

# Litho-Bio Facies Analysis and Systematic Paleontology of Sediments in Amansiodo-1 Well, Anambra Basin, Southeastern Nigeria

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**Abstract:** Sixty-two (62) ditch cutting samples were obtained from Amansiodo-1 well within the Anambra Basin, Nigeria, at depth intervals between 16 - 2191 m and analyzed for lithofacies, Foraminiferal, and systematically described. A total of thirty (30) benthonic foraminiferal species were retrieved: twenty-six (26) arenaceous and four (4) calcareous. The age of the well is determined to be Maastrichtian base on the appearance of benthonic arenaceous *Haplophragmoides sahelense* (Petters) species. Facies analysis of the samples indicated ten (10) lithofacies and two (2) facies associations. The facies comprise a base to top, the shale facies, shale/sandstone facies, shale/mudstone facies, mudstone/coal facies, sandstone/clay facies, mudstone/clay facies, very coarse sandstone facies, coarse sandstone facies, sandstone/clay facies and siltstone/clay facies, association FA-1 (subtidal) and FA-2 (Intertidal) corresponding to the Mamu Formation in the Anambra Basin. The studied sediments are assigned a shallow marine depositional environment based on the triangular plot of foraminiferal suborder test type (arenaceous, porcelaneous, and hyaline) and lithofacies distribution. The paleosalinity studies suggest a transition from brackish to an open marine depositional environment. Also, paleo-oxygenation of the sediments is anoxic based on foraminiferal distribution and the ratio of epifaunal to infaunal benthonic foraminifera respectively.

**Keywords:** Paleontology, Paleosalinity, Biostratigraphy, Foraminifera, Paleo-Oxygenation

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## 1. Introduction

The study well (Amansiodo-1) is located in Ezeagu town of the present Enugu State in south-eastern Nigeria with geographical coordinates 6° 28' 0" N, 7° 17' 00" E (Figure 1), and was drilled by Shell BP in 1953 to a depth of 2191 m. During the Mid Santonian period, global plate re-organization was accompanied by a significant folding and uplifting of all pre-Santonian sediments [1]. In the Abakiliki

axis, intense folding accompanied by a mild igneous activity promoted the formation of the Anticlinorium (Abakiliki Anticlinorium), characterized by extensive depression within its sides. These depressions constitute the Afikpo Syncline located in the South East and the Anambra Basin located to the North West. The transgression in the Southern Benue Trough was followed by periods of regression that commenced after the mid-Santonian folding, making the Anambra Basin a new depocenter. This basin comprises

Campanian-Maastrichtian shales (Enugu and Nkporo Formations), the Coal Measures (Mamu Formation), and Fluvial-Deltaic Sandstone (Ajali Formation) [2-4]. During the Paleocene time, a major transgression that occurred in the Southern Benue trough halted the advancement of the Upper Cretaceous proto-Niger-Delta Basin and restricted the sedimentation and deposition of the Imo Shale and Ameki Formation to the Anambra Basin [5, 6].

Oil exploration and other investigations (geophysical, biostratigraphic, lithostratigraphic) have contributed to the present knowledge of the stratigraphic and micropaleontological data for the Anambra Basin. Research in micropaleontology has gained importance owing to the increased exploration of hydrocarbons. Despite several publications on the Anambra Basin most of which were based on surface geological data, other reports on subsurface studies carried out by oil companies remain largely unpublished. Biostratigraphic investigations in the region were localized and often restricted to a single outcrop, section, or formation, for instance, works of Reymont [7],

Petters [8], Agagu and Ekweozor [9], Agagu *et al.* [10], Gebhardt [11], Lucas and Ishiekwe [12], Lucas and Balogun [13], Soronnadi and Omoboriowo [14], Ola-Buraimo [15], Ola-Buraimo [16], and Adiola *et al.* [17]. The regional biostratigraphic survey has been carried out by Petters [18], Petters [19] and Petters [20], and there is a need for more subsurface studies (both stratigraphic and micropaleontologic) for a better understanding of the general stratigraphy of the basin.

The present research on the facies analysis, systematic paleontology, and paleoenvironmental reconstruction of sediments in Amansiodo-1 well, Anambra Basin is significant as it will provide information for the understanding of the facies, foraminiferal association, depositional history of the sediments, and to a large extent, the Anambra Basin. The aim of this study is to describe and identify the various lithologic association and characterize the foraminiferal biofacies of sediments in Amansiodo-1 well to deduce its depositional environment.

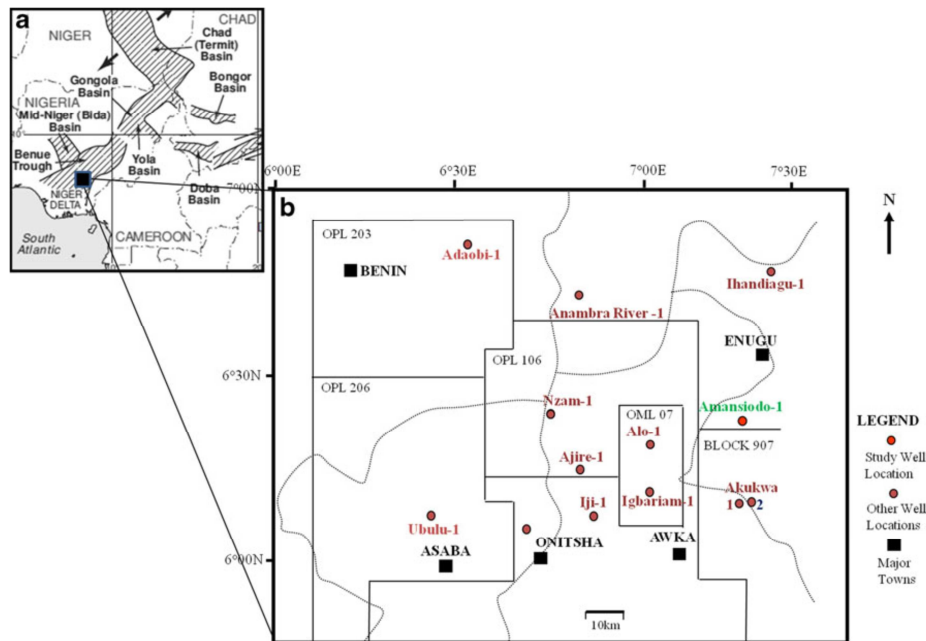


Figure 1. Benue Trough and the mid-African Rift System, b: location of the study well (in green) [21].

