner, J.C. (Eds.), Sea-level Changes: An Integrated Approach, vol. 42. SEPM Special Publication, pp. 125–154.

Prothero, D.R., Schwab, F., 1996. In: Sedimentary Geology. W.H. Freeman and Company, New York, p. 575.

Rahamani, R.A., 1988. Estuarine tidal channel and nearshore sedimentation of a Late Cretaceous epicontinental sea, Drumheller, Alberta, Canada. In: De Boer, P.L., Van Gelder, A., Nio, S.D. (Eds.), Tide-Influenced Sedimentary Environments and Facies. D. Reidel Publishing Company, Dordrecht, pp. 433–471.

Reijers, T.J.A., Petters, S.W., Nwajide, C.S., 1997. The Niger Delta Basin. In: Selley, R.C. (Ed.), African Basins. Elsevier, Amsterdam, pp. 151–172.

Retallack, G.J., 1986. The fossil record of soils. In: Wright, V.P. (Ed.), Palaeosols: Their Recognition and Interpetation. Blackwell Scientific Publications, Oxford, pp. 1–57.

Retallack, G.J., 1988. Field recognition of paleosols, In: Reinhardt, J., Sigleo, W.R. (Eds.), Paleosols and Weathering Through Geological Time: Principles and Applications Geological Society of America, Special Paper 216, pp. 1–20.

Reyment, R.A., 1965. In: Aspects of the Geology of Nigeria. University of Ibadan Press, Nigeria, p. 145.

Reyment, R.A., 1969. Ammonite biostratigraphy, continental drift and oscillatory Transgressions. Nature 224, 137–269.

Schumm, S.A., 1993. River response to baselevel change: implications for sequence stratigraphy. Journal of Geology 101, 279–294.

Shanley, K.W., McCabe, P.J., Hettinger, R.D., 1992. Tidal influence in Cretaceous fluvial strata from Utah, USA—a key to sequence stratigraphic interpretation. Sedimentology 39, 905–930.

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

Sokal, R.R., Michener, C.D., 1958. A statistical method for evaluating systematic relationships. University of Kansas Science Bulletin 38, 1409–1438.

Swift, D.J.P., Niedoroda, A.W., 1985. Fluid and sediment dynamism on continental Shelves. In: Tilman, R.W., Swift, D.J.P., Walker, R.G. (Eds.), Shelf Sands and Sandstone Reservoirs. SEPM Short Course Notes 13, pp. 47–133.

Traverse, A., 1988. In: Paleopalynology. Unwyn-Hyman, Boston, p. 600.

Traverse, A. (Ed.), 1994. Sedimentation of Organic Particles. Cambridge University Press, p. 544.

Tyson, R.V., 1995. In: Sedimentary Organic Matter, Organic Facies and Palynofacies. Chapman and Hall, London, p. 615.

Vail, P.R., Mitchum, R.M., Thompson III, S., 1977. Seismic stratigraphy and global changes of sea level, part 3: relative changes of sea level from coastal onlap, In: Payton, C.W. (Ed.), Seismic Stratigraphy Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists Memoir 26, pp. 63–97.

Van Bergen, P., Janssen, N., Alferink, J., Kerp, J., 1990. Recognition of organic matter types in standard palynological slides. In: Fermont, W.J.J., Weegink, J.W. (Eds.), Proceedings of the International Symposium on Organic Petrology January 1990, vol. 45. Mededelingen Rijks Geologische Dienst, pp. 9–21.

Van Heijst, M.W.I.M., Postma, G., van Kesteren, W.P., de Jongh, R.G., 2002. Control of syndepositional faulting on systems tract evolution across growth-faulted shelf margins: An analog experimental model of the Miocene Imo River field, Nigeria. American Association of Petroleum Geologists Bulletin 86, 1335–1366.

Van Wagoner, J.C., Mitchum Jr., R.M., Campion, K.M., Rahmanian, V.D., 1990. Siliciclastic Sequence Stratigraphy in Well Logs, Cores and Outcrops: Concepts for High-Resolution Correlation of Time Facies. American Association of Petroleum Geologists Methods in Exploration Series 7, 55.

Walker, R.G., Plint, A.G., 1992. Wave- and storm-dominated shallow marine systems. In: Walker, R.G., James, N.P. (Eds.), Facies Models: Response to Sea Level Change. Geological Association of Canada, pp. 219–238.

Weber, K.J., 1971. Sedimentological aspects of oil fields in Niger delta. Geologishe en Minjbouw 50, 559–576.

Weber, K.J., Daukoru, E.M., 1975. Petroleum geological aspects of the Niger delta. In: 9th World Petroleum Congress Proceedings, vol. 2, Tokyo, pp. 209–221.

White, E.I., 1926. Eocene fishes from Nigeria. Bulletin of the Geological Survey of Nigeria 10, 1–78.

Wright, V.P. (Ed.), 1986. Paleosols: Their Recognition and Interpretation. Blackwell Scientific Publications, Oxford, p. 315.

Yang, C.S., Nio, S.D., 1985. The estimation of palaeohydrodynamic processes from subtidal deposits using time series analysis methods. Sedimentology 32, 41–57.

Ye, L.S., 1995. Paleosols in the upper Guantao Formation (Miocene) of the Gudong oil field and their application to the correlation of fluvial deposits. American Association of Petroleum Geologists Bulletin 79, 981–988.

Ye, L.S., Kerr, D., 2000. Sequence stratigraphy of the Middle Pennsylvanian Bartsville Sandstone, northeastern Oklahoma: a case of an underfilled incised valley. American Association of Petroleum Geologists Bulletin 84, 1185–1204.