

## Research Article

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# Trace fossils from the campanian - maastrichtian enugu formation of the Anambra Basin, South-eastern Nigeria: implications for paleoenvironmental interpretation

## Abstract

Trace fossil assemblages and lithofacies associations of the Late Campanian-Lower Maastrichtian Enugu Formation studied at outcrops along Enugu-Onitsha expressway were described and their paleoenvironmental interpretations discussed. The ichnofauna in the Enugu Formation comprises of *Teichichnus rectus*, *Planolites* isp and *Thalassinoides* isp, all belonging to the Cruziana ichnofacies. All these trace fossil belong to the ethological class; fodinichnia (feeding burrows). The lithofacies include fossiliferous black shale (f1), bioturbated mudstones (f2), sandstone-siltstone heteroliths (f3), siltstone-shale heteroliths (f4), concretionary black shales (f5), ironstone concretionary beds (f6) wave ripple laminated fine grained sandstone (f7) and wave ripple laminated sandstone / shale heteroliths (f8). The bioturbation index of these lithofacies varies from 1 to 6. Four lithofacies association were distinguished and discussed as follows; fossiliferous black shale facies association represents an offshore marine environment. The heterolithic facies association suggests an offshore to lower shoreface transition. The concretionary black shale facies association is interpreted as a lower shoreface deposit. The wave ripple laminated fine grained sandstone represents middle to upper shoreface sediments. The gross depositional environment suggests an offshore marine environment with an occasional influx of middle to lower shoreface sediments.

**Keywords:** tracefossils, ichnofossils, lithofacies, enugu formation, Anambra basin

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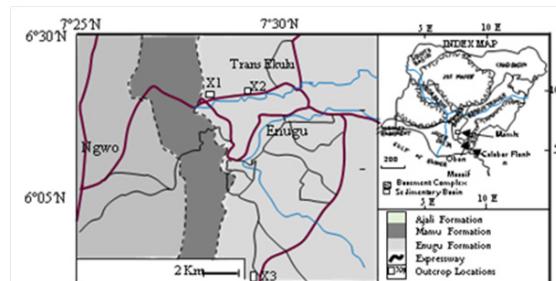
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## Introduction

The Enugu Formation is a member of the Nkporo Group, and forms part of the basal stratigraphic unit of the Anambra Basin in south-eastern Nigeria. The Enugu Formation has been the subject of many studies concerning stratigraphy,<sup>1</sup> depositional environments,<sup>2</sup> Onuigbo et al.,<sup>3</sup> organic geochemistry,<sup>4-6</sup> paleoecology,<sup>7</sup> palynology<sup>7-9</sup> and ichnology.<sup>10</sup> Nwajide & Reijers<sup>2</sup> were the first to document the presence of some ichnofossils such as *Planolites* and *Thalassinoides* in the formation, but did not give any detailed descriptions of the trace fossils. Onuigbo & Okoro<sup>10</sup> made the first attempt at describing the distribution and significance of the trace fossils in the Enugu Formation. They reported the presence of some trace fossils such as Skolithos and Chondrites in association with *Planolites*, *Thalassinoides* and *Teichichnus* at the road cut near the flyover located 200 m from the NNPC filling station at Enugu along the Onitsha – Enugu expressway. However, the ichnofossil assemblage present were not properly described and documented. Their paleoenvironmental interpretation did not consider the lithofacies association of the ichnofossils present. Taxonomic descriptions and paleoecologic interpretation were also lacking. The purpose of this study therefore, is to describe the morphology of the various trace fossils, describe their mode of occurrence and interpret their paleoenvironmental significance by integrating ichnological and lithofacies data. The study area is bounded by the longitudes 7°25'E to 7°30'E and latitudes 6°25'N and 6°30'N. The study is limited to two outcrops located at: 200 m from NNPC filling station and Trans Ekulu junction, both along Onitsha – Enugu expressway (Figure 1).

