Lithofacies, Palynostratigraphy and Paleoecology of the Outcropping Rock Succession at Ogbunike Old Toll Gate, Niger Delta Basin, Nigeria

E. N. Onuigbo¹, A. U. Okoro¹, C. M. Okolo¹ and H. C. Okeke¹

¹Department of Geological Sciences, Nnamdi Azikiwe University, P.M.B 5025, Awka, Nigeria.

Authors’ contributions

Authors worked together and approved the submission of the manuscript.

ABSTRACT

Aim: Sedimentary succession exposed at Ogbunike old toll gate is part of the outcropping sediments of the Niger Delta Basin and its age is controversial. The outcrop was studied for the purpose of age determination, lithostratigraphic placement and interpretation of paleoecology, paleoclimatology and depositional environment.

Methodology: Lithofacies and biofacies analyses were integrated in the study.

Results: Thirteen lithofacies identified include; bioturbated sandstone, ripple laminated sandstone, ripple laminated claystone, dark shale, ferruginized sandstone, carbonateous sandstone, greyish shale, very fine sandstone, mudstone, massive claystone, coarse sandstone, cross bedded sandstone and flaser bedded sandstone lithofacies. Four lithofacies associations consisting of lower shoreface to inner neritic, fluvial channel, lagoonal/mixed flat and subtidal sandwave associations were delineated. Middle Eocene age is assigned to the succession based on the high abundance of marker pollen such as Margocolporites foveolatus, Ctenelophonidites costatus, Monocolpites marginatus, Retibrevitricolporites triangulatus, Proxapertites cursus, Bombacacidites sp. and common occurrences of Scrabratispores simpliformis, Anacolosidites luteoides, Pslatricolporites crassus, Gabonisporis viaourouxii, Striatricolporites catatumbus and Retistephanocolporites williamsi. These co-occur with Cordosphaeridium cantharellus. Palynofloral
group recovered are dominated by mangrove and palm pollen. Pteridophyte spores are also abundant whereas the hinterland pollen group is very low. Benthic foraminiferal assemblages of Textularia, Milliammina, Ammobaculites, Haplophragmoides, Fursenkoina, Heterolepa, Reophax, Nodosaria, Florilus, Uvigerina, Cibicides and Bolivina recovered from the dark shale suggest deposition in an inner neritic setting. Trace fossil suite of Skolithos- Cruziana ichnofacies is an attribute of the sedimentary units.

**Conclusion:** The sedimentary succession is part of the Ameki Group (Nanka Formation) deposited under varied environmental setting. Paleoclimate is tropical.

**Keywords:** Palynomorph; foraminifera; dinoflagellates; depositional environment; Ameki group; sandstone.

1. **INTRODUCTION**

The Ameki Group which comprises the Ameki, Nanka and Nsugbe formations [1] have been described as the outcropping lithostratigraphic units of the Niger Delta Basin. The Agbada Formation has also been identified as the subsurface equivalent of the mentioned group [2-3]. The Ogwashi Asaba and the Benin formations conformably and successively overlie the Ameki Group (Table 1).

The Ameki Group has been dated as Early to Mid Eocene on the basis of the diverse gastropod and pelecypod fauna [4-8]. Wright et al [3] dated the group as Eocene to Oligocene. The overlying Ogwashi Asaba Formation has been dated also as Mid to Late Eocene on the basis of palynomorphs [9], Oligocene to Miocene [3,10] and Upper Eocene to Miocene [11]. The environment of deposition has also been variously interpreted as estuarine [12], barrier-ridge-lagoon complex to intertidal and subtidal [13], and shallow marine [14].

There is a controversy in age and stratigraphic placement of the sedimentary succession at Ogbunike old tollgate. On the basis of palynomorphs, the exposure was dated Upper Eocene to Miocene and was stratigraphically assigned to the Ogwashi Asaba Formation [11]. Nwajide [1] grouped the exposure as part of the underlying Ameki Group (Nanka Formation). Chiaghanam et al [15] dated the same outcrop as Mid Eocene and also stratigraphically assigned it to underlying Nanka Formation (Ameki Group). Stratigraphic placement of a particular sedimentary succession into two different lithostratigraphic units within a basin is improper and thus, a confusion especially to the academic community as to where to place the said outcrop within the Niger Delta stratigraphic framework. This confusion calls for re-evaluation of the shales and mudstone facies of the outcrop for age determination and lithostratigraphic placement of the exposure within the stratigraphic framework of the Niger Delta Basin.

This study aims at interpreting the age of the outcrops at the Ogbunike old toll gate using both palynomorphs and foraminiferal data for stratigraphic placement. It also attempts to interpret the environments of deposition. The paleoecological and paleoclimatic conditions under which the sediments were deposited will also be interpreted. Fig. 1 is the geologic map of the study area.

1.1 **Regional Tectonics and Stratigraphic Setting**

The origin of the Niger Delta Basin is related to the evolution of the Benue Trough as a failed arm of the West and Central African Rift System during the Jurassic. The development of the Benue Trough is associated with the break-up of Gondwana Supercontinent and subsequent opening of the Southern Atlantic Ocean during the Lower Cretaceous. The trough represents a major tectonic phase in the Nigerian sedimentation history [16-20]. Deposition commenced in the trough during the Aptian to Early Albian when the sediments of Awi and Mamfe Formations were laid down as the basal units in the southern part of the trough. The filling in of the trough with the sediments of the Abakaliki Formation and Mfamosing Limestone (Albian); the Ezeaku Group (Cenomanian-Turonian) and the Awgu Formation (Coniacian) was controlled by two cycles of marine transgressions and regressions. The sediments in the trough were folded and uplifted during the Santonian epeirogenic tectonics which resulted into the formation of the Abakaliki-Benue Anticlinorium and a simultaneous subsidence of the Anambra Basin and the Afikpo Sub-Basin to the northwest and southeast of the folded axis respectively [21-23]. The Anambra Basin and the
Afikpo Sub-Basin were filled from Late Campanian to Danian. Further subsidence after the filling up and compaction of the sediments of the Anambra Basin induced the major marine transgression of the Early Paleocene as well as initiation of the sedimentation and subsidence of the Niger Delta Basin (Table 1).

