The Paleoenvironmental Significance of Trace Fossils from the Paleocene Imo Formation, South-eastern Nigeria

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Abstract
Trace fossils and lithofacies associations were studied to understand the paleodepositional environment of the Paleocene Imo Formation. The methodology involves lithologic logging to obtain sedimentological and ichnological data. Bioturbation index were used to estimate the intensity of biotubation of the various lithofacies associations. The trace fossils observed in the Imo Formation includes *Ophiomorpha and Altichnus* belonging to the *Skolithos* ichnofacies and *Chondrites*, *Thalassinoides*, *Planolites*, and *Rosselia* which belongs to the *Cruziana* ichnofacies. Six lithofacies association were distinguished and interpreted as follows; swaly cross-stratified sandstone represents a middle shoreface environment, laminated shale representing offshore to lower shoreface transition sediments, interbedded sandstone and shale as well as bioturbated sandstone deposited in upper shoreface environments, fossiliferous shale representing an upper offshore deposit while crossbedded sandstone is inferred to as foreshore-upper shoreface sediments. The gross depositional environment suggests sediments deposited in shallow marine environments lying between the foreshore-shoreface to offshore depositional settings.
Keywords: Trace fossils, Ichnofossils, Lithofacies, Imo Formation, Niger Delta Basin

1 Introduction

The Imo Formation refers to a formation which was previously known as “Imo Rivers shales”[Tattam, 1944] or the “Clay-shales” [Groove, 1951; Simpson, 1954 and Reyment and Barber, 1956]. However, Reyment [1965] formalized the name as Imo Shale with its type locality at the outcrops along the Imo River, in southeastern Nigeria. The formation is approximately 1000m in thickness [Reyment, 1965]. It consists of three different sandstone members, Ebenebe Sandstone, Umuna Sandstone and Igbaku Sandstone. These sandstone members of the Imo Formation, which outcrop up dip in the northern fringes of the Niger Delta, has been regarded as the outcrop equivalent of the Akata Formation [Short and Stauble, 1967; Avbovbo,1978], and is the main hydrocarbon source rock in the Niger Delta.

Several palynological, lithological and stratigraphic based paleoenvironmental studies have been done for the Imo Formation. These previous studies include the works of Anyanwu and Arua [1990], Nwajide and Reijers [1996], Oboh-ikuonobe et al [2006], Odumodu and Nfor [2014] and Ekwenye et al [2014]. Previous studies that utilized ichnological data in facies analysis and paleoenvironmental reconstruction for the Imo Formation is very few [Anyanwu and Arua, 1990]. Pemberton et al [1992], Ekdale et al [1984] and Bromley [1996] outlined the usefulness of trace fossils in paleoenvironmental reconstruction. The sandstone member of the Imo Formation as exposed in the vicinity of Ndiwo, Ikporom and environs contains abundant tracefossils that will be useful for this purpose. The study area is situated around Ndiwo and Ikporom, located respectively at Akwa Ibom and Abia State (Fig. 1). The purpose of this paper is to describe the morphology, mode of occurrence of trace fossils from the Imo Formation studied around Ndiwo and Ikporom and interpret their paleoenvironmental significance using some evidence deduced from lithofacies analysis and trace fossil assemblages.

2. Method of study

Outcrops of the Paleocene Imo Formation situated along Ikporom – Ndiwo road were systematically logged. Its lithology, stratal contacts, physical and biogenic sedimentary structures were equally observed. The ichnofossils were described and classified into various ichnogenera, ethological classes and ichnofacies associations using methods described by Seilacher [1964] and adapted by Mode [1997], Odumodu and Mode [2014] and Mode and Odumodu [2015]. Measurement of bioturbation intensity (B.I.) follows the scheme of Droser and Bottjer [1986, 1989] and Bottjer and Droser [1991]. Bioturbation intensity (B.I.) refers to the semi-qualitative determination of the extent of bioturbation or the degree to which the original physical sedimentary structures have been disrupted by biogenic reworking [Droser and Bottjer, 1986]. B.I. categorizes the extent of bioturbation into six classes; 1 (no bioturbation), 2(less than 10%), 3 (10 – 40 %), 4 (40-60%), 5 (60 – 100 %) and 6 (complete homogenization).