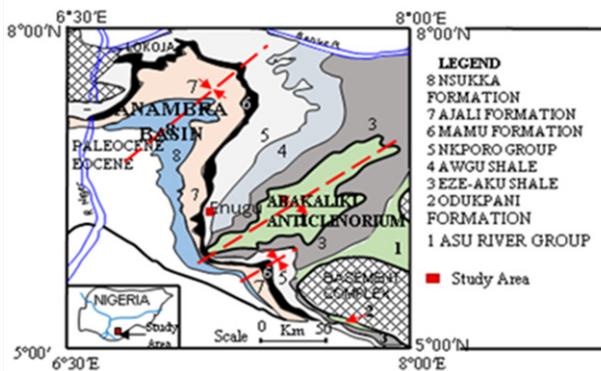


**Figure 1** Geologic map of the study area (Inset is a map showing sedimentary basins).

## Geological setting

The study area lies within the Anambra Basin, in south-eastern Nigeria (Figure 2). The Anambra Basin was initiated as a result of the uplift of the Abakaliki anticlinorium during the Santonian. This uplift led to the westward shift of the depocenter and subsidence of the Anambra Basin and the Afikpo sub-basin during the Campanian. The stratigraphic sequence in the Anambra Basin (Table 1) starts with the basal Nkporo Group which is made up of the following members; Nkporo Shale, Enugu Shale, Afikpo Sandstone, Owelli Sandstone and Otobi Sandstone. The Nkporo Group is successively overlain by the Mamu Formation, Ajali Formation, and Nsukka Formation. The age of these formations range from Campanian to Late Maastrichtian. The Nsukka Formation is overlain by the Paleocene Imo Formation

of the Niger Delta Basin. The Enugu Formation has been described by Rement [11] to consist of soft-greyish blue to black shale and mudstone with occasional beds of white sandstone and striped sandy shale.



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

## Materials and methods

Two road sections of the Enugu Formation located at about 200 m from the flyover after NNPC filling station and at Trans Ekulu junction, both along Onitsha – Enugu expressway were studied. The sections were logged systematically. Its lithology, stratal contacts, physical and biogenic sedimentary structures were observed and noted. The trace fossils were described and classified into various ichnogenera, ethological classes and ichnofacies associations using the method described by Seilacher,<sup>12</sup> Mode,<sup>13</sup> Odumodu & Mode<sup>14</sup> and Mode & Odumodu.<sup>15</sup> Measurement of bioturbation intensity (B.I.) in the field follows the scheme of Droser & Bottjer,<sup>16,17</sup> and Bottjer & Droser.<sup>18</sup> The bioturbation intensity or index (BI) is a semi-quantitative method of determining the extent or intensity of bioturbation. It is also based on the degree to which the original physical sedimentary structures have been disrupted by biogenic reworking Droser & Bottjer.<sup>16</sup> 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). The lithofacies were defined by integrating ichnological and lithologic data, which is also used to decipher the paleodepositional environment of the formation.

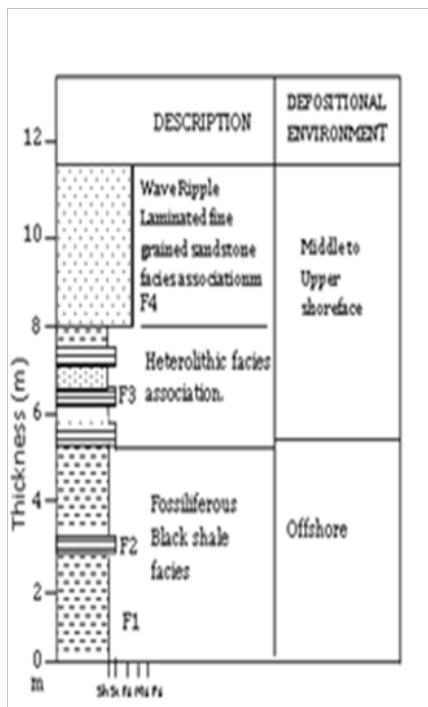
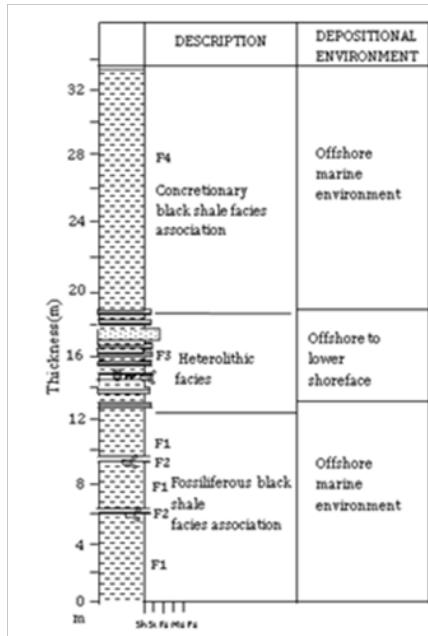
## Results and discussion

### Lithofacies association

The eight lithofacies recognised in the Enugu Formation were grouped into four lithofacies associations based on sedimentological and ichnological criteria (Table 2, Figure 3a & 3b),<sup>19,20</sup> These facies associations represent deposition in a variety of shallow marine environments from open marine (offshore) to shoreface water depths .