## 2. Methodology

A total of 143 ditch cuttings of the Amansiodo-1 well from the Nigerian Geological Survey Agency, Kaduna, with a sample depth interval ranging from 16 - 2191 m, were acquired. Systematic Lithostratigraphic logging is done through the examination of the ditch cuttings using a hand lens for lithologic characteristics such as color, grain sizes, fissility, and plant remain observed. A composite sample was made from the ditch cutting at an interval of 18 m, with a total of Sixty-two (62) cuttings used for foraminiferal analysis. The procedure adopted for the microfossil extraction is in line with the standard micropaleontological

sample preparation technique of [22-24], each fraction is examined under a binocular microscope. All the foraminifera, ostracods, shell fragments, and other microfossils observed were picked with the aid of a sable brush 000, counted, placed in foraminifer's slides, and covered with cover slide for safety. The slides were well labeled, with a good name and sample depth for identification. Scanning Electron Microscope was used to acquire images of the required species as presented (Plates I and II). Foraminifera identification is made to genus and species levels where possible using the taxonomic scheme of [25] and other relevant foraminiferal literature Such as [26-30]. Foraminiferal descriptions were done alongside previously published catalogs as listed above.

### 3. Results and Discussion

#### 3.1. Results

Table 1 shows the lithological distributions of the studied well from the base to the top. The well is generally characterized by coarsening upward sequence with the lithologies mainly shale, sandstone, mudstone, claystone, siltstone, and coal. The recovered foraminifera are well preserved and with high diversity. The arenaceous and calcareous benthics forms species were obtained and presented in Figure 2. Most of the species have a long stratigraphic range, while others have restricted distribution (Figure 2). Associated fossils like ostracods, shell fragments, and gastropods are recovered from some of the studied samples.

#### 3.2. Benthonic Foraminifera

The benthonic foraminifera found in sediments from the studied well chiefly comprises diverse and rich to fairly abundant species. A total of thirty (30) species (benthonic) are recovered from the studied interval, with four (4) being calcareous species accounting for 13% of the counts, and twenty-six (26) arenaceous species (Table 3), accounting for 87% of the foraminifera count (Table 2). The benthonic foraminifera is dominated by the species of *Haplophragmoides sahelense*, *Haplophragmoides sahariense*, *Haplophragmoides* sp., *Ammobaculites amabensis*, *Ammobaculites* sp., and *Haplophragmoides talokaense* all of which have a count greater than 18; others have poor representation with a single occurrence as in the case of *Ammonium* cf *bornum* and *Miliammina tsogaensis*.

**Table 1.** Lithologic Description of sediment samples from Amansiodo-1 well, Anambra Basin.

Depth (m)	Lithology	Description
16.7	Claystones/ironstone/woody material	White (Fine-grained), red (hard, fine-grained) and plant remains.
17.7	Siltstone	Fine-grained, grey containing plant remains
30.5	Siltstone	Coarse grained, grey containing plant remains
30.5	Sandstone	Fine-medium grained, light brown
33.5	Sandstone	Medium grained, light brown, well sorted
45.7	Claystone	Very Fine grained, white
48.7	Claystone	Very fine grained, light brown
48.7	Sandstone	Medium grained, light brown
51.8	Clay	Light brown, fine grained
61.0	Sandstone	Coarse grained, light brown, well sorted
67	Sandstone	Coarse grained, light brown, well sorted
73.2	Sandstone/mudstone	Fine-medium grained sandstone with mudstone intercalation
79.2	Sandstone	Medium-coarse grained, brown
85.3	Sandstone	Medium-coarse grained, brown
91.4	Sandstone	Medium-coarse grained, brown
94.5	Sandstone	Medium-coarse grained, dark brown
97.5	Sandstone	Medium-coarse grained, dark brown
109.7	Sandstone	Medium-coarse grained, dark brown
128.0	Sandstone	Medium-coarse grained, dark brown
134.1	Sandstone	Medium-coarse grained, dark brown
167.6	Sandstone	Coarse- grained, light brown
173.7	Sandstone	Coarse- grained, light brown
179.8	Sandstone	Medium grained, light brown
182.9	Sandstone	Medium grained, light brown
185.9	Sandstone	Medium-coarse grained, reddish brown
192.0	Sandstone	Medium-coarse grained, reddish brown
198.1	Sandstone	Medium-coarse grained, reddish brown
204.2	Sandstone	Medium-coarse grained, reddish brown
213.4	Sandstone	Medium-coarse grained, reddish brown
228.6	Sandstone	Medium-coarse grained, reddish brown
234.7	Sandstone	Medium-coarse grained, reddish brown
252.9	Sandstone	Medium-coarse grained, reddish brown
259.1	Sandstone	Medium-coarse grained, reddish brown
265.2	Sandstone	Medium-coarse grained, reddish brown with plant remains
283.5	Sandstone/mudstone	Medium-coarse grained, reddish brown with plant remains
289.6	Sandstone/mudstone	Medium-coarse grained, reddish brown
295.6	Sandstone/mudstone	Medium-coarse grained, reddish brown
302.7 – 307.5	Clay	Fine grained, white
307.8	Sandstone	Coarse grained, light brown
313.9	Sandstone	Medium-coarse grained, light brown
326.1	Sandstone	Medium-coarse grained, light brown
332.2	Sandstone	Coarse grained, light brown

