THE MAASTRICHTIAN SEDIMENTARY SUCCESSIONS OF THE ANAMBRA BASIN RECENTLY EXPOSED AROUND OKPEKPE AND IMIEGBA: PART OF THE MAMU OR AJALI FORMATION?

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ABSTRACT
The sedimentary successions of the Anambra basin recently exposed around Okpekpe, Imiegba, and the surrounding areas offer a unique opportunity to describe, associate the lithofacies with their depositional environment(s), and assign them to the right stratigraphic unit (formation). A geological field mapping and facies analyses of the sedimentary rocks in the study area revealed the following facies: shales, sandstones, mudstones (siltstones and claystones), a localized coal seam, the ichnogenus *Thalassinoides* and burrows suspected to be that of *Ophiomorpha*. The lithofacies and ichnofacies observed in eight logged sections were classified into three lithofacies associations genetically related to their depositional environments namely: (i) shales with intercalated siltstones and sandstones of intertidal flat/lagoon lithofacies association, (ii) the coal swamp/marsh lithofacies association, and (iii) the heterolithic tidal lithofacies association. These lithofacies and ichnofacies are comparable with those of the Mamu formation, although earlier reports on this formation stated that it is restricted to the southeastern part of the basin and is terminated at Idah, East of the Niger River. This study therefore highlights the possibility of the Mamu Formation extending (both in terms of surface and subsurface geology) to the western flank (west of the Niger River) of the basin, not only in the southeastern part of the basin as was hitherto reported. The lithofacies indicates paralic conditions as their gross depositional environment. The presence of *Thalassinoides* and *Ophiomorpha*-like burrows revealed sediments deposited under a shallow water environment, upholding the interpretation of the lithofacies associations.

Key words: Sedimentary successions, thalassinoides, lithofacies, ichnofacies, lithofacies associations, mamu formation.

INTRODUCTION
The Mamu Formation (previously referred to as the lower coal measures by Simpson, 1954; but later renamed by Reyment, 1965) has been widely discussed. Reyment (1965) described the stratigraphy of most sedimentary basins in Nigeria (including the Mamu Formation, Anambra basin) and presented a concise but renowned account regarding their lithostratigraphic and biostratigraphic divisions. The Mamu Formation consists of sandstones, shales and sandy shales with coal seams; of which the yellowish coloured sandstones are fine to medium grained; while dark blue to grey shales and mudstones frequently intercalate the sandstones to form a characteristic stripe stratigraphy (Reyment, 1965; Whiteman, 1982). Murat (1972), Burke et al. (1972), Petters (1978), Whiteman (1982), Ladipo (1988), Kogbe (1989a) and others have described various aspects of the Mamu Formation such as its paleogeography, sedimentation, stratigraphy and tectonics. The rank and petroleum potential of the coal facies of the Mamu Formation was highlighted by Akande et al. (1992) and Ogala (2011), respectively. Studies involving the depositional environments, sequence stratigraphy, palynology, facies analysis and ichnology of this formation have also been researched (Nwajide and Reijers, 1996; Oboh-Ikuenobe et al., 2005; Onyekuru and Iwuagwu, 2010; Ogala et al., 2009; Onuigbo et al., 2012; Soronadi-Ononiwu, 2012; Nwajide, 2013; Odumodu, 2014).

Despite these numerous research endeavors, there remain unresolved stratigraphic issues. For example, Kogbe (1989b) reported that though stratigraphical and paleontological aspects of the sedimentary successions of the southern Nigeria basins have been studied extensively, there still exists controversies about the rock-stratigraphic units, particularly when it comes to nomenclature, type section/locality, superposition and spatio-temporal extent. This situation is attributable to poor and inadequate rock exposures constituting a great setback that is partly solvable by drilling of boreholes or mining pits or road cuts.