The oldest sediment in the outcropping part of the Niger Delta Basin is the Imo Formation deposited during the Late Paleocene marine transgression. This was successively overlain by the Ameki Group (Ameki, Nanka and Nsugbe formations) and Ogwashi Asaba Formation respectively which were laid down under regressive conditions [2-3,1].

2. MATERIALS AND METHODS

The methods adopted in this study include outcrop logging and laboratory analyses.

The outcrop at Ogbunike old toll gate was logged from base to the top and the litholog of the outcrop was produced (Fig. 2). Lithofacies were identified based on lithology, grain size and sedimentary structures. Vertically stacked and conformably overlying lithofacies that reflect a model for any particular depositional environment was interpreted as facies association of that environment [25-26].

Eight (8) samples of shale and carbonaceous mudstone were collected from the exposure for biostratigraphic analyses.
Table 1. Stratigraphic succession in the southern Benue Trough, Anambra and Niger Delta Basins [7,24,2,21,8]

| TIME SCALE       | SEDIMENTARY UNITS          |
|------------------|-----------------------------|
|                  | Benin Formation             |
| Polynecene       |                             |
| Miocone          |                             |
| Oligocene        |                             |
| Eocene           |                             |
| Paleocene        |                             |
| Thanolan         |                             |
| Danian           |                             |
|                           | Nanka Formation             |
|                           |                             |
|                           | Ameik Formation             |
|                           |                             |
|                           | Imo Formation               |
|                           |                             |
|                           | Nsukka Formation            |
|                           |                             |
|                           | Ajali Sandstone             |
|                           |                             |
|                           | Mamiu Formation             |
|                           |                             |
|                           | Nkporo Fm                   |
|                           |                             |
|                           | Enugu Fm                    |
|                           |                             |
|                           | Owoli Set                   |
|                           |                             |
|                           | Aki Set                     |
|                           |                             |
| Early Cretaceous   | Unconformity                |
| Anambra Basin      |                             |
| Early Cretaceous   | Awi Formation               |
| Southern Benue Trough |                             |
| Early Cretaceous   | Ezeaku Group                |
|                   |                             |
|                   | Ifamosing Limestone         |
|                   |                             |
|                   | Abakaiki Formation          |
|                   |                             |
|                   | Awi Formation               |
|                   |                             |
| Precambrian        | Basement Complex            |

Shale samples for palynological studies were processed using the conventional acid maceration, alkali treatment and staining methods. These helped to concentrate and recover the acid insoluble organic microfossils present in the shale. About 10g of each sample was crushed and treated with 35% of hydrochloric acid (HCl) to remove the carbonates that might be present in the sample. The samples were allowed to stay in the fume cupboard for 48 hours before the acid was decanted. Distilled water was used three consecutive times at six hours intervals to neutralize the acid and to thoroughly wash the samples. The silicates in the samples were removed (dissolution) by treatment with 40% hydrofluoric (HF) acid. The samples were stirred at regular intervals with a nickel rod and were then allowed to stand for 24 hours in a fume cupboard before the acid was carefully decanted. The process of neutralization of the acid using distilled water was again repeated in order to ensure that the samples were thoroughly washed. A 10 micron sieve was used to wash the samples for the recovery of the palynomorphs. During the first round of washing the samples were oxidized with about 40% of 60% trioxonitrate (v) ($\text{HNO}_3$) acid. The oxidation lasted for about 20 minutes and the normal process of neutralization was repeated. To further neutralize the effect of the oxidation, 10ml of 5% potassium hydroxide (KOH) solution was added during the second round of washing and sieving. The residue was centrifuged with 1ml of Zinc Chloride (specific gravity of 2.2) in order to separate the palynomorphs from other organic debris. The recovered palynomorphs were mounted on glass slide using the Norland Gel as a mounting medium. Identification and counting were done using a Leitz light microscope.

The shale samples were also analyzed for foraminiferal contents. 20g each of the samples was treated with one teaspoonful of anhydrous sodium carbonate for thorough disintegration. Enough water was used to soak the sample and allowed to stay over-night. A 53μ mesh sieve was used to wash the samples. The washed samples were dried at a minimum temperature of 20°C and were sieved into coarse, medium and fine fractions. The microfossils were picked and identified using a binocular microscope.
3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Lithofacies description

Thirteen lithofacies were identified and are shown on Figs. 2-6. These include:

1. Bioturbated sandstone lithofacies (F1): The sandstone is fine grained and pinkish in colour with a thickness of about 1.42 m (Fig. 2). Long tubes of Thalassinoides burrows are common (Fig. 3a). The lithofacies occurs at the basal part of the exposure.

2. Ripple laminated claystone lithofacies (F2): This consists of wave ripple laminated whitish claystone at the basal part of the exposure and are sandwiched in between bioturbated sandstone and ripple laminated sandstone lithofacies. Its thickness varies from 15.2 cm to 20 cm (Fig. 2).

3. Ripple laminated sandstone lithofacies (F3): The lithofacies consists of fine grained sandstone with very low amplitude wave ripple laminations (Fig. 2 and 3b). The thickness of the sandstone is about 1.45 m. Bioturbations also occur.