Depth (m)	Lithology	Description
338.3	Sandstone	Medium-coarse grained feruginized
344.4	Mudstone/clay	Fine grained, brown to white
344.4	Sandstone	Medium –coarse grained, brown containing plant remains
350.5	Sandstone	Medium-coarse grained, brown containing plant remains
357.6	Sandstone	Medium grained, light brown
362.7	Sandstone	Medium-coarse grained, light brown
368.8	Feruginized sandstone	Medium grained, light brown
370.9	Sandstone/mudstone	Medium-to coarse grained with mudstone intercalation
374.9	Sandstone	Fine-medium, brown
381	Sandstone	Fine-medium, brown
393.2	Mudstone	Fine grained with clay intercalation and plant remains
399.3	Mudstone	Fine grained, brown with clay intercalation
405.4	Mudstone	Fine grained, brown with clay intercalation
411.5	Mudstone	Fine grained, brown with clay intercalation
414.5	Mudstone	Fine grained, grey
521.2	Mudstone	Fine grained, grey
527.3	Coal	Lithified showing lamination
527.3	Mudstone	Fine grained, grey with clay intercalation
533.4	Mudstone	Lithified, fine grained, brown to grey
539.5	Mudstone	Fine grained, brown to grey
545.6	Mudstone	Fine grained, brown to grey
551.7	Mudstone	Fine grained, brown to grey
557.8	Coal	Powdery, dark, fine grained
563.9	Mudstone	Fine grained, grey
570	Mudstone	Fine grained, Brown to grey
573	Coal	Fine grained, dark, powdery
582.2	Mudstone	Fine grained, grey
588.3	Mudstone	Fine grained, grey
594.4	Mudstone	Fine grained, grey
600.5	Mudstone	Fine grained, grey
606.6	Mudstone	Fine grained, grey
612.7	mudstone	Fine grained, grey
615.7	Mudstone	Fine grained, grey
618.7	Mudstone/clay	Fine grained, light grey with clay intercalation
624.8	Mudstone	Fine grained, dark grey
630.9	Mudstone	Fine grained, dark grey
637	Mudstone	Fine grained, grey
643.1	Mudstone	Lithified, fine grained, grey
649.2		Lithified, fine grained, grey
655.3	Mudstone	Lithified, fine grained, grey
661.4	Mudstone	Lithified, fine grained, grey
673.6	Mudstone	Lithified, fine grained, grey
679.7	Mudstone	Lithified, fine grained, grey
685.8	Shale	Fissile, fine grained, dark grey
691.9	Shale	Fissile, fine grained, dark grey
698	Shale	Fissile, fine grained, dark grey
704.1	Shale	Fissile, fine grained, grey
715.4-716.6	Shale	Core sample, fine grained, dark grey
716.3	Shale	Fine grained, fissile, greyed
722.4	Shale	Fissile, fine grained, grey
734.6	Mudstone/shale	Fissile, fine grained, grey
740.7	Shale	Fissile, fine grained, grey
746.8	Shale	Fissile, fine grained, grey
752.9	Shale	Fissile, fine grained, grey
755.9	Shale	Fissile, fine grained, grey
765.4	Core shale	Fissile, fine grained, grey
766.3 – 768.1	Core shale	Fissile, fine grained, grey
763.5 – 768.1	Core shale	Fissile, fine grained, grey
813.8	Core shale	Fissile, fine grained, grey
816.9	Mudstone/shale	Fissile, greyed
819.9	Shale	Fissile, fine grained, grey
826.0	Shale	Fissile, fine grained, grey
832.1	Shale	Fissile, fine grained, grey
838.2	Shale	Fissile, fine grained, grey

Depth (m)	Lithology	Description
844.3	Shale	Fissile, fine grained, grey
850.4	Shale	Fissile, fine grained, grey
853.5	Shale	Fissile, fine grained, grey
868.7	Shale	Fissile, fine grained, grey
923.5	Mudstone/shale	Fissile, fine grained, grey
929.6	Shale	Fissile, fine grained, grey
932.7	Shale	Fissile, fine grained, grey
935.7	Shale	Fissile, fine grained, grey
941.8	Shale	Fissile, fine grained, grey
957.9	Shale	Fissile, fine grained, grey
954.0	Shale	Fissile, fine grained, grey
960.1 – 1124.7	Shale	Fissile, fine grained, grey
1128.4 – 1134.5	Shale	Fissile, fine grained, grey
1136.9 – 1155.2	Core sandstone	Medium grained, brown
1174.1 – 1175.9	Shale	Fissile, fine grained, grey
1191.7 – 1221.9	Sandstone core	Medium grained, brown colour
1221.9 – 1225.9	Shale	Fissile, fine grained, grey
1225.9 – 1277.1	Sandstone core	Medium grained, brown
1278.6	Shales	Fissile, fine grained, dark grey
1277.7	Shale	Fissile, fine grained, dark grey with mud intercalation
1280.8 – 1283.8	Core sandstone	Medium grained, brown
1284.7 – 1348.7	Core sandstone	Medium grained, brown
1349.7 – 1351.8	Shale	Fissile, fine grained, dark grey
1356.4 – 1432.6	Core shale	Fissile, fine grained, dark grey
1435.6 – 1505.7	Shale	Fissile, fine grained, dark grey
1508.8	Shale	Fissile, fine grained, dark grey
1508.8 – 1700.8	Core shale	Fissile, fine grained, dark grey, indurated
1758.7 – 2191.5	Shale	Fissile, fine grained, dark grey
2312.8 – 2313.1	Shale	Fissile, fine grained, dark grey
	Shale core	Fissile, fine grained, grey (indurated)