A case in point in the Anambra basin is the spatio-temporal extent of the Mamu Formation. Most of the previous studies on this formation are concentrated in the southeastern and northeastern parts of the basin where exposures of its lithofacies are very out-standing. A review of earlier works (Simpson, 1954; Reyment, 1965, p.52; Kogbe, 1989a p.263), other studies (Nwajide and Reijers, 1996; Nwajide, 2013) and the geological map of Nigeria published by the Nigerian Geological Survey Agency (NGSA, 2006) all revealed that the Mamu Formation is found within the southeastern part and terminated at Idah, a town located east of the River Niger (Figure 1). The intent here is not to reverse this assertion, because what the aforementioned authors reported was based on noticeable exposed sections of the formation as at that time. However, the construction of road network linking the uphill settlements in the study area exposed and gave new insights to the geology of the southwestern flank of the Anambra basin that necessitates relating the recent outcrops to the lithofacies of the Mamu Formation.

Prior to this study, this area was generally

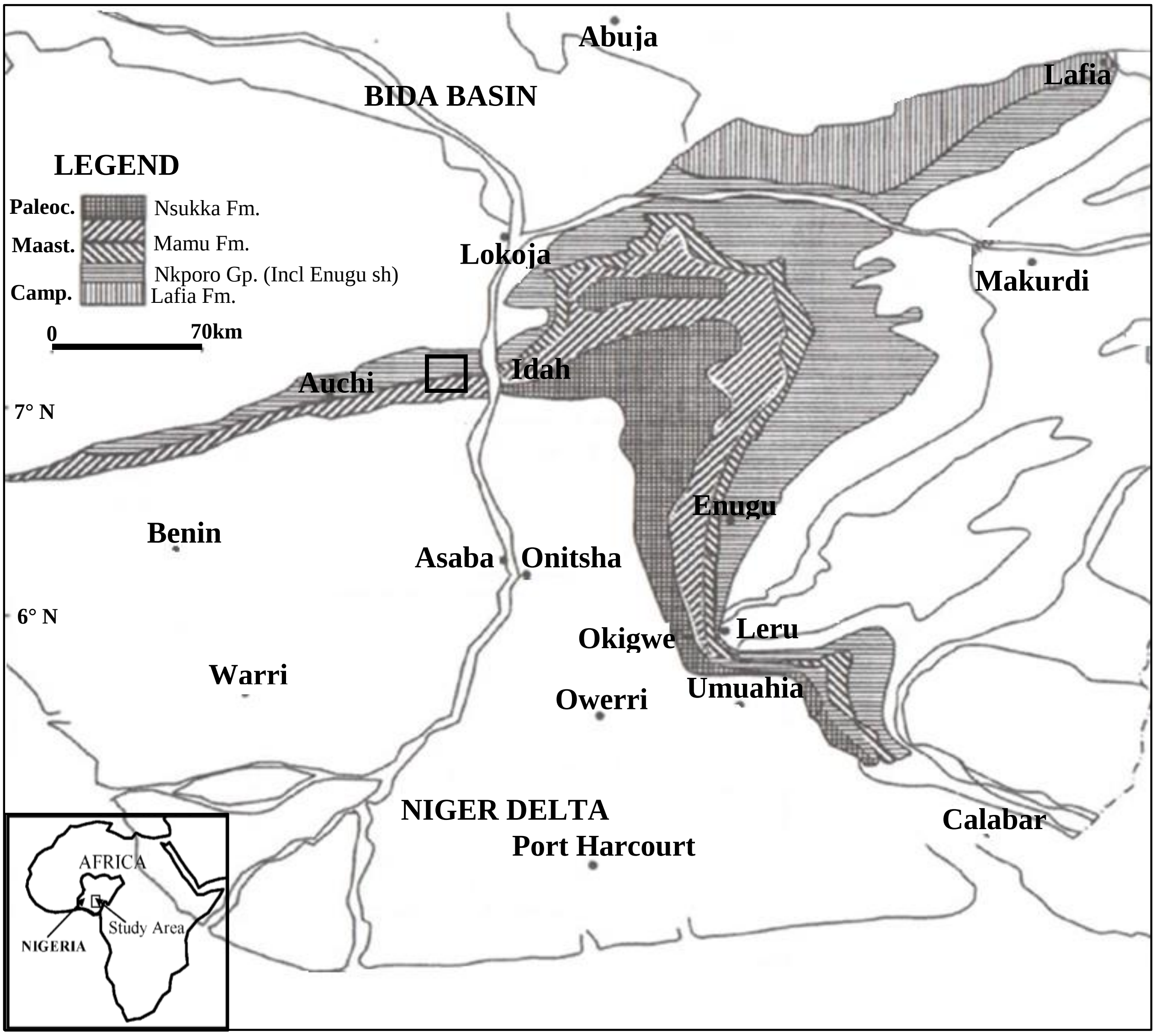


Figure 1. Outline geological map of the Anambra Basin (Modified after Nwajide, 2013)