4. Dark shale lithofacies (F4): The facies overlies the wave ripple laminated fine grained sandstone lithofacies. It consists of dark, very fissile and pyritic shale (Figs. 2 and 3c) which yields a yellowish brown coloration on weathering. Long tubes of Thalassinoides burrows measuring up to 20 cm long and 2 – 3 cm in diameter is characteristic. The thickness is about 2.65 m.

5. Ferruginized sandstone lithofacies (F5): This consists of fine to medium grained ferruginized and massive sandstone with an erosional base exposed at the middle part of the outcrop. Thickness varies from 0.9 m to 1.19 m (Figs. 2 and 4a).

6. Greyish shale lithofacies (F6): This consists of non- pyritic, indurated shale that is greyish in colour and is about 0.79 m thick (Fig. 2).

7. Mudstone lithofacies (F7): The lithofacies consists of greyish mudstone with thickness that varies from 0.6 m to 1.15 m. It has some thin laminations and lenses of very fine grained, whitish sandstone (Figs. 2, 4b & 5a).

8. Very fine grained sandstone lithofacies (F8): The lithofacies consists of very thin bed (17 cm thick) of very fine grained whitish, clayey sandstone which overlies the carbonaceous mudstone lithofacies (Fig. 2).

9. Flaser bedded sandstone lithofacies (F9): This consists of fine to medium grained sandstone with whitish claystone flasers (Figs. 2, 5b and 6). Thickness varies from 5 cm to 0.55 m. Ophiomorpha burrows occur.

10. Coarse grained sandstone lithofacies (F10): The lithofacies consists of coarse grained sandstone of about 0.3 m thick which is generally massive and clay free (Fig. 2).

11. Carbonaceous sandstone lithofacies (F11): It consists of medium grained, greyish sandstone of about 10 cm thick (Fig. 2)

12. Massive claystone lithofacies (F12): The thickness varies from 10 cm to 0.73 m. It consists of whitish claystone that is devoid of physical sedimentary structures (Fig. 2).

13. Cross bedded sandstone lithofacies (F13): This consists of cross bedded fine to medium grained sandstone of about 0.34 m to 0.62 m thick which constitute the upper part of the exposure (Figs. 2 and 6). Cross beds are of planar type in which the foresets are draped by whitish claystone. Reactivation surfaces, tidal bundles, herringbone structures and Ophiomorpha burrows are characteristics.

These lithofacies were grouped into four facies associations as follow:

Lithofacies Association I (FA1): This association consists of vertically stacked succession of bioturbated sandstone, ripple laminated claystone, ripple laminated sandstone and dark shale lithofacies which conformably overlie each other (Figs. 2 and 3). Long tubes of Thalassinoides burrows are common on the bioturbated sandstone and dark shale lithofacies. Thalassinoides belong to Cruziana ichnofacies and are suggestive of low energy depositional setting. The depositional environment is interpreted as lower shoreface to inner neritic settings.

Lithofacies Association II (FA2): This consists of conformable succession of ferruginized sandstone, greyish shale, mudstone and very fine grained sandstone lithofacies (Fig. 2). The inferred depositional environment is fluvial channel.

Lithofacies Association III (FA3): The association consists of inter- bedded fine to
Fig. 2. Lithologic section of the Ameki Group exposed at Ogbunike old toll gate (N06°10´855, E06°51´953)

Fig. 3. Lower shoreface to anoxic inner neritic facies association (a) Bioturbated fine grained sandstone lithofacies (b) Low amplitude wave ripple laminated fine grained sandstone (c) Dark shale lithofacies
Fig. 4a & b. Fluvial channel facies association consisting of ferruginized fine to medium grained sandstone lithofacies which truncate one another and greyish shale, carbonaceous mudstone and very fine grained sandstone lithofacies. (b) The thin laminations and lenses of the whitish very fine grained sandstone lithofacies in the mudstone lithofacies are shown at the middle part of the figure above the ferruginized sandstone lithofacies.

Fig. 5. Lagoonal/mixed flat facies association (a) Bioturbated carbonaceous mudstone. *Thalassinoides* burrows are common (b) Flaser bedded fine to medium grained sandstone lithofacies. Pen is pointing at *Ophiomorpha* burrow.

Fig. 6. Subtidal sandwave facies association showing the flaser and cross bedded sandstone lithofacies.
medium grained sandstone with clay flaser laminations, coarse grained sandstone, carbonaceous mudstone, massive claystone and carbonaceous sandstone lithofacies. Clay flasers are common on the basal sandstone (Fig. 2). *Ophiomorpha* and *Thalassinoides* burrows are common on the sandstone and mudstone respectively (Fig. 5). These ichnofossils belong to both *Skolithos* and *Cruziana* ichnofacies and can be interpreted to depict energy fluctuation from high to low respectively. The sandstone lithofacies were deposited under higher energy, the carbonaceous mudstone lithofacies under lower energy conditions whereas clay flasers formed on the sandstone under quiet water condition. Depositional environment is interpreted as lagoonal/mixed flat.

**Lithofacies Association IV (FA4):** This consists of inter-beded cross bedded and flaser bedded fine to medium grained sandstone lithofacies which constitute the upper part of the exposure. The base is flaser bedded (Figs. 2 and 6). *Ophiomorpha* burrows are common. Inferred depositional environment is subtidal sandwave.

### 3.1.2 Palynological analysis

The palynomorph recoveries from the carbonaceous mudstone, greyish shale and dark pyritic shale samples were fairly abundant and diverse. Diverse species of pollen, 5 species of spores, fungal hyphae, acritarch (*Leiosphaeridia*), dinoflagellate (*Cordosphaeridium cantharellus*) and foraminiferal wall linings were recovered in this study. Marine species (dinoflagellates, acritarchs and foraminiferal wall linings) were recovered from the dark shale lithofacies whereas clay flasers formed on the sandstone under quiet water condition. Depositional environment is interpreted as lagoonal/mixed flat.