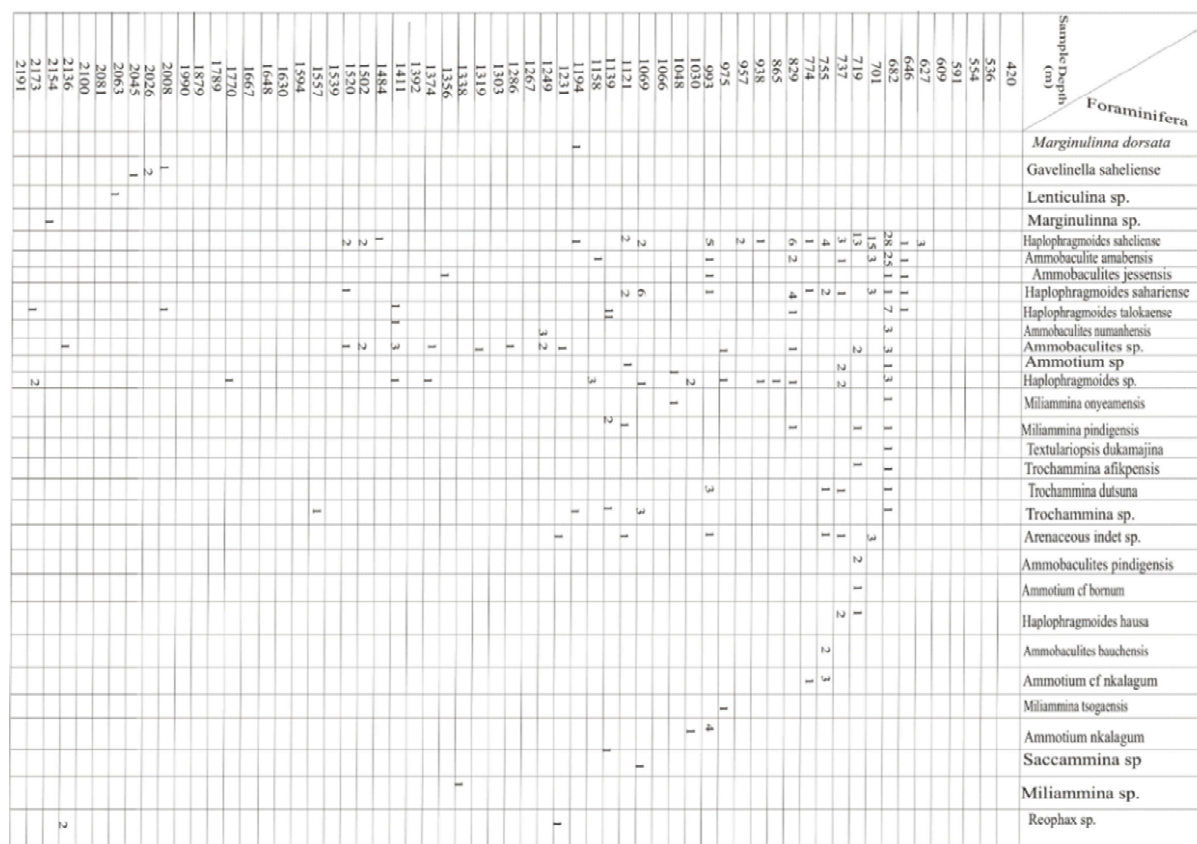


Figure 2. Foraminifera distribution chart for sediments in Amansiodo-1 well.

**Table 2.** Shell-type count for sediments in Amansiodo-1 well.

AGGLUTINATED SHELL (Counts)		PORCELANEIOUS SHELL (Counts)		HYALINE SHELL (Counts)	
<i>Ammobaculites amabensis</i>	41	<i>Marginulina dorsata</i>	3	<i>Gavelinella sahelense</i>	9
<i>Ammobaculites bauchensis</i>	3	<i>Marginulina</i> sp.	4	<i>Lenticulina</i> sp.	2
<i>Ammobaculites jessensis</i>	5				
<i>Ammobaculites numanhensis</i>	4				
<i>Ammobaculites pindigensis</i>	4				
<i>Ammobaculites</i> sp.	25				
<i>Ammotium</i> sp.	3				
<i>Ammotium</i> cf <i>bornum</i>	1				
<i>Ammotium</i> cf <i>nkalagum</i>	5				
<i>Ammotium nkalagum</i>	8				
<i>Arenaceous indet</i> sp.	13				
<i>Haplophragmoides hausa</i>	2				
<i>Haplophragmoides sahelense</i>	97				
<i>Haplophragmoides</i> sp.	27				
<i>Haplophragmoides saheriense</i>	33				
<i>Haplophragmoides talokaense</i>	21				
<i>Miliammina onyeamensis</i>	3				
<i>Miliammina pindigensis</i>	6				
<i>Miliammina tsogaensis</i>	1				
<i>Miliammina</i> sp.	5				
<i>Reophax</i> sp.	3				
<i>Saccamina</i> sp.	2				
<i>Textulariopsis dukamajina</i>	2				
<i>Trochammina afikpensis</i>	3				
<i>Trochammina dutsuna</i>	9				
<i>Trochammina</i> sp.	11				
TOTAL Count	337		7		11

**Table 3.** Infaunal and Epifaunal foraminifera counts.

INFAUNAL	EPIFAUNAL
<i>Ammobaculites amabensis</i>	<i>Gavelinella sahelense</i>
<i>Ammobaculites buachensis</i>	<i>Textulariopsis dukamajina</i>
<i>Ammobaculites jessensis</i>	<i>Trochammina afikpensis</i>
<i>Ammobaculites numanhensis</i>	<i>Trochammina dutsuna</i>
<i>Ammobaculites pindigensis</i>	<i>Trochammina</i> sp.
<i>Ammobaculites</i> sp.	
<i>Ammotium</i> cf <i>bornum</i>	
<i>Ammotium</i> cf <i>nkalagum</i>	
<i>Ammotium nkalagum</i>	
<i>Ammotium</i> sp.	
<i>Haplophragmoides sahelense</i>	
<i>Haplophragmoides saheriense</i>	
<i>Haplophragmoides talokaense</i>	
<i>Haplophragmoides hausa</i>	
<i>Haplophragmoides</i> sp.	
<i>Trochammina afikpensis</i>	
<i>Trochammina dutsuna</i>	
<i>Trochammina</i> sp.	
<i>Miliammina onyeamensis</i>	
<i>Miliammina pindigensis</i>	
<i>Miliammina tsogaensis</i>	
<i>Miliammina</i> sp.	
<i>Reophax</i> sp.	
<i>Saccamina</i> sp.	