viewed as part of the Ajali sandstone Formation (Reyment, 1965; Kogbe, 1989a; Nwajide and Reijers, 1996; Nwajide, 2013) probably because this formation outcrops in localities such as Auchi, Ogbonna, Fugar, Othame, Iviukwe, and Agenebode, all of which are in the western flank of the basin and are relatively close to the study area.

The study area and geological background

The study area located in the south western flank of the Anambra basin is bounded by latitudes 7° 8´ to 7° 18´N and longitudes 6° 18´ to 6° 30´E (Figure 2). The evolution of the Anambra basin has been attributed to the breakup of the South American and African continents in the Cretaceous (Murat, 1972; Burke, 1996). A rift basin model backed by structural, stratigraphic, paleontologic and tectonic settings has been suggested for its evolution. Short and Stäuble (1967) reported that the coastal basins (Anambra basin inclusive) have undergone three cycles of sedimentary deposition. The first cycle (Abakaliki-Benue phase) involved the deposition of mainly marine sediments, which prevailed from pre-Albian time with a mild folding episode that terminated during Santonian. The second cycle (Anambra-Benin phase) was quite crucial to the development of the Anambra basin and lasted from Campanian to mid Eocene. In this cycle, the folding episode during Santonian was succeeded by subsidence that induced marine transgression which led to the deposition of the Nkporo Group (Campanian-Maastrichtian) and the lateral equivalents, Enugu Shale and Owelli Sandstone (Figure 3).