A single count of *Cordosphaeridium cantharellus* together with few occurrences of *Leiosphaeridia* sp., foraminiferal wall linings and fungal spores and hyphae are attributes of the units.

The total palynomorph counts and percentages are shown in Table 3 whereas Fig. 7 shows the percentage distribution of the palynomorphs in the stratigraphic units sampled.

Results in Table 3 and Fig. 7 show pollen group to be of greater abundance and more diverse than other palynomorph groups. Distribution of palynomorphs in the stratigraphic unit, in the order of decreasing abundance is as follow: pollen (*Psilatricolporites* sp., *Longapertites marginatus*, *Psilastephanocolporites*, *Proxapertites operculatus* and *Retibrevitricolporites triangulatus*) and for spores *Laevigatosporites* sp. and *Leiotriletes* sp. dominated the group and were also abundant in all the samples analyzed. Some of the palynomorph groups recovered are shown as Fig. 8.

### 3.1.3 Micropaleontological analysis

The result of foraminiferal analysis is shown in Table 4. The mudstone and greyish shale lithofacies are barren of foraminiferal species. The assemblages in the dark shale lithofacies consist of low abundance of benthic species represented by both calcareous and agglutinated forms. Fig. 9 shows some of the forms recovered.

### 3.1.4 Paleoeocological classes and paleoclimatic studies

The palynoflora recovered belong to five paleoeocological classes namely; the mangrove/palm swamp, coastal plain/swamp, rainforest, freshwater swamp and marine groups (Fig. 10). Mangrove/ palm (*e.g* *Spinizonocolpites echinatus*, *Psilatricolporites* sp, *Longapertites marginatus* and *Proxapertites operculatus*) and fresh water pteridophytes (*e.g* *Laevigatosporites* sp and *Leiotriletes* sp) dominated the floral assemblage. Table 5 shows paleoecology and paleoclimatic conditions based on the palynomorphs recovered.

### 3.1.5 The Mangrove/palm group

Mangrove is grouped into nypa and pelliciera. nypa group recovered in this study consists of *Spinizonocolpites echinatus* (Fig. 8b) which shows high abundance in the stratigraphic units. *Psilatricolporites crassus* also show common occurrences and abundant.

### 3.1.6 Coastal plain/swamp and forest groups

The species of coastal plain/swamp recovered in this study show minor occurrences and are represented by *Monocolpites marginatus*, *Pachydermites diederixi*, *Retitricolporites irregularis*, *Retibrevitricolporites triangulatus*, *Polypodiaceoisporites* sp. among others.

The rainforest group is represented by *Psilastephanocolporites laevigatus* (*Saptoceae*) and *Bombacacidites* sp. which also show minor occurrences.
| Sample no. | Pollen | Spores | Others |
|------------|--------|--------|--------|
| Longapertites marginatus | | | |
| Palatalcolporites sp. | | | |
| Psilatricolporites sp. | | | |
| Psilatricolporites rotundus | | | |
| Psilastephanocolporites laevigatus | | | |
| Proxapertites operculatus | | | |
| Psilatricolporites crassus | | | |
| Scabratisporites anummensis | | | |
| Retibrevitricolporites triangulatus | | | |
| Monocolpites marginatus | | | |
| Scabratisporites ibadanensis | | | |
| Psilatricolporites calabarensis | | | |
| Margocolpites foveolatus | | | |
| Reticolporites irregularis | | | |
| Striatricolporites undulatus | | | |
| Retitricolporites ituensis | | | |
| Syncolporites marginatus | | | |
| Incerti cerdi | | | |
| Costatricolporites reticulatus | | | |
| Pachydermites diederixi | | | |
| Periretipollis spinosus | | | |
| Polypodiaceoisporites sp | | | |
| Cordosphaeridium cantharellus | | | |
| Leiosphaeridia | | | |
| Microforaminiferal test lining | | | |
| Fungi | | | |

Table 2. Palynological distribution chart of the shale samples
Table 3. Total count and percentage occurrences of the palynomorph groups recovered in the study

| Palynomorph group          | Total count | % Occurrence |
|----------------------------|-------------|--------------|
| Pollen                     | 1,114       | 72.20        |
| Spores                     | 349         | 22.62        |
| Fungi                      | 49          | 3.18         |
| Acritarch                  | 26          | 1.69         |
| Foraminiferal wall lining  | 4           | 0.25         |
| Dinoflagellates            | 1           | 0.06         |
| Total                      | 1543        | 100          |

Fig. 7. Percentage distribution of palynomorphs groups in the stratigraphic units

3.1.7 Fresh water swamp
Fresh water swamps dominated by the pteridophyte ferns such as Laevigatosporites sp and Leiotriletes sp which are fairly abundant in the samples. Others include Verrucatosporites sp., Syncolporites marginatus and fungal hyphae which show minor occurrences. These suggest fresh water influx from terrestrial environments.

3.1.8 Marine group
The marine group recorded very low counts of an acritarch (Leiosphaeridia), foraminiferal test linings and dinoflagellate cyst (Cordosphaeridium cantharellus).

Paleoclimatic condition of the period based on the palynomorphs is inferred to vary from wet to dry but wetter periods predominated over dry ones (Table 4). The climate is interpreted as humid and warm (tropical). Mangrove vegetation was dominant during wetter climates whereas rainforest was minimal. They expanded further into the coastal plain/savanna.