### 3.3. Discussion

#### 3.3.1. Lithofacies Analysis

Table 1 shows the lithological distributions of the studied well from the base to the top. The well is generally characterized by fine, medium to coarse-grained sandstone sometimes, with intercalation of shale; mudstone, claystone, and coal occur within specific intervals of the mudstone, while siltstone/clay occur at the top of the section. Lithofacies analysis of the studied interval (16-2191 m) reveals that it penetrated the Mamu Formation of the Anambra Basin. These studies revealed ten lithofacies and two associations viz:

##### (i). Shale Facies (A)

The presence of shale in a stratigraphic section is indicative of deposition in the quiet water paleoenvironment suggesting marine relatively low energy conditions. Shales fissility indicates that burrowing organisms were absent in the depositional environment [31], the variation in color from dark grey to grey towards the top suggests quantitative variation in organic matter content that may have been caused by a change from a relatively anoxic towards oxic paleo-environmental situations. The fissility and the fine nature of the shale as indicated by the section of the good interval suggest that the shale was deposited below the wave base, and accumulated at a relatively low energy

environment, that is, in a distal to a proximal lagoon [32]. These facies contain foraminifera and accessory microfossils such as ostracods and gastropods.

#### **(ii). Shale/Sandstone Facies (B)**

The presence of medium to coarse sands reflects the fluctuation in the energy of deposition of the sediments. The predominance of poorly to moderately sorted values indicates rapid deposition by fluvial processes [33]. This unit is rich in microfossils. These features of the sandstone suggest deposition in the upper flow regime. The alternation of sand and shale infer a paralic environment.

#### **(iii). Shale/Mudstone Facies (C)**

The presence of mudstone and shale in a stratigraphic section suggest deposition in a quiet water environment. The presence of shaly mud suggests marine relatively low energy conditions. The dark grey color is suggestive of anoxic paleo-environmental situations.

#### **(iv). Mudstone/Coal Facies (D)**

The presence of coal is suggestive of deposition in deltaic and anoxic conditions. The alternation of coal and mudstone in the interval also indicates that the deposition was in an estuarine environment similar to the observation of [7, 34].

#### **(v). Sandstone/Clay Facies (E)**

Medium to coarse-grained sandstone is suggestive of deposition in the upper flow regime. The clay suggests deposition in a low-energy depositional environment. This implies deposition in a transitional environment, possibly a shallow marine to brackish paleoenvironment of deposition.

#### **(vi). Mudstone/Clay Facies (F)**

The presence of mudstone and clay points to deposition by suspension process in quiet water, confirming a low energy depositional environment. The change of color from dark grey to grey of the mudstone is suggestive of a change from anoxic to oxic conditions. The lack of microfauna indicates a lack of marine influence and possible dominance of fluvial influence.

#### **(vii). Very Coarse-Grained Sandstone Facies (G)**

Very coarse-grained sandstone suggests deposition in an upper flow regime. The clay lens result from deposition out of suspension in the upper flow regime suggestive of a shallow marine to brackish paleoenvironment of deposition.

#### **(viii). Course Sandstone Facies (H)**

Coarse sand is suggestive of high energy of deposition of the sediments which indicates a fluvial influence.

#### **(ix). Sandstone/Clay Facies (I)**

Medium to coarse sands reflects fluctuations in the energy of sediment deposition and the clay suggest low energy paleoenvironment of deposition.

#### **(x). Siltstone/Clay Facies (J)**

Siltstone suggests deposition in a floodplain environment. This results from deposition out of suspension in the upper

flow regime. Therefore a continental environment is inferred.

The general design of deposition of the section reveals a low energy environment at the base of the section typified by shales, mudstone, and a transition to high energy towards the top distinctive by sandstones and a continental environment at the topmost part characterized by siltstone/clays.

### **3.3.2. Facies Association**

Facies association is a group of facies that define a particular sedimentary environment [35, 36]. From the description and interpretation of the lithofacies, two facies associations are recognized; the FA-1 (subtidal) and the FA-2 (Intertidal) viz:

#### **(i). FA-1 (Subtidal)**

These facies compose of E (sandstone/clay facies), G (very coarse-grained sandstone facies), H (coarse sandstone facies), and I (sandstone /clay facies). The association range in thickness between 35.4 m to 277 m. Due to its fining upward sequence, it is usually associated with a high energy environment and characterized by high current velocity, therefore, interpreted as a subtidal environment [37, 38].

#### **(ii). FA-2 (Intertidal)**

These facies comprises A (shale facies), B (shale/sandstone facies), C (shale/mudstone facies), D (mudstone/coal facies), F (mudstone/clay facies), and J (siltstone/clay facies). These facies reflect a decrease in energy from upper to lower parts as recorded by decreasing grain sizes. This suggests an intertidal environment [37].

### **3.4. Systematic Paleontology**

In this study, some foraminifera species representing the calcareous and arenaceous benthonics found in the sediments were classified, according to [25]. The identification of the various foraminifera was achieved greatly by comparison with forms that have been previously described and illustrated by [18, 20, and 25]. Since most of the species illustrated in this work have been described in detail in readily accessible micropaleontological literature [18], species synonyms are not included.

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Kingdom PROTOZOA SCHULTZE 1854

Phylum SARCODINA

Class RHIZOPODA

Order FORAMINIFERIDA VAN EICHWALD 1830

Genus *Ammobaculites* CUSHMAN 1910

*Ammobaculites bauchensis* PETTERS, 1979f

Figure 3 (1)

Description: Test small to moderate, broad and compressed, involute initial part, short uncoiled and uniserial part; peripheral outline moderately lobulated; peripheral



margin narrow; chambers narrow and numerous; umbilicus closed; sutures narrow, depressed, obscured in early part of test; aperture an elongate terminal opening; wall coarsely arenaceous with uniform grains and small amount of cement.

Occurrences: Common in the Mamu, Pindiga, Gongila, and Jessu formations.

*Ammobaculites jessensis* PETTERS, 1979f

Figure 3 (2)

Description: Test small, elongate, compressed, strongly involute, uniserial part not developed peripheral margin narrow; chambers indistinct, 4-6 in the last whorl, ultimate chambers partially erect; umbilicus closed; sutures obscured by coarse grains; aperture a narrow, vertical on the apertural face; wall very coarsely arenaceous with angular nearly equidimensional quartz grains and little non-calcareous cement.