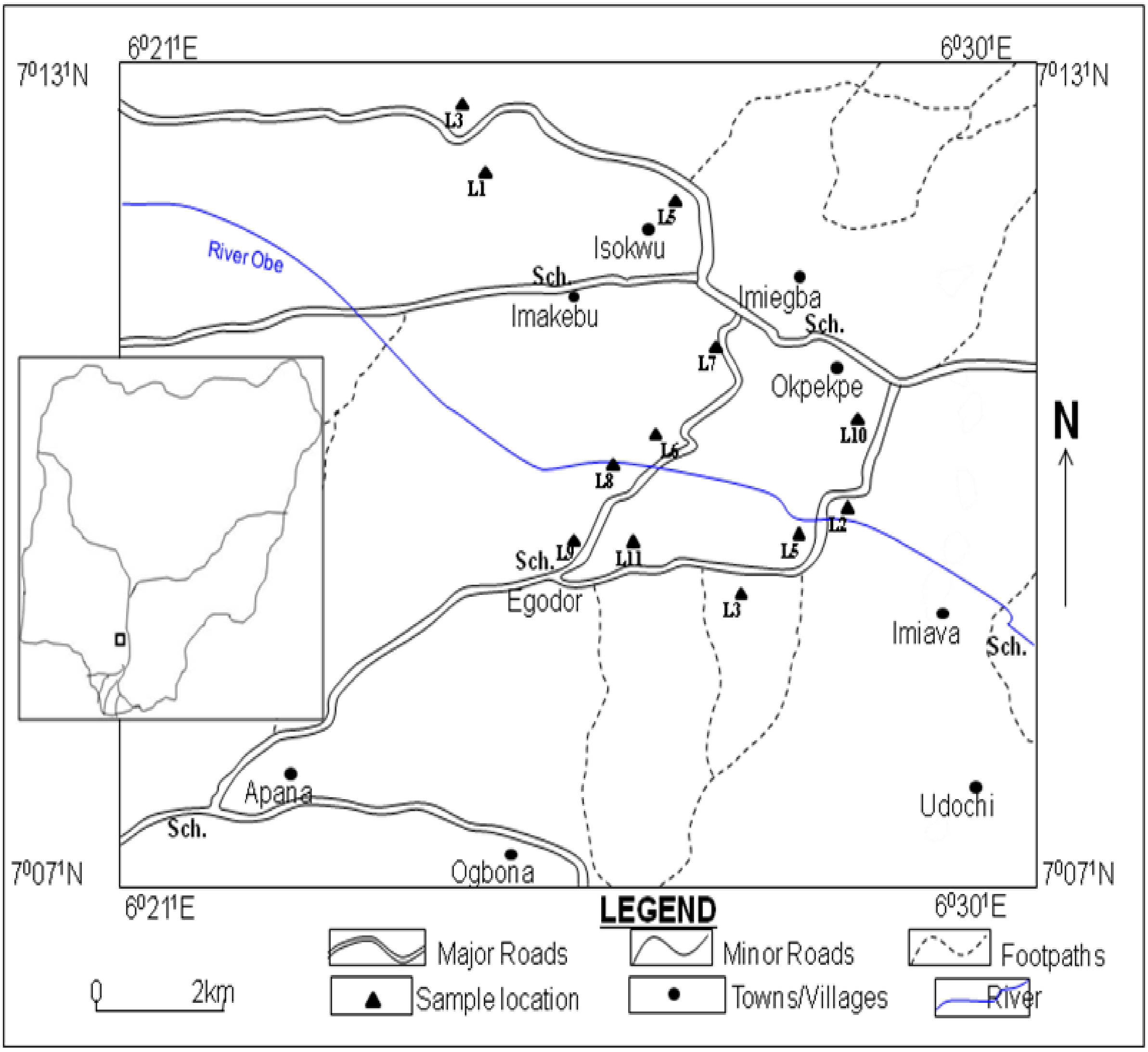


Figure 2. Location map of the Okpekpe, Imiegba, Egodor and surrounding areas.

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	Imo Formation
		Nsukka Formation	Nsukka Formation
73	Maastrichtian	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation
	Campanian	Npkoro Oweli Formation/Enugu Shale	Nkporo Shale/ Afikpo Sandstone
83 87.5	Santonian	Agbani Sandstone/Awgu Shale	Non-deposition/erosion
88.5	Coniacian	Agbani Sandstone/Awgu Shale	Non-deposition/erosion
	Turonian	Eze Aku Group	Eze Aku Group (incl. Amasiri Sandstone)
93 100	Cenomanian – Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Units	
	Precambrian	Basement Complex	

Figure 3. Stratigraphy of the Anambra Basin (After Oboh-Ikuenobe et al., 2005).

East of the Niger, the Maastrichtian is reported to encompass deltaic deposits - Mamu, Ajali and Nsukka Formations (Short and Stäuble, 1967); while the Paleogene is represented by the Imo Formation, Ameki Group and Ogwashi-Asaba Formation (Figure 3). Although the Nsukka Formation is depicted by fluvio-deltaic sediments deposited towards the end of the Maastrichtian and continued into the Paleocene (Obi et al., 2001). The marine influence was said to be restricted to the lower part of the Mamu Formation and reduced steadily at higher levels (Reyment, 1965). The third cycle (Late Eocene to Pliocene) was a regressive phase that marked the development of the proto-Niger Delta.

MATERIALS AND METHODS

The recent exposures of sedimentary successions in the study area (Figure 2) were studied in detail during a geological field mapping exercise in February, 2015. Sedimentological and ichnological characteristics (such as lithology, thickness, composition, texture, bedding characteristics, sedimentary structures, nature of contacts, trace and body fossils and post-depositional features) of the sedimentary facies were obtained, as well as their spatio-temporal distribution and variability. Analysis of facies associations that included the description of depositional processes and their environment was done. The lithofacies and the inferred lithofacies associations were compared to that of the Mamu Formation as earlier described by the authors. This comparative analysis assisted in the explanation of sedimentological and ichnological characteristics observed in the exposed sections; and in relating them to the Mamu Formation that is reported to have terminated at Idah which is about 35 km southeast of the study area (Figure 1).