Table 1: Stratigraphic units in the Niger Delta (Short and Stauble, 1967; Avbovbo, 1978)

Age	Surface	Subsurface Niger Delta
Miocene - Recent	Benin Formation	Benin Formation
U. Eocene - Oligocene	Ogwashi – Asaba Formation	Upper Agbada Formation
Middle – Lower Eocene	Nanka Formation / Ameki Formation	Agbada Formation
Paleocene	Imo Formation	Akata Formation

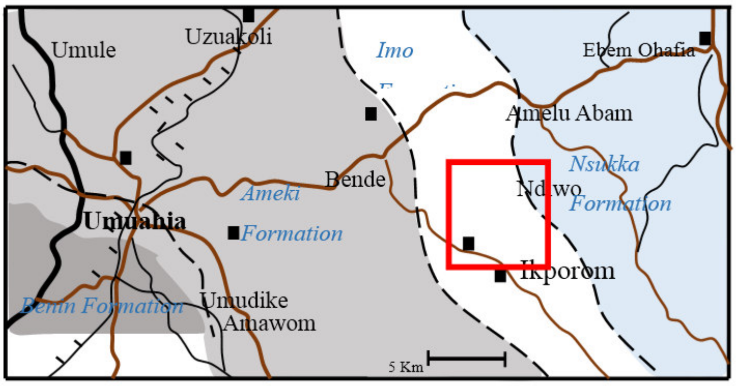

Fig. 1: Geologic map showing accessibility to the study area

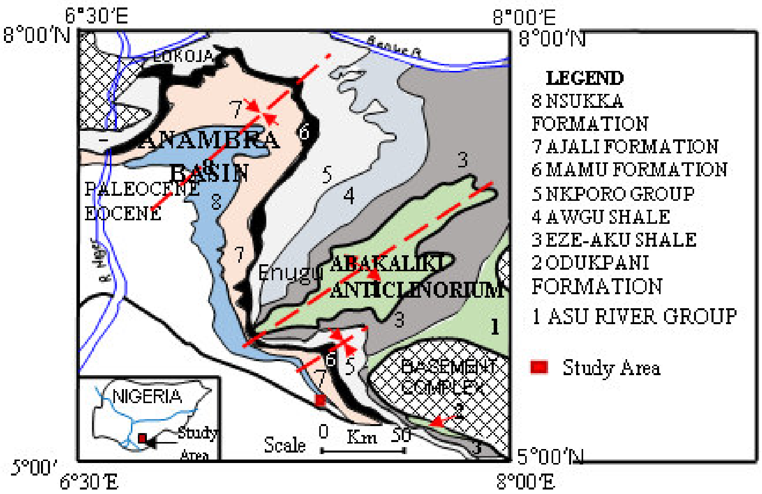

Figure 2: Geologic map of south-eastern Nigeria showing the study area.

Results

Facies Associations

The Imo Formation can be subdivided into six facies associations based on sedimentological and ichnological criteria (Table 2, Figure 3). These facies associations represent deposition in a variety of shallow marine environments from foreshore through shoreface to offshore water depths.

Swaly cross-stratified sandstone – Middle shoreface

Description

The swaly cross-stratified sandstone facies association occurs in the basal part of the sequence. A thickness of about 8 m was observed in this facies association. Constituent lithofacies include bioturbated sandstone, swaly-cross stratified sandstone and planar crossbedded sandstone (Table 2, Figure 3).

The bioturbated sandstone is present in the basal part of the section. It is 1 m thick and consists of fine grained sandstone. Sedimentary structure present is mainly planar cross beds. This facies association is fairly bioturbated (B.I. =2-3). Ichnogenera observed is only *Ophiomorpha.*

The swaly cross-stratified sandstone overlies the bioturbated sandstone gradationally. It is 2 m in thickness and consists of medium grained sandstones. Sedimentary structures present are swaly cross-stratification and planar crossbeds. It is moderately bioturbated (B.I. = 3-4). Ichnogenera present includes *Ophiomorpha and Rosselia* issp.

The planar cross-bedded sandstone makes a sharp contact with underlying and overlying lithofacies. It is 5 m in thickness and consists of medium grained sandstones which are typically cross-bedded. It is fairly bioturbated (B.I. = 2). Ichnogenera present is only *Ophiomorpha* burrows.