Occurrences: Common at the base of the Gongila Formation in the Ashaka quarry, Mamu Formation and in the Jessu Formation.

*Ammobaculites pindigensis*

Figure 3 (3)

Description: Test small, compressed, involute, subcircular initial part, well developed uniserial part, peripheral outline lobulated; peripheral margin narrow; chambers broad, wedge-shaped, four (4) chambers are visible in coiled part; umbilicus small; sutures raised and straight; aperture a narrow opening; wall with uniform small quartz grains and little non-calcareous cement.

Occurrence: This species is common in the Mamu Formation

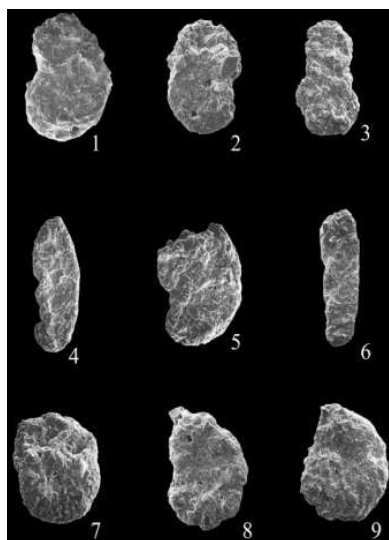


Figure 3. Description.

1. *Ammobaculites bauchensis*, Petters, 755m, x200
2. *Ammobaculites jessensis*, Petters, 627m, x256
3. *Ammobaculites pindigensis*, Petters, 701m, x141
4. *Ammotium cf bornum*, Petters, 719m, x200
5. *Ammotium nkalagum*, Petters, 994m, x256
6. *Ammotium* sp. Petters, 682m, x141
7. *Haplophragmoides sahariense* Petters, 682m, x227
8. *Haplophragmoides saheliense* Petters, 627m, x170
9. *Haplophragmoides talokaense* Petters, 2173m, x170.

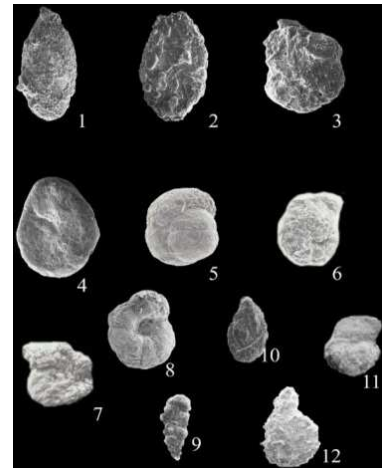


Figure 4. Description.

1. *Miliammina pindigensis*, Petters, 682m, x227
2. *Saccamina* sp. Petters, 1069m, x244
3. *Trochammina dutsuna*, Petters, 682m, x 217
4. *Gavelinella* sp. Petters, 2045m, x286
5. *Haplophragmoides* sp. Petters, 682m, x170
6. *Haplophragmoides saheliense*, Petters, 627m, x190
7. *Ammobaculites amabensis*, Petters, 646m, x 200
8. *Haplophragmoides haussa* Petters, 719m, x167
9. *Textulariopsis dukamajina* Petters, 682m, x150
10. *Miliammina tsogaensis* Petters, 975m, x150
11. *Ammobaculites numanhensis* Petters, 646m, x170
12. *Ammobaculites* sp. Petters, 1231m, x130.

Genus *Ammotium* LOEBLICH and TAPPAN 1953

*Ammotium bornum*. PETTERS 1979c

Figure 3 (4)

Description: The test is narrow, and compressed, comprising mostly of uncoiled portion; the periphery is weakly to moderately lobulated; there are 4-5 narrow, elongate and closely appressed chambers in the uncoiled part of the test; the sutures are flush to faintly depressed, and oblique; wall is coarsely agglutinated with little cement; aperture is a simple terminal opening which may be elongate as a result of test compression. Length of holotype 0.38 mm; maximum width 0.12 mm.

*Ammotium nkalagum* PETTERS 1979c

Figure 3 (5)

Description: The ovate to subcircular and compressed test has small, sometimes indistinct initial end; the fan-like uncoiled part comprises low and elongate chambers which reach down towards the initial, coiled end; sutures are depressed and oblique; the wall is fairly smooth, coarsely agglutinated, and with abundant cement; aperture is narrow opening which is slightly displaced towards the straight peripheral margin.

*Ammotium* sp. PETTERS, 1979c

Figure 3 (6)

Description: Test large, rather flat, finely agglutinated, outline suboval, slightly lobate

*Haplophragmoides sahariense* PETTERS 1979c

Figure 3 (7)

Description: Test small, planispiral, slightly evolute, moderately compressed, circular to subcircular in outline;



equatorial periphery slightly lobulated, may appear stepped because succeeding chambers start lower or higher than previous ones; axial periphery narrow, may appear truncate; chambers narrow and elongate in equatorial plane; 9-10 in the last whorl; umbilicus wide and shallow; sutures distinct, slightly curved, depressed; wall smooth; a mosaic of small, closely fitting equidimensional, angular quartz grain, non-calcareous; aperture low interior marginal slit.

Occurrence: Common in the lower shale and the middle marl band of the Middle-Late Maastrichtian Dukamaje Formation, from where it was originally described.

*Haplophragmoides sahelense* PETTERS, 1979c  
Figure 3 (8) and Figure 4 (6)

Description: Test moderate, planispiral, slightly evolute, moderately compressed, subcircular in outline; periphery highly lobulated; axial periphery narrow, appears truncate; six to seven wedge-shaped chambers in the last whorl; last few chambers are radially elongate and may be transformed into tubulospines; umbilicus moderately wide and shallow; sutures wide, depressed, radiate; wall coarsely arenaceous, non-calcareous; aperture equatorial, wide, high and rectangular.

Occurrences: Present in the Maastrichtian Mamu Formation of the Anambra Basin.