**Fossiliferous black shale facies association-Offshore marine environment:** This facies association occurs in the basal part of the sections. Constituent lithofacies include the fossiliferous black shale facies (f1) and the interbedded bioturbated mudstones / muddy siltstones facies (f2) (Table 2, Figure 3a & 3b). The fossiliferous black shale facies consists of parallel laminated dark grey shales interbedded with bands of siltstone and bioturbated mudstone. The shale contains some concretions that are gypsiferous, sideritic and pyritic. The shale is fossiliferous and contains microforms of gastropod. Burrowing is absent in the shale. Bioturbation index (BI) is 1. The bioturbated mudstones or muddy siltstone facies (f2) occur within the

fossiliferous black shale facies. It is parallel to wave ripple laminated. It contains *Thalassinoides* and *Planolites* burrows. Bioturbation index for this lithofacies is about 3-4.

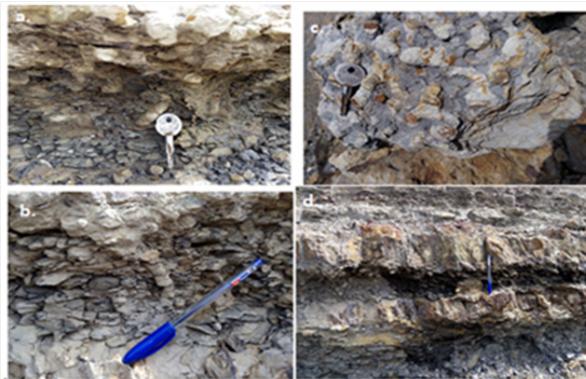


**Figure 3 a)** Litholog of Enugu formation near the first flyover at the Enugu end of the Onitsha-Enugu expressway.

**b)** Litholog of Enugu formation beside Trans- Enugu layout along Enugu end of the Onitsha-Enugu expressway.

**Interpretation:** The presence of marine invertebrate fossils suggests a quiet water open marine setting. The interbedded bioturbated mudstones and sandy siltstones are interpreted as storm beds that have been biogenically reworked by some organisms during fair-weather periods. The variations in bioturbation of the constituent

lithofacies suggests fluctuating environmental conditions influenced by such factors as salinity, sedimentation rates, substrate constituency, oxygen levels, food and light availability, heightened turbidity, etc. The fossiliferous black shale facies association is interpreted as an open marine offshore environment. Nwajide & Reijers<sup>2</sup> interpreted this lithofacies as an open marine setting because of the sideritic content of the shales. Ojo et al.,<sup>21</sup> and Kolawole<sup>22</sup> using the benthic foraminiferal contents such as Gavellinella, Planulina and Cibicides inferred a shelf environment for this lithofacies.



**Figure 4** Trace fossils from the Enugu Formation (a & b) *Teichichnus* and *Planolites* burrows (c) *Thalassinoides* burrows (d) fine sandstone-shale beds showing the Ichnofossils.

**Heterolithic facies association –offshore to lower shoreface transition:** The heterolithic facies association occurs above the fossiliferous black shale facies association. Constituent lithofacies include sandstone-shale (f3) and siltstone - shale (f4) heteroliths. The heterolithic facies association ranges from 3.8 to 6.0 m in thickness and has sharp contacts with the underlying and overlying facies associations. The heterolithic facies association is more intensely bioturbated (B.I.=4-6). Trace fossil diversity is low; observed ichnogenera include *Teichichnus*, *Thalassinoides* and *Planolites*. The sandstone–siltstone heterolith (f3) and siltstone – shale heterolith (f4) consists of an interbedding of very thin layers of fine grained sandstone, siltstone and shale. The thickness of the beds varies from 0.1 to 0.3 cm. Sedimentary structures present include parallel and wave ripple lamination. The sandstone and siltstone beds contain *Thalassinoides* and *Planolites* burrows while *Teichichnus* burrows are found within the interbedded shales. Bioturbation intensity (B.I.) varies from 3-6.

**Interpretation:** The heterolithic facies association is interpreted as a transitional zone between the offshore and the lower shoreface. The abundance of burrows such as *Thalassinoides*, *Planolites* and *Teichichnus* suggests deposition under quiescent conditions in the lower shoreface environment, between storm and fair-weather wave base. The thin interbedded units of fine sandstone, siltstones and shales are interpreted as an alternating high and low energy conditions. The thin beds of sandstone represent storm events in the offshore – lower shoreface transition environment.

**Concretionary black shale facies association–lower shoreface:** The concretionary black shale facies association occurs in the upper part of the section above the heterolithic facies association. It consists of the concretionary black shale facies (f5) and the abundant ironstone concretionary beds (f6). This lithofacies association has a thickness of about 15m and makes a sharp contact with the underlying facies association. The Concretionary black shale facies (f5) consists of parallel laminated dark grey to black shales with abundant ironstone

concretionary horizons. This lithofacies is intensely sheared and weathered. No trace fossils were observed in this lithofacies. The concretionary black shale facies association are typically not bioturbated (B.I.=1). The ironstone concretionary beds (f6) are interbedded with the concretionary black shales and have a thickness that ranges from 0.1 to 0.4 cm.