RESULTS AND DISCUSSION

Lithofacies and Ichnofacies

Eight lithologic sections of road cuts were logged and summarized into four (Table 1). Five lithofacies [Gray shales, very fine to fine grained sandstones, mudstones (siltstones and claystones), the heteroliths, and a localized coal] (Figure 4) were identified and grouped into three lithofacies associations that are genetically related to their sedimentary environment(s) of deposition. Also, the ichnogenus *Thalassinoides* and burrows suspected to be that of *Ophiomorpha* were identified in some sections (Figure 5). The tops of all the logged sections are lateritized, thereby obliterating the syn-sedimentary structures.

Lithofacies associations

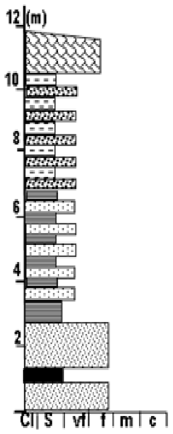
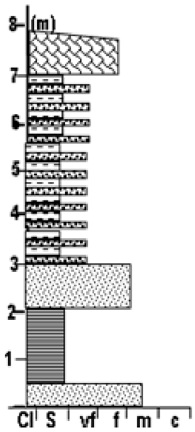
The lithofacies associations identified in relation to their environment of deposition are: (i) shales with intercalated siltstones and sandstones of intertidal flat/lagoon lithofacies association, (ii) the coal swamp/marsh lithofacies association, and (iii) the heterolithic tidal lithofacies association (Figure 4).

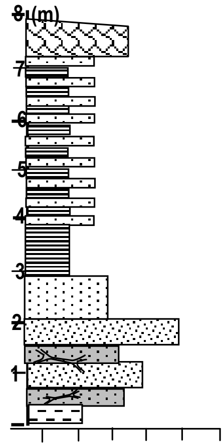
Shales intercalated with siltstones and sandstones of intertidal flat/lagoon lithofacies association

Description: The shale facies are light to dark gray in colour with well-defined fissility and carbonaceous streaks/fragments that are visible on the parting surfaces (Figure 4B and D).

Upper and lower contact relationships are usually sharp to gradational. They vary greatly in thickness from very thickly bedded (1 to 2 m) to thickly bedded (30 to 100 cm) to medium bedded (10 to 30 cm) to thinly bedded (3 to 30 cm). In

Table 1. Lithologic logs and interpretations of sections from Okpekpe, Imiegba, Egodor and surrounding areas.

	Logged section 2: Egodor-Imiegba road			
	Lateritic cap. Sed. Structures obliterated.	Absent		
	Mud-dominated heterolithic sandstone and siltstone facies. Same as logged section 1.	Rare	Mudstone and sandstone heterolithic tidal lithofacies association	Lower to middle shoreface
	Shale-dominated (>50%) heterolithic facies. Gray, fissile shale interlaminated with very fine sandstone. Sharp contacts.	Rare	Shale and sandstone heterolithic tidal lithofacies	Mixed tidal flat
	Localized coal intercalated within underlying and overlying fine sandstones & siltstone facies.	Rare	Coal swamp/marsh lithofacies	Lagoon Marsh/swamp
	Logged section 3: Egodor-Okpekpe road			
	Lateritic cap. Sed. Structures obliterated.	Absent		
	Mud-dominated (>50%) heterolithic with white coloured fine sandstone and siltstone facies, about 8m thick. Wave-rippled and thickly laminated. Sharp to gradational upper and lower contacts.	Rare	Mudstone and sandstone heterolithic tidal lithofacies	Lower to middle shoreface
	Fine, indurated sandstone facies	Absent	Shale intercalated with siltstone and sandstone of intertidal flat/lagoon lithofacies	Lagoon/ Intertidal flat
	Gay, fissile shale facies. Sharp to gradational upper and lower contacts.	Rare		
	Siltstone facies. Sharp upper contact.	Rare		



Logged section 4: Egodor-Okpekpe road	Absent		
Lateritic cap. Sed. Structures obliterated.			
Shale-dominated (>50%) heterolith facies. Same as in logged section 2.	Rare	Shale and sandstone heterolithic tidal lithofacies	Mixed tidal flat
Gray shale facies. Same as logged section3	Moderate to high bioturbation with *Thalassinoides* burrows	Shale intercalated with siltstone and sandstone of intertidal flat/lagoon lithofacies	Lagoon/ Intertidal flat
Fine sandstone, horizontal & medium bedded and siltstone facies. Sharp to gradational upper and lower contacts.			