*Haplophragmoides talokaense* PETTERS, 1979c  
Figure 3 (9)

Description: Test closely coiled planispiral, periphery rounded, axial periphery narrow, six to eight slightly compressed chambers in the last whorl; last chambers slightly raised; umbilicus narrow and deep; sutures narrow and depressed, radiate, almost obscured by coarse wall texture; wall coarse-grained, with a large range in the sizes of the constituent quartz grains; slightly calcareous cement; aperture equatorial, wide and squared.

Occurrences: Common in the lower and upper shales of the Middle-Late Maastrichtian Dukamaje Formation and Mamu Formation.

Superfamily Rzehakinidae CUSHMAN 1933

Genus *Miliammina* HERON-ALLEN and EARLAND 1930

*Miliammina pindigensis* PETTERS 1979f  
Figure 4 (1)

Description: Test small, elongate, narrow to broad, quinqueloculine; peripheral margin wide; chambers broad and elongate; Sutures narrow, depressed, distinct; Aperture wide and rounded; wall coarsely arenaceous, abundant grains and non-calcareous cement; rough wall texture.

Occurrence: Very abundant in Pindiga Formation, Upper Benue Trough, from where it was first described; also common in the Gboko Formation, Mamu Formation and the Fika Shale.

Family Trochamminidae SCHWAGER 1877

Subfamily Trochammininae SCHWAGER 1877

Genus *Trochammina* PARKER and JONES 1859

*Trochammina dutsuna* PETTERS 1979c

Figure 4 (3)

Description: Test low trochospire, umbilico-convex;

circular to subcircular in outline. Lobulate equatorial periphery; broadly rounded axial periphery; four inflated, subglobula chambers which increased rapidly in size; umbilicus narrow; sutures straight, depressed, radial on both umbilical and spiral sides; walls smooth, finely arenaceous with more grains than cement; aperture a wide, rather high, interior marginal extra-umbilical arch.

Occurrences: Common in the lower and upper shales of the Middle-Late Maastrichtian Dukamaje Formation and the Mamu Formation.

Family Anomaliniidae CUSHMAN 1927a

Subfamily Anomaliniinae CUSHMAN 1927a

Genus *Gavelinella* BROTZEN 1942

*Gavelinella sahelense*

Figure 4 (4)

Description: Test small, biconvex, trochospiral coil; circular to subcircular outline; moderately lobulated, equatorial periphery; axial periphery broad and rounded; 6-7 slightly inflated wedge-shaped chambers in the last whorl; the chambers expand gradually in size; sutures depressed and curved; wall smooth and perforate; umbilicus small, depressed, with groove; aperture a low umbilical, extra umbilical, interior marginal arch at the base of the last chamber, bordered by a short lip.

*Ammobaculites amabensis* PETTERS 1979f

Figure 4 (7)

Description: Test moderate to large, slightly compressed, last whorl evolute; last chambers tending to be erect; peripheral outline subrounded, lobulated in the later part of the test; peripheral margin rounded, may be narrow; chambers slightly compressed, broad, 6-7 in the last whorl; sutures wide and depressed especially in the later part of the test; indistinct in earlier part; aperture narrow extending high on apertural face; wall very coarsely arenaceous with angular equidimensional quartz grains which are closely fitting with little non-calcareous cement; wall rough.

Occurrences: Although originally described from the Campanian-Maastrichtian Nkporo Shale Formation in the Lower Benue Trough. *Ammobaculites amabensis* is also abundant in the Gboko Formation (Albian), Mamu Formation (Maastrichtian) and the Nkalagu Formation (Cenomanian-Early Santonian).

Family Lituolidae DE BLAINVILLE 1825

Subfamily Haplophragmoidinae MAYNC 1952

Genus *Haplophragmoides* CUSHMAN 1910

*Haplophragmoides hausa* PETTERS 1979c

Figure 4 (8)

Description: Test planispiral, last whorl slightly evolute, moderately lobulated equatorial periphery, broadly rounded axial periphery which may be secondarily compressed; chambers are slightly inflated and wedge-shaped in side view; they increased in size, eight chambers in the last whorl. Umbilicus is wide and deep; sutures straight and moderately depressed; wall smooth because of large amount of non-calcareous cement. Aperture a low equatorial interior marginal arch.

Occurrences: Abundant in the lower shale of the Middle-

Late Maastrichtian Dukamaje Formation where it was first described and the Mamu Formation.

Family Ataxophragmiidae SCHWAGER 1877

Subfamily Ataxophragmiinae SCHWAGER 1877

Genus Textulariopsis BANNER and PEREIRA 1981

*Textulariopsis dukamajina* PETTERS 1979c

Figure 4 (9)

Description: Test biserial, small elongate and slender, compressed; periphery lobulated, 7 elongate, interlocking chambers in each row; sutures distinct, depressed, slightly oblique in initial part of test, later sigmoid; wall shiny, finely arenaceous, non-calcareous; aperture a high arch at inner margin of the last chambers.

Occurrences: Common at the base of the lower shale of the Middle-Late Maastrichtian Dukamaje Formation.

Genus Miliammina HERON\_ALLEN and EARLAND 1930

*Miliammina tsogaensis* PETTERS 1979c

Figure 4 (10)

Description: Test elongate, sub-elliptical, broad, compressed; chambers are distinct, increasing in width and tending to overlap; suture distinct but poorly preserved; wall smooth under low magnification, composed of fine quartz grains with little cement; non-calcareous; aperture is wide and round.

Occurrences: Abundant in the lower and upper shales of middle-late Maastrichtian Dukamaje Formation, where it was first described.

*Ammobaculites numanhensis*

Figure 4 (11)

Description: Test small, circular to subcircular, planispirally involute, uniserial part poorly developed; peripheral outline slightly lobulated or even; peripheral margin narrow but not compressed; 7-8 chambers in the last whorl, slightly wedge-shaped and narrow; umbilicus wide, occasionally a small depression; sutures flush, indistinct; aperture a moderate vertical opening; wall coarsely arenaceous with considerable non-calcareous cement; wall rough.

Occurrence: This is the only foraminifera recovered from the Numanha Shale (Coniacian-Santonian), where it occurs commonly and the top of the Mamu Formation.