Interpretation

The presence of planar crossbeds, swaly cross-strata and medium to coarse grained sandstones indicate that this facies association was deposited in energetic middle shoreface water depths. Swaly cross-stratification were interpreted by Walker and Plint [1992] as a feature of prograding storm-dominated shorefaces, in which storm processes have obliterated all records of fair weather sedimentation. The presence of *Skolithos* ichnofacies represented by *Ophiomorpha nodosa* and *Cruziana* ichnofacies represented by *Rosselia* is consistent with a middle shoreface interpretation. The scarcity or low diversity of ichnofossils in this facies association suggests high sedimentation rates, an increase in storm activity and other factors that make conditions unfavourable for invertebrate activity.

Facies Associations	Common lithofacies and sedimentary structures	Fossils / Trace fossils	Depositional Environment
Swaly cross-stratified sandstone	Bioturbated sandstone, swaly cross-stratified sandstone and Planar crossbedded sandstone	Fairly bioturbated; *Ophiomorpha* and *Rosselia*	Middle shoreface
Laminated siltstone-shale	Siltstone-shale heterolith and shale. Horizontal parallel lamination,	Contains microforms of bivalves and gastropods	Offshore transition
Interbedded sandstone and shale	Bioturbated sandstone (low angle crossbeds), wave ripple laminated sandstone, trough crossbedded sandstone, laminated shale and massive pebbly beds.	Bioturbation moderate in bioturbated sandstone; *Ophiomorpha* and *Chondrites*. Bioturbation weak or absent in other facies	Upper shoreface
Bioturbated sandstone	Bioturbated sandstone (Planar crossbeds), wave ripple laminated sandstone, bioturbated fine grained sandstone (high angle planar crossbeds)	Bioturbation fairly moderate to intense in bioturbated facies; *Ophiomorpha*, *Chondrites and Altichnus*. Bioturbation absent in wave ripple laminated facies.	Upper shoreface
Fossiliferous shale	Bioturbated sandstone, sandstone-shale heterolith, laminated shale, fossiliferous mudstone and shelly beds	Bioturbation is moderate to intense; *Ophiomorpha, Chondrites*, *Thalassinoides* and *Planolites.* Bioturbation is absent in laminated shale facies and shelly beds.	Upper offshore
Planar crossbedded sandstone	Wave ripple laminated sandstone, Planar crossbedded sandstone	Bioturbation is moderately high in planar crossbedded sandstone but absent in the rippled sandstone; *Ophiomorpha* and *Chondrites*	Foreshore-Upper shoreface

Laminated siltstone-shale facies association – Offshore Transition

Description

The laminated siltstone– shale facies association overlies the swaly cross-stratified sandstone facies association. A thickness of about 4.3 m was observed for this facies association. Constituent lithofacies include the siltstone-shale heterolith and the laminated shale facies (Table 2, Figure 3).

The siltstone-shale heterolith is 1.8 m thick, dark grey in colour and horizontally parallel laminated. Bioturbation is absent or rare (B.I. = 1). It has a gradational contact with overlying facies.

The laminated shale facies is 2.5 m thick, dark grey in colour and parallel laminated. Sedimentary structure present is horizontal parallel lamination. Bioturbation is weak or absent (B.I. = 1). The shale is composed of microforms of bivalves and gastropods.

Interpretation

The presence of bivalves and gastropods suggests a quiet water depositional setting whereas the presence or scarcity of bioturbation in this facies association suggests some unfavourable conditions for persistent invertebrate activity during the deposition of the sediments. The heterolithic character of this facies association suggests marked variations in physical energy, under a storm influenced, fluctuating high and low energy setting, lying between the offshore and lower shoreface. This facies association is interpreted as an offshore transitional deposit.

Interbedded sandstone and shale facies association – Upper shoreface

Description

The interbedded sandstone and shale facies association overlies the laminated shale facies association. Constituent lithofacies include bioturbated fine grained sandstone, wave ripple laminated sandstone, trough crossbedded sandstone, laminated shale and pebbly sandstone. This facies association has an observed thickness of about 7.4 m.