**Interpretation:** The concretionary black shale facies (F4) suggests deposition under quiescent conditions in the lower shoreface environment lying between storm and fair-weather wave base. Wave ripple laminated fine grained sandstone facies association – **Middle to Upper Shoreface**. The wave rippled fine grained facies association occurs in the upper part of the section (Figure 3b) studied and makes a sharp contact with the heterolithic facies association. Constituent lithofacies include the wave ripple laminated fine grained sandstone (f7) and the wave rippled sandstone-shale heterolith (f8).

**The wave ripple laminated fine grained sandstone facies association is not bioturbated (B.I. = 1):** The wave rippled fine grained sandstone facies (f7) consist of parallel to wave rippled, well-sorted friable fine grained sandstone. Biogenic structures are absent in this lithofacies. Bioturbationindex (II) is 1. The wave rippled sandstone-shale heterolith (f8) consists of wave rippled laminated interbeds of sandstones and shales.

**Interpretation:** The heterolithic units of fine grained sandstones and shales and the wave rippled fine grained sandstone suggests deposition in a wave dominated, moderate energy shallow marine (foreshore-shoreface) environment.

### Ethology

The trace fossils discussed in this study belong to one ethological group; fodinichnia (Table 3). Fodinichnia refers to deposit feeding burrows. It encompasses the combined activities of feeding and dwelling of organisms in sediments. It involves a systematic mining of the sediment for food which is exhibited mainly by endobenthic deposit feeders inhabiting the burrows. In the heterolithic unit, the sandstone and siltstone beds are dominated by the deposit feeding burrows of *Planolites* and *Thalassinoides*, while the *Teichichnus* occurs mainly in the interbedded shales. Also in the black shale facies, the *Thalassinoides* burrows occur within the thin siltstone beds. The distribution of trace fossils within the marine environments are influenced by some paleoenvironmental conditions. The occurrence of *Planolites* and *Thalassinoides* within the thin sandstones and siltstone beds are influenced by waves and currents, high oxygen level and lower salinity conditions whereas in the shales, where the energy is lower, and oxygen level drops and salinity level increases, only organisms producing *Teichichnus* burrows are favoured. Systematic

### Ichnology

The ichnofossils observed in the study area include *Teichichnus*, *Planolites*, and *Thalassinoides*. All these trace fossils belong only to the Cruziana ichnofacies (Figures 4a & 4c).

### Ichnogenus teichichnus seilacher 1955:

**Description:** *Teichichnus* consists of a series of long horizontal burrows starched normal to bedding, straight or slightly sinuous, and generally non-branching.

**Diameter:** 2-3 cm, **Height:** 10 cm

**Remarks:** *Teichichnus* are burrows that are made by deposit feeding activity of a group of organisms such as annelids and arthropods.

The burrows suggest near-shore shelf environment below wave base, without current or wave activity.

#### Ichnogenus *planolites* nicholson 1873 and ichnogenus *thalassinides* ehrenberg 1944 to ichnogenus *thalassinooides* ehrenberg 1944:

**Planolites** isp: Figure 4a & c

**Description:** *Planolites* are unlined rarely branched, straight to tortuous, smooth to regularly walled or annulated burrows and circular to elliptical in cross-section.

**Diameter:** 3-5 cm, Length: 15-20 cm

**Remarks:** These are burrows of deposit feeding animals and suggests littoral to sub-littoral environment.

#### Ichnogenus *thalassinooides* ehrenberg, 1944:

**Thalassinooides** isp: Figure 4b

**Description:** *Thalassinooides* are smooth walled cylindrical burrows of variable diameter with no surface ornamentation. They are horizontal to sub-horizontal in orientation. They form 3-D horizontal branching networks connected to the surface by vertical shafts; commonly shows swelling at points of branching.

**Diameter:** 3-4 cm Length: 8-16 cm.

**Remarks:** these are feeding and dwelling burrows made by callianasid crustaceans.

## Conclusion

This study shows that the Enugu Formation was deposited in an offshore open marine setting interbedded with some shoreface sediments. Four lithofacies association were identified and depositional environments vary from offshore marine environment, offshore to lower shoreface transition, lower shoreface and middle to upper shoreface. The trace fossil assemblage is of very low diversity consisting of *Cruiziana* ichnofacies (*Teichichnus rectus*, *Thalassinooides* isp and *Planolites* isp.). The distribution of ichnofossils in the sediments is influenced by several factors such as sedimentation rate, organic richness, degree of oxygenation and salinity concentration, etc.

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## Conflicts of interest

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