*Ammobaculites* sp.

Figure 4 (12)

Description: Test moderately inflated, planispirally involute in early part; raised chambers to slightly uncoil in the later part; sutures are flush, hence the chambers are somewhat indistinct in the coarsely agglutinated species. Occurrences: Common in the lower shale of the Dukamaje Formation and the shales of Mamu Formation.

Paleoenvironmental Reconstruction and Age Determination.

Foraminiferal data (benthonic foraminifera) was most useful in paleobathymetric estimation, this involves utilizing the relative abundance and diversity of benthonic

foraminifera [39, 40]. Benthonic foraminifera has evolved to exist in a range of environments, from marginal marine to deep ocean. The percentage of planktonic to benthonics in sediments provides a paleoenvironmental guide (proportion of planktonic specimens increases from 0% in a shallow marine environment to more than 90% in a deep marine environment, on this basis, the recovered foraminifera shows a shallow marine paleoenvironment due to absence of planktonic foraminifera [40]. The percentage ratio of calcareous benthonic to arenaceous benthonic foraminifera (FOBC/FOBA) also provides a useful paleoenvironmental guide, the higher the percentage FOBC ratio, the shallower the paleodepths, conversely, the higher the percentage FOBA, the deeper the paleodepths [41]. The percentage ratio of arenaceous which is greater than calcareous depicts a greater depth of deposition of the sediments.

The microfauna of the investigated samples did not yield any index planktonic foraminifera. However, [42, 19, 20] have used *Haplophragmoides sahelense* as an index of Campanian-Maastrichtian. Petters [20] dated the *Bolivina afra* /*Haplophragmoides talokaense* zone to be Maastrichtian which corresponds to the benthonic zonation of the studied well interval. Hence, the sediments in the studied well are assigned Maastrichtian.

### 3.5. Paleosalinity

A Paleosalinity interpretation for the sediments in the studied well was made based on the Shell-type ratio. The ratios between Textulariina, Miliolina, and Rotaliina plotted on a foraminiferal shell-type ratio (morphogroup) triangular cross-plot and foraminiferal abundance/diversity enabled the discrimination of a range of paleosalinity of deposition [43, 44]. The triangular plot (Figure 5) reveals the dominance of arenaceous agglutinated shell type (97.8%) which depicts a paralic (hyposaline lagoon and most shelf sea) environment. The high proportion of agglutinated forms suggests an intertidal marsh [45] and in comparison with modern seas suggests a marginal marine environment [46]. The environment of deposition as such suggests a transition from brackish to an open marine depositional environment.

### 3.6. Paleo-Oxygenation

The ratio of epifaunal to infaunal genera (Table 3) reflects the degree of oxygenation. In the studied well, the predominance of arenaceous forms shows low oxygen concentration for most parts of the good sediments (Gebhardt 1998), the dominance of agglutinated forms and the abundance of infaunal forms indicate oxygen depletion and therefore interpreted to be a dysoxic paleoenvironment for sediments of the well, this is similar to the work of Petters (1982) and Gebhardt (1998).

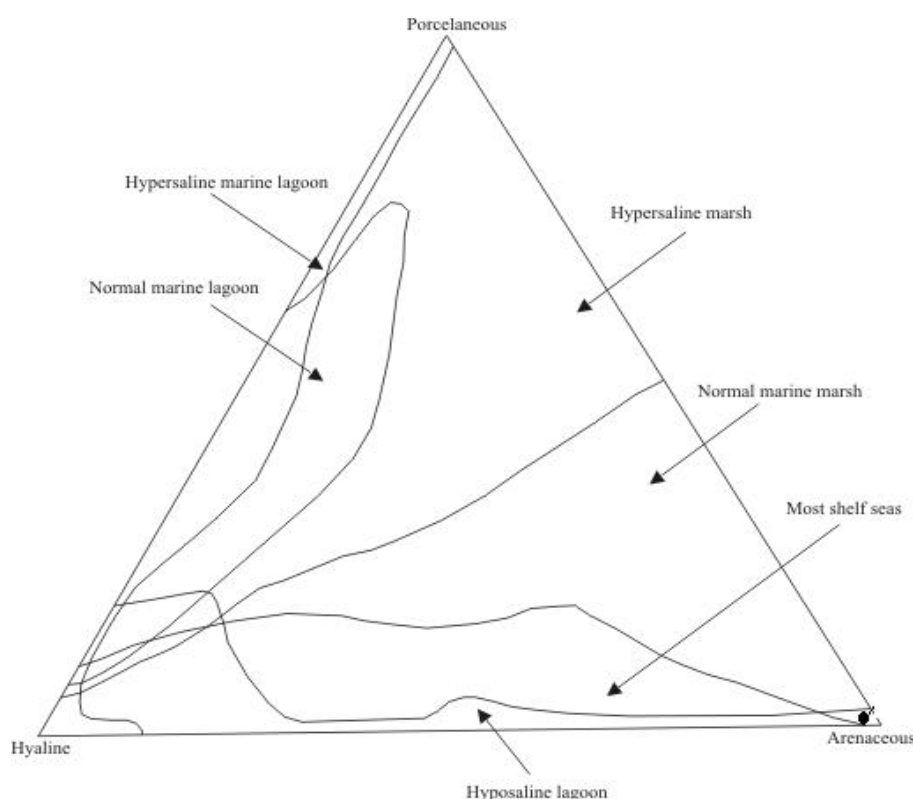


Figure 5. Triangular plot of the three suborders (After Murray, 1974).

## 4. Conclusion

Based on litho and biofacies analyses, this study has established the penetrated interval to be the Mamu Formation of the Anambra Basin deposited during the Maastrichtian (Middle to Late) Depositional environment, paleosalinity and paleo-oxygenation interpretation of the sediments in the well revealed a transition to a deep shelf or shallow marine setting and deposition under dysoxic condition respectively.

## 5. Recommendations

Further work is recommended on the integration of techniques such as high resolution and multi-proxy techniques of isotope geochemistry and palynology to provide a paleoredox condition of the organic facies of the sediments of this well.

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