The bioturbated fine grained sandstone facies is about 4 m thick. It is the most abundant lithofacies in this facies association. Sedimentary structures present are low angle crossbeds. Bioturbation is moderate (B.I. = 3-4). Ichnogenera present includes Ophiomorpha nodosa and Chondrites isp. The bioturbated fine grained sandstone facies have sharp contacts with overlying and underlying lithofacies.

The wave ripple laminated sandstone sharply overlies the bioturbated fine grained sandstone facies. It is about 0.6 m in thickness. Sedimentary structure present is wave ripple lamination. Bioturbation is absent (B.I. = 1).

The trough crossbedded sandstone facies consist of fine grained sandstones with sharp contacts with overlying and underlying facies. Its thickness is about 0.3 m. Sedimentary structure present is trough crossbeds. Bioturbation is rare or absent (B.I. = 1).

Overlying the trough crossbedded sandstone facies is the laminated shale facies, which is about 1.7 m in thickness. Sedimentary structure present is only parallel lamination. Bioturbation is absent (B.I. = 1).

The pebbly sandstone facies is the topmost lithofacies present in this facies association and is about 0.8 m in thickness. The sandstones are coarse grained to pebbly and poorly sorted. The beds are massive. Bioturbation is absent (B.I. = 1).

Interpretation

The presence of wave ripple lamination, low angle planar crossbeds, trough crossbeds and coarse grained pebbly sandstones suggests a high energy upper shoreface environment. The scarcity of bioturbation indicates rapid emplacement and conditions hostile to marine invertebrate activity.

Bioturbated coarse grained sandstone facies association – Upper shoreface

The bioturbated coarse grained sandstone facies association is present in the middle part of the section studied. Constituent lithofacies include bioturbated coarse-grained sandstone, wave ripple laminated sandstone, and bioturbated fine grained sandstone. The total thickness of this facies association is about 20.5 m.

The bioturbated coarse-grained sandstone is a very prominent lithofacies in this facies association. It is about 10 m in thickness. Sedimentary structure present is mainly planar crossbeds. Bioturbation is intense (B.I. = 5 - 6). Ichnogenera present include Ophiomorpha, Chondrites, and Altichnus. The bioturbated coarse-grained sandstone facies have sharp contact with overlying facies.

The wave ripple laminated sandstone facies consists of moderately sorted medium grained sandstones which is about 0.3 m in thickness. Bioturbation is absent (B.I. = 1). The wave ripple laminated sandstone facies have sharp contacts with overlying and underlying facies.

The bioturbated fine grained sandstone is the most abundant lithofacies in this facies association. Its thickness is approximately 10.1 m. Sedimentary structure present is typically high angle planar crossbeds. Bioturbation is fairly moderate (B.I. = 4). Ichnogenera present includes Ophiomorpha and Chondrites.

Interpretation

The presence of wave ripple lamination and high angle planar crossbeds in this lithofacies association indicates an energetic shallow marine environment that formed during fair-weather conditions in upper shoreface water depths. The presence of Skolithos ichnofacies represented by Ophiomorpha, Altichnus and Chondrites suggests a high energy upper shoreface environment of deposition.

Fossiliferous shale facies association – Upper offshore

Description

The fossiliferous shale facies association occurs in the upper part of the section studied. It is about 12 m in thickness. Constituent lithofacies include bioturbated fine grained sandstone, sandstone-shale heterolith, laminated shale, fossiliferous mudstone and shelly beds.

The bioturbated fine grained sandstone facies is the basal member of this facies association. It is 1.3 m in thickness and has sharp contacts with the overlying and underlying facies. Bioturbation is moderate (B.I. = 3). Ichnogenera present is Ophiomorpha and Chondrites. Two beds of the bioturbated sandstone are present in this facies association.

The sandstone-shale heterolith overlies the bioturbated fine grained sandstone facies. Its thickness is about 1.2 m. It has sharp contact with overlying and underlying facies. Sedimentary structure present is horizontal parallel lamination. Bioturbation is intense (B.I. = 5-6). Ichnogenera present includes Planolites, Thalassinoides and Ophiomorpha.