3.2 Discussion

3.2.1 Depositional environment
Lithofacies and biostratigraphic analyses of the Ogbunike old toll gate succession show that the
Fig. 8a. Photomicrograph of some of the palynomorphs recovered in this study. All the palynomorphs are of the same size (X400)
1. Margocolporites foveolatus [27], 2. Retibrevitricolporites triangulates [28], 3. Retibrevitricolporites triangulates [28], 4. Psilatricolporites crassus [29], 5. Psilatricolporites crassus [29], 6. Monocolpites marginatus [30], 7. Ctenolophonidites costatus [31, 28], 8. Ctenolophonidites costatus [31, 28], 9. Scrabratisporites simpliformis [28], 10. Proxapertites cursus [28], 11. Proxapertites operculatus [32], 12. Anacolosidites luteoides [33], 13. Gabonisporites viaourouxii [34], 14. Margocolporites foveolatus, 15. Psilatricolporites sp, 16. Longapertites marginatu [31]

Fig. 8b. Photomicrograph of some of the palynomorphs recovered. All the palynomorphs are of the same size (X400)
(1). Spinizonocolpites echinatus [35], (2). Bombacacidites sp, (3) Psilatricolporites owerriensis [10], (4) Psilamonocolpites sp, (5) Leiotrilete sp, (6) Laevigatosporites sp, (7) Fungal hyphae (8) Foraminiferal wall lining
Table 4. Summary of age and bathymetry of recovered foraminifera

| Sample no | Lithofacies              | Foraminifera Species                                                                 | Bathymetry | Age          |
|-----------|--------------------------|--------------------------------------------------------------------------------------|------------|--------------|
| NAK5a     | Carbonaceous mudstone    | Barren of foraminifera                                                              | Non marine | Indeterminate|
| NAK5b     | Greyish shale            | Barren of foraminifera                                                              | Non marine | Indeterminate|
| NAK5c     | Dark pyritic shale       | *Heterolepa pseudoungeriana* *Florilus exgrcostiperium* *Ammobaculites sp, Cibicides sp, Shell fragment* | Inner Neritic | Non-diagnostic|
| NAK5d     | Dark pyritic shale       | *Hanzawaia strattoni* *Haplophragmoides cf. excavatus* *Haplophragmoides sp* *Reophax sp, Ammobaculites sp, Echinoid remains* | Inner Neritic | Indeterminate|
| NAK5f     | Dark pyritic shale       | *Heterolepa pseudoungeriana* *Haplophragmoides sp* *Ammobaculites sp, Nodosaria sp, Uvigerina subperegrina Bolivina sp, Uvigerina sp, Uvigerinella sp* | Inner Neritic | Non-diagnostic|
| NAK5g     | Dark pyritic shale       | *Fursenkoina bowie* *Haplophragmoides sp, Miliammina sp, Textularia sp*              | Inner Neritic | Indeterminate|
| NAK4      | Dark pyritic shale       | *Florilus atlanticus*                                                               | Inner Neritic | Non-diagnostic|
| NAK 3     | Greyish shale            | Barren of foraminifera                                                              | Non marine | Indeterminate|

Fig. 9. Some of the foraminifera recovered from the study

1. *Nodosaria sp* (Fragment)(Magnification: x402, Dimension: 176.1x27.1um); 2. *Milliammina sp* (Magnification: x610, Dimension: 375.3x217.2um); 3. *Ammobaculites sp* (Magnification: x360, Dimension: 251.3x152.1um); 4. *Reophax sp* (Magnification: x360, Dimension: 232.1x93.1um); 5. *Haplophragmoides cf excavatus*(Magnification: x420, Dimension: 300.2x202um); 6. *Ammobaculites sp* (Magnification: x320, Dimension: 207.3x176um); 7. *Haplophragmoides sp* (Magnification: x375, Dimension: 214.2x168um)
Fig. 10. Paleoecology of the palynomorphs showing the five classes

Table 5. Paleoecology and paleoclimatic conditions based on the palynomorphs

| Palynomorph Group | Species                                      | Vegetation/paleoecology | Climate  |
|-------------------|----------------------------------------------|--------------------------|----------|
| Pollen            | Spinizonocolpites echinatus                  | Mangrove                 | Wet      |
|                   | Pilatricolporites crassus                    | Mangrove                 | Wet      |
|                   | Psilatricolporites sps.                      | Palmae/mangrove          | Wet      |
|                   | Longapertites marginatus                     | Palmae/mangrove          | Wet      |
|                   | Proxapertites operculatus                    | Palmae/mangrove          | Wet      |
|                   | Mauritidiites sp                             | Palmae/mangrove          | Wet      |
|                   | Psilamonocolpites sp.                        | Back-mangrove            | Wet      |
|                   | Bombacacidites sp                            | Rainforest/back-mangrove | Wet      |
|                   | Pslastephanocolpites laevigatus              | Rain forest              | Wet      |
|                   | Retitricolporites irregularis                | Coastal plain/Savanna    | Dry      |
|                   | Retibrevitricolporites triangulatus          | Upper coastal plain      | Dry      |
|                   | Monocolpites marginatus                      | Upper coastal plain      | Dry      |
|                   | Pachydermites diederixi                      | Coastal plain            | Wet      |
|                   | Syncolporites marginatus                     | Fresh water              | Wet      |
| Spores            | Laevigatosporites sp.                        | Fresh water              | Wet      |
|                   | Leiotriletes                                 | Fresh water              | Wet      |
|                   | Verrucatosporites sp                         | Fresh water              | Wet      |
|                   | Polypodiaceoisporites sp                     | Coastal plain            | Wet      |
| Marine palynomorphs | Acritharch                             | Marine                   | Wet      |
|                   | Microforaminiferal wall lining                | Marine                   | Wet      |
|                   | Dinoflagellates                              | Marine                   | Wet      |

Sediments were deposited in a varying environmental setting that fluctuated from fluvial channel through marginal marine to shelf (shallow marine). Deposition of the units started with the lower shoreface bioturbated and wave ripple laminated fine grained sandstone and claystone at the base of the succession. Abundant burrows of *Thalassinoïdes* and low amplitude wave
The age of the samples could not be determined from the benthic foraminiferal assemblages due to non-recovery of age diagnostic forms. The succession is stratigraphically assigned to the Ameki Group (Nanka Formation).