Figure 4. Lithofacies and Lithofacies Associations of Okpekpe and Imiegba areas: (A) Mudstone and sandstone heterolith tidal lithofacies association (B) Sandstone and shale heterolith tidal lithofacies association (C) Coal swamp/marsh lithofacies association (D) Shales intercalated with siltstones and sandstones of intertidal flat/lagoon lithofacies association.

some localities, they are interlaminated with very fine sandstones and siltstones. Body fossils and bioturbations are rare.

The siltstone facies are light coloured, thinly bedded (3 to 30 cm), horizontal and highly indurated. They usually occur at the middle of the logged section between the gray shale facies at the base and the sandstone facies at the top. Bioturbations are present in some of them, especially at the upper and lower sharp to gradational contacts.

The sandstone facies are mostly light coloured, very fine to fine grained (although a few are medium grained), well sorted, texturally

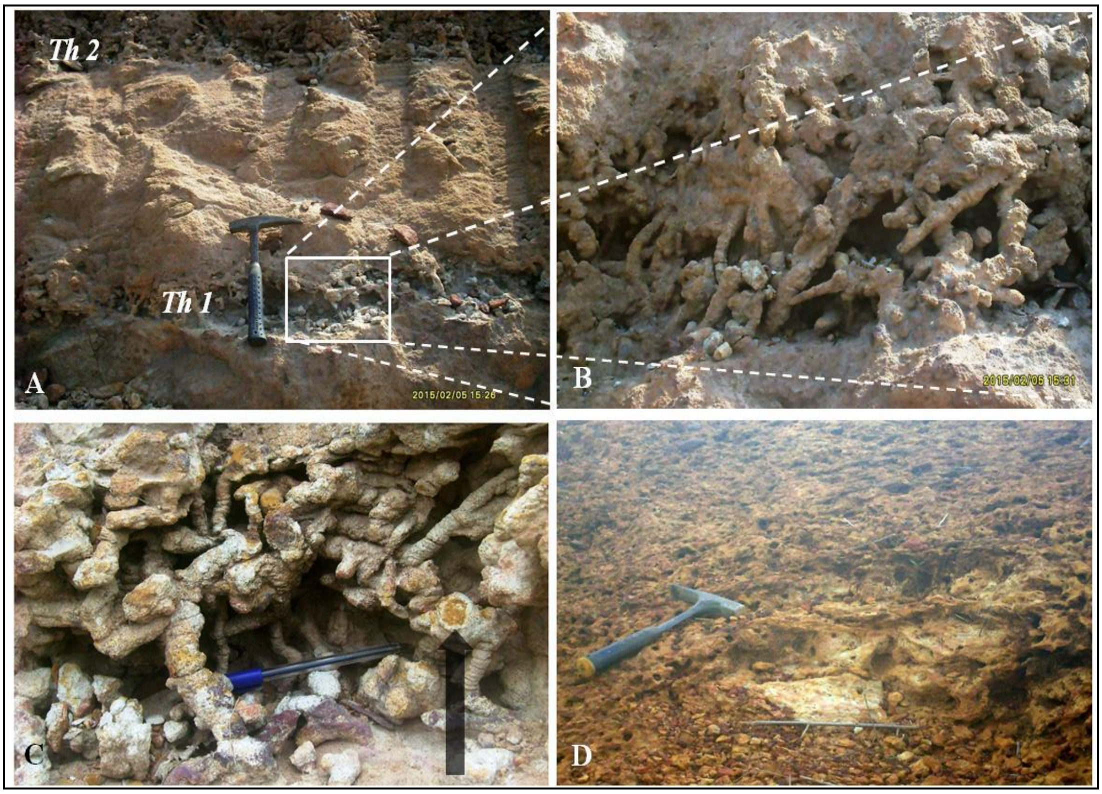


Figure 5. Ichnogenus from Okpekpe and Egodor areas: (A) Thalassinoides layers Th1 and Th2 (B) Close-up view of Thalassinoides paradoxicus (C) Filled Thalassinoides burrow (black arrow head) (D) Ophiomorpha-like burrows.

mature (little or no clay) and highly indurated. They are also thickly bedded (30 to 100 cm) to medium bedded (10 to 30 cm) to thinly bedded (3 to 30 cm) and are spatially persistent for several metres especially along the *Egodor* – *Okpekpe* and *Egodor-Imiegba* roads. This lithofacies occurs mostly in the lower part of the logged sections and occasionally interbedded with siltstones.