The laminated shale is the most prominent lithofacies in this facies association. It is about 3 m in thickness. Sedimentary structure present is horizontal parallel lamination. Bioturbation is absent (B.I. = 1). Two beds of laminated shale facies are present in this facies association.

The shelly beds gradationally overlie the laminated shale facies and consist of loose shells of the bivalves Ostrea. It is about 1 m in thickness. Bioturbation is absent (B.I. = 1).

The fossiliferous mudstone overlies the shelly beds. The fossiliferous mudstone is massive and has a thickness of about 1 m. It has sharp contacts with overlying and underlying facies. Bioturbation is moderate (B.I. = 3). Ichnogenera present is only Planolites.

Interpretation

The constituent lithofacies in this facies association which is made up of shales, fine grained sandstones and mudstones suggests deposition in an environment beyond the influence of most currents and waves. The diverse ichnofossil assemblage present which is dominated by deposit feeding structures or behaviours reminiscent of an archetypical Cruziana ichnofacies, and is suggestive of quiescent conditions in environments that lies between storm and fair-weather wave base. The vertical burrows of Ophiomorpha, which are the dwelling structures of suspension feeding organisms of the Skolithos ichnofacies, and are suggestive of an opportunistic colonization of the storm beds. This facies association is interpreted to reflect deposition in an upper offshore environment. The decreased level of bioturbation in some facies may suggest a combination of increased sedimentation rates, sporadic deposition, fluctuating salinity levels, periods of reduced oxygenation and soupy substrates.

Planar crossbedded sandstone facies association – Upper shoreface – foreshore

Description

The planar crossbedded sandstone facies association is the topmost facies association in the section studied. It has a thickness of about 21.5 m. Constituent lithofacies include wave ripple laminated sandstone – clay heterolith and planar crossbedded sandstone facies (Table 2, Figure).

The wave ripple laminated sandstone-clay heterolith is the basal facies in this facies association. It consists of a heterolith of very fine grained sandstone and clays which is about 3.5 m in thickness. Sedimentary structure present is wave ripple and parallel lamination. Bioturbation is absent (B.I. = 1).

The planar crossbedded sandstone is the most abundant lithofacies in this facies association. It consists of about 1.8 m thick fine grained to very fine grained sandstones. Sedimentary structures present is mainly high angle planar crossbeds. Bioturbation is moderately high (B.I. = 5). Ichnogenera present includes Ophiomorpha and Chondrites

Interpretation

The presence of planar crossbeds and wave ripple laminated heterolith in this facies association suggests a high energy shallow marine environment. The presence of Ophiomorpha nodosa and Chondrites isp corroborates this interpretation of an energetic shallow marine environment of deposition. Following McEarchern and Pemberton [1992], this facies association is interpreted as a wave-dominated foreshore to upper shoreface deposit

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Ethology

Ethology is the classification of trace fossils in terms of the behavioural patterns or activities of the organisms forming the trace. The fundamental behavioural patterns of trace fossils observed in sedimentary rocks as classified by Seilacher [1964]) include; domichnia (dwelling structures), repichnia (locomotion traces), cubichnia (resting or nesting traces), pasichnia (grazing trails) and fodinichnia (deposit feeding burrows). Additional categories of preservable behavioural patterns of organisms in sediments are fugichnia (escape traces), agrichnia (highly patterned burrows, which suggests farming activities) and praedichnia (predation traces).

The trace fossil assemblage in this study is categorized into two ethological groups; domichnia and fodinichnia (Table 3). Domichnia represents dwelling structures. These structures are made by sessile and semi-sessile endobenthic animals which are mainly suspension feeders, predators and scavengers. Fodinichnia are burrow systems produced by the combined activities of dwelling and feeding on the sediments. They suggest a systematic mining of sediment for food by endobenthic deposit feeders, which inhabit the burrows. Swaly cross stratified sandstone facies association is associated with dwelling burrows of suspension feeders (*Ophiomorpha* and *Rosselia*). No trace fossil were observed in laminated shale-siltstone facies association. The interbedded sandstone-shale facies association has both dwelling burrows (*Ophiomorpha*) and feeding burrows (*Chondrites*). The fossiliferous shale facies association consisting of siltstone shale heterolith contains fodinichnia burrows (*Planolites* and *Thalassinoides*) and the dwelling structures of *Ophiomorpha*. The Planar cross-bedded sandstone facies association which is the topmost facies association contains both dwelling (*Ophiomorpha*) and feeding (*Chondrites*) burrows