3.2.3 Paleoecological interpretation

Five paleoecological groups of palynomorphs identified in this study is also attributed to fluctuation in paleoenvironmental conditions of deposition. Spinizonocolpites echinatus recovered in this work is a mangrove pollen. Psilatricolporites crassus has been described as a woody mangrove community, widespread across Africa [38] and South America [29,60] but endemic today to central and northern South America [61-64]. Longapertites marginatus, Proxapertites operculatus, Retimonocolpites asabaensis, Psilatricolporites sp., Mauritidites sp. are elements of mangrove swamp forest (though considered as weak mangrove) recovered in abundance and are referred to as pollen with affinity to modern palms [38,65,44]. The mangrove must have resulted from tides along the margins of the coastal lagoons and brackish tidal waters [66]. The predominance of the mangrove and palm groups over other palynomorphs in the stratigraphic units probably is suggestive of the deposition of the sediments during a predominantly wet and warm period when mangroves and palms thrived most.

Paleoecological parameters evaluated from the foraminiferal data in Table 4 include; paleobathymetry, oxygenation and paleo-temperature.

3.2.3.1 Paleobathymetry

Foraminifera are considered as an important tools in paleoenvironmental and paleoecological studies (e.g Cicha [67-68]). The benthic ones are widely used for paleobathymetric reconstruction because they dwell in a wide range of environment varying from shallow marine to deep marine settings. Benthic foraminiferal assemblages recovered from the dark shale lithofacies suggest shallow marine (inner neritic) setting for the lithofacies. Similar assemblages were recovered from the inner neritic environment in the subsurface part of the Niger Delta [69-70]. According to Allen [71], inner neritic environment lies within 0-30 m on the continental shelf.
4. CONCLUSION

Lithofacies analysis of the outcropping succession at Ogbunike toll gate have shown that the exposure was deposited in an environmental settings that vary from fluvial to marginal and shallow marine (inner shelf). Pollen and spores assemblages recovered from the shale and mudstone lithofacies indicated Middle Eocene age for the succession. The exposure is stratigraphically assigned to the Ameki Group and the age is here interpreted as Middle Eocene. Five paleoecological groups consisting of mangrove/palm, coastal plain, rain forest, fresh water swamp and the marine groups were identified based on palynomorphs. Benthic foraminiferal assemblages from dark shale lithofacies suggest sub-oxic, nutrient-rich, inner shelf setting. Paleoclimatic condition from biofacies was warm and humid (tropical).

3.2.3.2 Oxygenation

The usefulness of benthic foraminifera in the reconstruction of paleo- oxygenation in marine is documented [72-77]. Abundance of Bolivina, Fursenkoina and Uvigerina has been noted as a good indicator of oxygen- depleted environments [78-80,72-73,81-83,74]. Association together with low abundance of Bolivina, Fursenkoina and Uvigerina in the dark shale may probably indicate suboxic condition of deposition for the facies. Moreover, calcareous benthic foraminifera such as Bolivina sp. and Cibicides sp. have been described and grouped as oxic to suboxic foraminiferal indicators [84]. High diversity and abundance of such foraminiferal assemblages with thick- walled, large and ornamented tests are possible indication of oxygenated marine environment [85-86]. Low abundance of these indicator foraminifera agrees with suboxic condition of deposition for the dark shale.

3.2.3.3 Paleotemperature

The diversity of planktonic foraminifera is related to paleotemperature conditions of the sea [87-88]. Its diversity in modern oceans was reported to be lower in cool water than in warm waters [89]. Rare occurrence of planktonic foraminiferal assemblage in the dark shale studied suggests deposition mostly during the period of cool water temperature. Bolivina and Uvigerina have been referred to as cold water assemblages [85].

REFERENCES

1. Nwajide CS. Geology of Nigeria’s Sedimentary Basins, first ed. CSS Press: Lagos Nigeria; 2013. [ISBN: 978-978-8401-67-4]
2. Maron P. Stratigraphical aspects of the Niger Delta. Journal of Mining and Geology.1969;4(1 & 2):3-12. Available: nmgsjournal.org
3. Wright DA., Hastings JB, Jones WB, Williams HR. Geology and mineral resources of West Africa. George Allen and Unwin: London; 1985. Available:https://doi.org/10.1002/gij.3350220519
4. Newton RB. Eocene Mollusca from Nigeria. Geological Survey of Nigeria Bulletin. 1922;3:115. Available: https://doi.org/10.5962/bhl.tittle.29842
5. Eames FE. Eocene Mollusca from Nigeria. A revision. Bulletin of the British Museum (Natural History). 1957;3(2):23-70. Available:https://biodiversitylibrary.org/page/2290338
6. Berggren WA. Paleocene biostratigraphy and planktonic foraminifera of Nigeria (W. Africa). Proceedings 21st International Geological Congress, Copenhagen, Rept., Pt. 1960;6:41-55. Available:https://books.google.com.ng
7. Reyment RA. Aspects of the geology of Nigeria: The stratigraphy of the Cretaceous and Cenozoic deposits. Ibadan University Press: Ibadan; 1965. Available:https://searchworks.standford.edu/view/1132180
8. Whiteman AJ. Nigeria: Its petroleum geology, resources and potential. Graham and Trotman; London; 1982. Available:https://doi.org/10.1007/978-94-009-7361-9
9. Jan du Chene RE, Onyike MS, Sowunmi M.A. Some new Eocene pollen of the Ogwashii Asaba Formation, southeastern Nigeria. Rev. Esp. de Micropal. 1978;10(2):285-322.
10. Okezie CN, Onuogu SA. The lignite of southeastern Nigeria. Geological Survey of Nigeria Occasional Paper. 1985;10:28.
11. Umeji OP. Palynological data from the road section at the Ogbunike toll gate, Onitsha, southeastern Nigeria. Journal of Mining and Geology. 2003;39:95-102. Available:https://www.ajol.info/index.php/jmg/article/view/18797