Interpretation: The shale intercalated with siltstone and sandstone facies association is interpreted to be of intertidal flat/lagoon environment in line with the model proposed by Walker and Plint (1992) and Nwajide and Reijers (1996). The thin parallel and horizontal laminations exhibited by the gray shale lacking reactivation surfaces depict suspension sediment fallout (Donselaar and Geel, 2007). The rare occurrence of ichnofacies is an indication of stressed environment with brackish and fresh water inputs (Postma, 1982; Buatois et al., 1999). On these bases, this lithofacies association can be said to be deposited as suspension sediments during a periodic low energy conditions in a restricted tidal to lagoonal settings under a moderate bathymetric profile (Table 1).

Coal swamp/marsh lithofacies association

Description: A localized coal seam (<0.3 m) was observed along *Egodor - Imiegba* road shortly after the bridge towards *Imiegba* (Figure 4C). This black coal facies is underlain and overlain by siltstone and very fine, highly indurated sandstone, respectively. The siltstone served as the substrate for the development/growth of the coal swamp and the coalification process.

Interpretation: The coal facies developed through the processes of deposition, accumulation, burial and coalification of peat under a swamp or marsh environmental conditions. Anoxia may have also been established for the organic matter to be preserved under rapid burial. These assumptions are based on the high organic matter content (noticeable from the black colour usually associated with carbon black), laminated, and compacted nature of this coaliferous facies. Within this logged section, shale facies also occurred above the overlying very fine sandstone, indicating a possible development of proximal to marine or mixed marine conditions.

Heterolithic tidal lithofacies association

Description: The thinly bedded/laminated heterolithic tidal lithofacies association is of two types namely: (i) shale and sandstone heterolith, and (ii) mudstone and sandstone heterolith (Figure 4A and B). Tidal processes are usually inferred from heteroliths based on the presence of mud drapes, laminations, reactivation surfaces, and cyclic bundles (Nio and Yang, 1991).

Shale and sandstone heterolith

Description: This lithofacies association is a shale-dominated heterolithic succession with more than 50% shales. It is about 4 m thick and laterally extensive along the *Egodor-Imiegba* and *Egodor-Okpekpe* roads. It dominates the lower and middle part of the logged sections. The sandstones are light coloured, very fine grained and well sorted; while the shales are dark grey, exhibiting ripple laminations (Figure 4B).

Interpretation: The shale and sandstone heterolith is of sub-tidal/coastal or mixed tidal flat settings based on the presence of shale drapes, laminations and cyclic bundles (Nio and Yang, 1991). The lack of reactivation surface and the thin horizontal laminations indicated sediment fallout devoid of traction current. Tidal flats are often protected from wave actions by barrier islands, sand bars or sheltered bays leading to the deposition of shales, mud (clay and silts) and very fine sands; the origin of which is related to the alternation of tidal currents and slack water (Reineck, 1972).

Mudstone and sandstone heterolith

Description: This lithofacies association is a mud-dominated heterolithic succession with greater than 50% mud (silt and clay). It dominates the upper parts of the logged sections, about 6 to 8 m thick, and quite extensive (Figures 4 and 5A). This heterolith is typified by whitish-grey, very fine and well sorted sandstone. The siltstones are whitish and wave ripple laminated traceable spatially for several metres; while the light coloured sandstones are very fine grained and laminated.