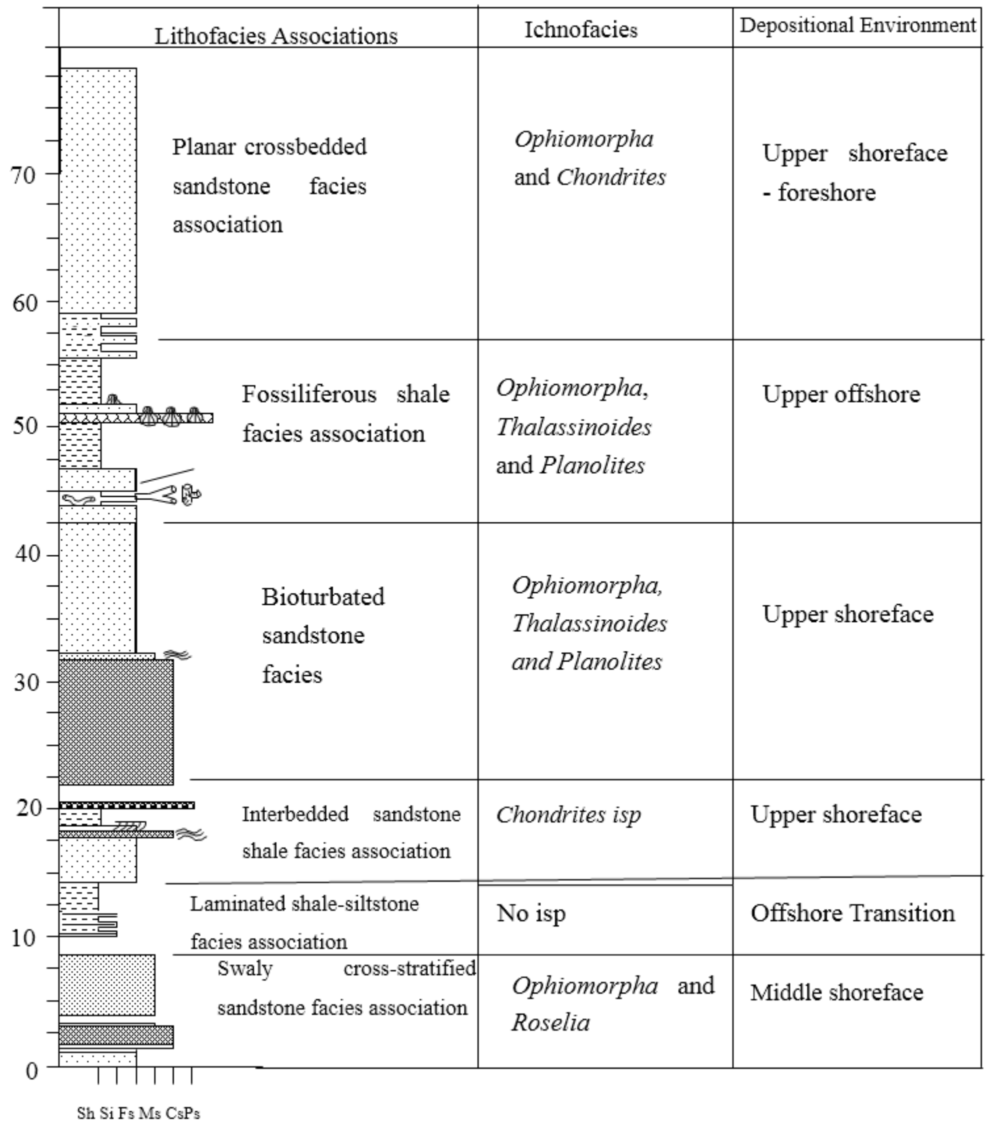

Fig. 3: Composite lithology of the Imo Formation along Ikporom-Ndiwo road showing the Lithofacies, ichnofacies and depositional environments

Table 3: Ethology of the trace fossils found in the Imo Formation and their interpreted primary impact on sediment fabric

Ichnofossil	Ethological interpretation
Ophiomorpha	Domichnia (sediment dweller)
Rosselia	Dominichnia (sediment dweller)
Thalassinoides	Fodinichnia (sediment processor)
Planolites	Fodinichnia (sediment processor)
Chondrites	Fodinichnia(sediment processor)

Systematic Ichnology

The trace fossils observed in the Imo Formation in the study area belong to six ichnogenera; *Ophiomorpha*, *Altichnus*, *Chondrites*, *Thalassinoides*, *Paleophycus*, *Planolites* and *Rosselia*.