12. White EL. Eocene fishes of Nigeria. Bulletin of Geological Survey of Nigeria. 1926;10:78. Available:https://trove.nla.gov.au/work/33082785

13. Nwajide CS. A lithostratigraphic analysis of the Nanka Sand, Southeastern Nigeria. Journal of Mining and Geology. 1979;16:103-109. Available: nmgsjournal.org

14. Fayose EA, Ola PS. Radiolarian occurrences in the Ameke type section, eastern Nigeria. Journal of Mining and Geology. 1990;26:75-80. Available: nmgsjournal.org

15. Chiaghanam OI, Chidiakaobi, KC, Ikegwuonwu ON, Omoboriowo AO, Onyemesili OC, Yikarebogha Y. Sedimentology and sequence stratigraphy of the Eocene Nanka Formation (Ameke Group): An evaluation of Ogbunike Reference locality in Anambra Basin, southeastern Nigeria. Journal of Applied Geology and Geophysics. 2014;2(3):1-10. DOI: 10.9790/0990-0230110

16. Burke KC, Dessauvagie TFJ, Whiteman AJ. Geological history of the Valley and its adjacent areas. In: Dessauvagie TFJ, Whiteman AJ editors. African Geology. University of Ibadan Press: Ibadan; 1972. Available:https://www.worldcat.org/oclc/640002964

17. Benkheil J. Benue Trough and Benue Chain, Geology magazine. 1982;119:155-168. Available:https://doi.org/10.1017/S001675680002584X

18. Benkheil J. The origin and evolution of the Cretaceous Benue Trough (Nigeria). Journal of African Earth Sciences. 1989;9:251-282. Available:https://doi.org/10.1016/s0899-5362(99)80028-4

19. Hoque M, Nwajide CS. Tectono-sedimentological evolution of an elongate intracratonic basin (aulacogen): The case of the Benue Trough of Nigeria. Journal of Mining and Geology. 1984;21:19-26.
28. Van Hoeken Klinkenberg PMJ. Maastrichtian, Paleocene and Eocene pollen and spores from Nigeria. Geologische Mededelingen. 1966;38:37-48. Available:https://www.narcis.nl/publication/recordID/506002

29. Van der Hammen T, Wymstra TA. A palynological study on Tertiary and upper Cretaceous of British Guiana. Mededelingen Rijks Geologische Dienst. 1964;30:183-241. Available:https://www.narcis.nl/publication/RecordID/3A505816

30. Van der Hammen T. The development of Columbian flora throughout geological periods, I. Maastrichtian to Lower Tertiary. Boletín Geológico (Bogotá). 1954;2(1):49-106. Available:fossilworks.org/bridge.pl?756192

31. Van Hoeken Klinkenberg PMJ. A palynological investigation of some Upper Cretaceous sediments in Nigeria. Pollen et Spore. 1964;6(1):209-231. Available:fossilworks.org/bridge.pl?757722

32. Van der Hammen T. A palynological systematic nomenclature. Boletin Geologico (Bogotá). 1966;4(2-3):63-101. Available:https://revistas.sgc.gov.co/index.php/boletingeo/article/196

33. Cookson IC, Pike KM. Some dicotyledonous pollen types from Cainozoic deposits in the Australian region. Australian Journal of Botany. 1954;2(2):197-219. DOI: 10.1071/bt9540197

34. Boltenhagen E. Spores et pollen du Crétacé. Supérieur du Gabon. 1967;9(2):335-355. Available:https://paleobotany.ru/palynodatable/palynodatable/1544

35. Muller J. Palynology of the Pedawan and Plateau Sandstone formations (Cretaceous-Eocene) in Sarawak, Malaysia. Micropaleontology. 1968;14:1-37. DOI: 10.2307/1484763

36. Evamy DD, Haremboire J, Kamerling P, Knaap WA, Molley FA, Rowlands PH. Hydrocarbon habitat of Tertiary Niger Delta. American Association of Petroleum Geologist Bulletin. 1978;62(1):1-39. Available:https://doi.org/10.1306/C1EA47E-D-16C9-11D7-864500102C1865D

37. Biostrat. Sub-committee of Niger Delta. Palynological taxonomy project, Cenozoic Niger Delta, Nigeria; 2000.

38. Germeraad JH, Hopping CA, Muller J. Palynology of Tertiary sediments from tropical areas. Review of Palaeobotany and Palynology. 1968;6(3-4):189 -348. Available:https://doi.org/10.1016/0034-6667(68)90051-1

39. Stead DT, Awad MZ. Palynological zonation of Cenozoic non-marine sediments, Muglad Basin, Sudan. In: Powell AJ, Riding JB, editors. Recent developments in applied biostratigraphy. Geological Society of London/British Micropaleontological Society Special Publication; UK. 2005;161-178. DOI: 10.114/TMS001.10

40. Muller J, Giacom E, Van Erve AW. A palynological zonation for the Cretaceous, Tertiary and Quaternary of Northern South America. American Association of Stratigraphic Palynologists Contribution Series. 1987;19:7-76. Available:https://paleobotany.ru/palynodata/palynodata/14737

41. Kogbe CA, Mebes K, Le-Calvez Y, Grekoff N. Micro-biostatigraphy of lower Tertiary sediments from the south-eastern flanks of the Lullemmeden basin (Northwestern Nigeria). In: Kogbe CA editor. Geology of Nigeria. Elizabethan Pub; Lagos;1975. Available:https://www.worldcat.org/679130