Interpretation: This heterolithic lithofacies association is interpreted to be typical of tidal setting likely in lower to middle shoreface sub-environment. In this setting fluctuations in energy levels is capable of transporting sands during strong currents, but when still conditions set in, suspended mud (silt and clay) is deposited, draping the earlier deposited sands. The interlaminations of very fine sands and mudstones are common features where there is mean low-tide level to the fair weather base (Reijers, 1996) corresponding to the lower to middle shoreface sub-environment.

Systematic description of the ichnofossils

The ichnogenus *Thalassinoides* Ehrenberg (1944) (Figure 5A and B) and intense burrowing in the upper part of one of the sections believed to be that of *Ophiomorpha* (Figure 5D) were identified in the study area. These trace fossils belong to the Cruziana ichnofacies. The occurrence of the suspected *Ophiomorpha* burrows was not extensive; as such a very detailed description of this genus is not presented here. The *Ophiomorpha* burrows found along *Egodor-Imiegba* road are of high intensity making the sediments almost completely bioturbated with mottlings. At this level of intense bioturbation (grade 4, 61 to 90% bioturbated) bedding planes are indistinct, with trace density overlap (Taylor and Goldring, 1993).

Ichnogenus *Thalassinoides* (Ehrenberg, 1944)
Ichnospecies: *Thalassinoides Paradoxicus* Rieth, 1932 (Figure 5A and B)

Description: They are smooth walled cylindrical Y to T shaped trace fossils, displaying vertical and irregularly branched burrow system with common dichotomous bifurcation. Most of the burrow networks are filled with homogenous light to dark clay material. *Thalassinoides suevicus* mostly occurred in the interface between the underlying siltstone and overlying sandstone

Thickness/Diameter: Along bedding plane, thickness of the *Thalassinoides* layer is about 15 cm and extending for over 400 m along the *Egodor-Okpekpe* road before the bridge. Two bedding planes with associated *Thalassinoides* burrows are clearly visible in this area. The cylinders and shafts are 1 to 2 cm in diameter and 10 to 15 cm long.

DISCUSSION

Environmental and palaeo-environmental distribution

Present day burrows of *Ophiomorpha* and *Thalassinoides* are mostly found in intertidal flats and marginal marine environments (for example, salt marshes) (Howard and Frey, 1975; Letzsch and Frey, 1980; Myrow, 1995), although their distribution in deep marine settings has been grossly under studied due to logistics. However, in terms of their palaeo environmental distribution *Thalassinoides* ranged from tidal flats (Curran and Frey, 1977; Belt et al., 1983; Miller and Knox, 1985) to shoreline settings and outer shelf facies (Ekdale et al., 1984; Ekdale and Broomely, 1984). The interpretation of *Ophiomorpha* and *Thalassinoides* ichnofacies from the study area are indications of intertidal flats and marginal margin settings that is also closely related to the lithofacies associations aforementioned. There is a clear indication of the interplay between the lithofacies and ichnofacies, as part of the facies defining parameters.

Conclusions

The sedimentary successions of the Anambra basin recently exposed in the western flank that were mapped indicate shale intercalated with siltstone and sandstone, coal and heteroliths. Facies analysis revealed three lithofacies associations: (i) shales with intercalated siltstones and sandstones of intertidal flat/lagoon lithofacies association, (ii) the coal swamp/marsh lithofacies association, and (iii) the heterolithic tidal lithofacies association that are closely related to their depositional environments. Also, the ichnogenus *Thalassinoides* and burrows believed to be that of *Ophiomorpha* were observed and interpreted to be of intertidal flats and other marginal marine sub-environments.

From the foregoing, with due consideration to the field based facies attributes and parameters studied (lithology, fossils, sedimentary structures, and other sedimento-logical characteristics), the sedimentary successions exposed at Okpekpe, Imiegba, Egodor and surrounding areas are closely related to the Mamu Formation. This view based on recent exposures of the formation in the study area is in sharp contrast to what was hitherto agreed that it was part of the Ajali. Also, considering the proximity of the study area to where the Ajali Formation is well exposed, it can be said conclusively that this study was done in a transition or contact zone between these formations. This research also highlights the fact that the current knowledge of the geology of a particular place is strongly dependent on the availability of both surface and subsurface data set that largely guides making definitive descriptions.

Conflict of interest

The author has not declared any conflict of interest

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