Ichnogenus *Ophiomorpha* Lundgren 1891

Ophiomorpha nodosa Lundgren, 1891

Figs 4b, d & f.

Description: Ophiomorpha occurs as a three dimensional cylindrical vertical to slightly inclined burrow systems. It swells at points of bifurcation and possesses clayey and knobby walls. Interior wall lining of the burrow is smooth.

Remarks

Altichnus Bromley and Hanken 1991.

Altichnus isp
Fig. 4a.
Description; Altichnus consists of J-shaped curved burrows or funnel shaped tubes (straight to gently curved but clearly perpendicular to bedding plane in the upper part) or oblique to bedding plane. Diameter of the tube decreases from 10 – 30 mm at the opening to 2 – 4 mm in the deeper part. Additional wide variations in diameter are possible. Burrows are generally abundant throughout the whole bed, especially in the upper part. Maximum observed length (depth); 200 mm.
Remarks; these are probably a dwelling burrow of a suspension feeder. The burrows occur in sandstone. The burrow fill is mainly clayey shale or clay. The traces are unwalled and have diameters increasing upwards.
Ichnogenus *Chondrites* Von Sternberg 1833
Chondrites isp.
Figs 4d & f.
Description: *Chondrites* is a complex branching root like burrows with dendritic branching shafts and tunnels possessing diameters ranging from 2 – 4 mm. The maximum observed length of the burrow system is 20 mm. Angle of branching varies from 20° - 30°. Fill sediment is clay and differs from the host rock.
Remarks: *Chondrites* occur in association with *Ophiomorpha.* The complex tunnel system is probably a burrow of an unknown sediment feeder.
Ichnogenus *Planolites* Nicholson 1873
Planolites isp
Fig. 5a.
Description: *Planolites* are generally unbranched cylindrical or sub cylindrical infilled burrows, which are generally horizontal; they are straight to gently curved and commonly overlap one another.
Diameter; 0.3 – 1.2 cm, Length; 18 – 22 cm
Remarks: They are burrows constructed by deposit feeding animals
Ichnogenus *Thalassinoides* Ehrenberg, 1944.
Thalassinoides isp
Fig.5b.
Description: *Thalassinoides* are cylindrical burrows forming 3-D horizontal branching networks connected to the surface by vertical shafts; commonly shows swelling especially at points of branching.
Diameter; 1.5 – 2.5 cm, Length; 1.0 – 1.4 cm.
Remarks; they are feeding and dwelling burrows of crustaceans especially callianassid crustaceans.
Ichnogenus *Rosselia socialis*.
Rosselia isp
Fig. 4c.
Description: *Rosselia* is a conical-shaped sand filled burrow which turns horizontally downward. It may pass into other cones above or flatten into zones of *Planolites*. It can as well be described as concentric sand-clay laminae (commonly weathered) that taper downwards towards the central tube.

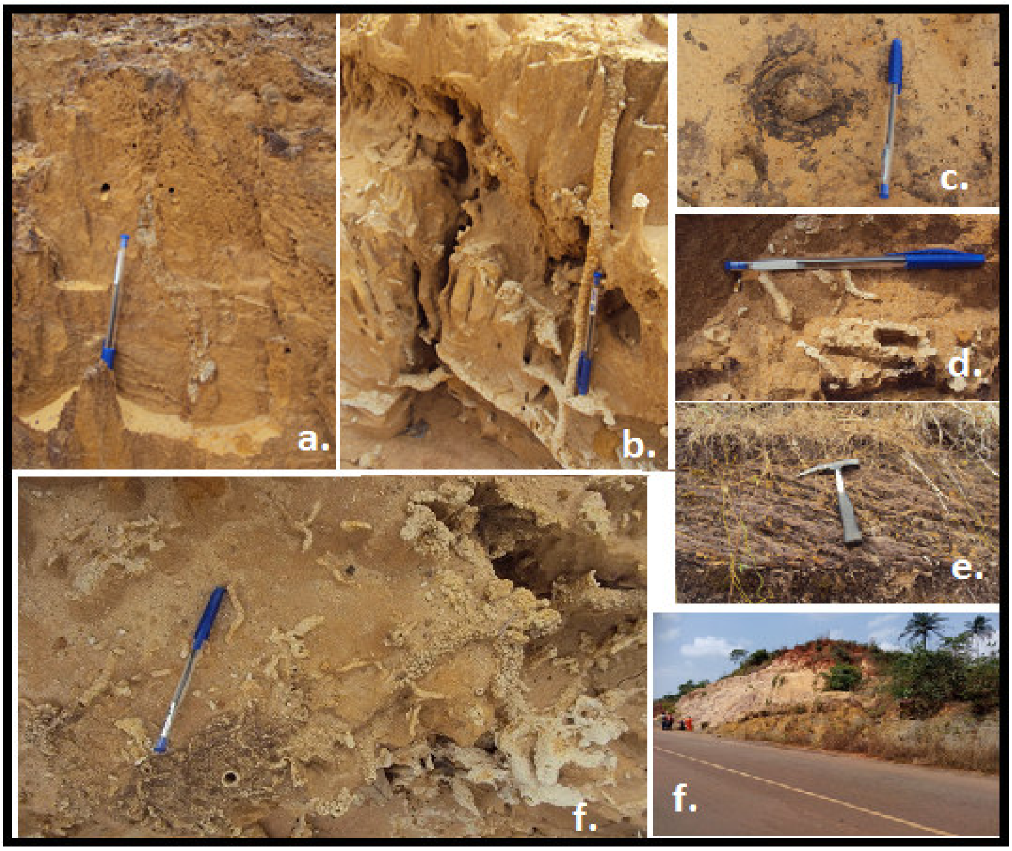

Fig. 4:Trace fossils from the Imo Formation: (a) *Altichnus* (b) *Ophiomorpha* (c) *Rosselia* (d & f) *Ophiomorpha* and *Chondrites* (e) planar cross beds (g)

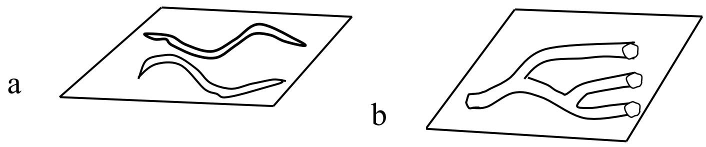

Fig. 5: A sketch of some trace fossils from the Imo Formation

DISCUSSION

The result of this study has shown that the sediments were deposited in shallow marine environments of foreshore-shoreface to upper offshore marine settings. Several complimentary and conflicting depositional environments have been interpreted for the Imo Formation. The variable interpretations may be due to the criteria used for the study, stratigraphic horizon being interpreted or the location of the study area. Complimentary interpretations adduced include the foreshore – shoreface setting of Nwajide and Reijers [1996], foreshore-shoreface to upper offshore setting given by Odumodu and Nfor [2014], and offshore –upper shoreface, tidally dominated shelf and lagoonal setting of Ekwenye et al [2014]. Contradictory interpretations include the delta front facies setting of Anyanwu and Arua [1990] as well as the estuarine lithic fill interpretation of Oboh-ikuenobe et al [2005].

Summary and Conclusion

This study has shown that the Imo Formation was deposited in a shallow marine setting, between foreshore – shoreface to offshore water depths by currents, waves and occasional storm activity. Six lithofacies associations have been observed. The trace fossil assemblage is of low diversity consisting of *Skolithos* ichnofacies (*Ophiomorpha nodosa*) and *Altichnus* issp) and *Cruziana* ichnofacies *Chondrites*, *Thalassinoides*, *Planolites* and *Rosselia*) traces. The distribution of the trace fossils in the sediments was influenced by the depositional energy, percentage of organic detritus present, oxygenation and salinity levels.

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