42. Thanikaimoni G, Caratini C, Sivak J, Tissot C. Striatoechoporites, a new pollen genus from offshore Tano Basin, southwestern Ghana. Revista Española de Micropaleontología. 2004;36(3):451-465. [ISSN: 0556-655X] Available:https://www.researchgate.net/publication/228776954

43. Muller J. Palynology of the Pedawan and Plateau Sandstone formations (Cretaceous-Eocene) in Sarawak, Malaysia. Micropaleontology. 1968;14:1-37. DOI: 10.2307/1484763

44. Atta-Peters D, Salami M.B. Late Cretaceous to early Tertiary pollen grains from offshore Tano Basin, southwestern Ghana. Revista Española de Micropaleontología. 2004;36(3):451-465. [ISSN: 0556-655X] Available:https://www.researchgate.net/publication/228776954

45. Edward LE. Dinocyst biostratigraphy of Tertiary sediments from five cores from Screven and Burke countries, Georgia. In: Edward LE editor. Geology and
Onuigbo et al.; JGEESI, 24(3): 80-99, 2020; Article no.JGEESI.56237

paleontology of five cores from Screven and Burke countries, Eastern Georgia. Geological Survey of United States Professional Paper. 1998;1603- G, G1- 24. Available:https://books.google.com.ng

46. Van Pelt R, Christopher RA, Engelhardt DW, Lucus-Clark J. Establishing a hydrostratigraphic framework using palynology: An example from the Savannah River Site, South Carolina, USA. Office of Scientific and Technical Information, Technical Report, UNT Libraries; 2000. Available:https://doi.org/10.1007/978-1-4615-4167-7_19

47. Claus H, Stefaan VS. Dinoflagellate cysts from the middle Eocene to? Lower most Oligocene succession in the Kysing Research borehole, Central Danish Basin. Palynology. 2005;29:143-204. Available:https://doi.org/10.1080/01916122.2005.9899606

48. Camille H. Palynological analysis of ocean drilling program Leg 210 Wellsite 1276: Trends surrounding the Paleocene–Eocene thermal maximum. Dalhousie University; 2017. Available:http://hdl.handle.net/10222/75174

49. Bujak JP, Downie C, Eaton GL, Williams GL. Dinoflagellate cyst and acritarchs from the Eocene of southern England. Paleontology Association of London. Special Paper in Paleontology. 1980;24: 96. Available:https://www.researchgate.net/publication/313585232

50. Mohamed O, Egger H. Lutetian to Priabonian organic-walled dinoflagellate cyst assemblages from the northwestern Tethyan margin (Adelholzen section, Eastern Alps, Germany). EGU General Assembly, Vienna, Australia. 2015;17: EGU2015-11082. Available:https://www.researchgate.net/publication/275953239

51. Condon PJ, Jolley DW, Morton AC. Eocene succession of the east Shetland Platform, North Sea. Marine and Petroleum Geology. 1992;9(6):633-647. Available:https://doi.org/10.1016/0264-8172(92)90036-E

52. Edward LE. Paleocene and Eocene dinocysts from the salt range, Punjab, northern Pakistan, P. C-C 10, in: Warwick, P.D. and Wardlaw, B.R., (Eds.), Regional Studies of the Potwar Plateau area, northern Pakistan. Geological Survey of United States Bulletin 2078;2007. Available:https://pubs.usgs.gov/bul/2078/B2078

53. Lakovleva Al. Middle- late Eocene dinoflagellate cysts from NE Ukraine (Borehole, No 230, Dnepr- Donets Depression): Stratigraphic and Paleoenvironmental approach. Acta Palaeobotanica. 2015;55(1):19-51. DOI: 10.1515/acpa-2015-0001

54. Ali Akbar JN, Ebrahim GN. Late Paleocene to early Oligocene dinoflagellate cysts of the Zagros Basin, west Iran (Paleopalynology and palynostratigraphy). Journal of Applied Science and Environmental Management. 2015;19(3):480-485. Available:http://dx.doi.org/10.4314/jasem.v19i3.18

55. Ali Akbar JN, Ebrahim G, Tayeben M, Ali A. Paleogene dinoflagellate cysts and thermal maturity from Pabdeh Formation (Zagros basin, west of Iran). Journal of Applied Science and Environmental Management. 2015;19(3):353-358. Available:http://dx.doi.org/10.4314/jasem.v19i3.3

56. Jan du Chene RE, Adediran SA. Late paleocene to early eocene dinoflagellates from Nigeria. Cahiers de Micropaleontologie. 1985;3:1-38. Available:https://www.worldcat.org

57. Oloto IN. Succession of palynomorphs from the early Eocene of Gbekebo -1 well in southwest Nigeria. Journal of African Earth Sciences. 1992;15(3):441-452. DOI: 10.1016/0899-5362(92)90027-A

58. Crouch EM, Brinkhuis H, Visscher H, Bolle MP. Late Paleocene – early Eocene dinoflagellate cyst records from the Tethys; Further observations on the global distribution of Apectodinium. Special Paper of the Geological Society of America 369; 2003. DOI: 10.1130/0-8137-2369-8.113

59. Arun K. New palynological evidence for the age of the Beda Formation, Sirte Basin, Libya. Palaeontologia Electronica. 2016;19.3.43A:1-14. DOI: 10.26879/639

60. Rull V. A quantitative palynological record the early Miocene of Western Venezuela, with emphasis on mangroves. Palynology. 2001;25(1):109-126. DOI: 10.2113/0250109
61. Wyrmstra TA. The identity of *Psilatricolporites* and *Pelliciera*. Acta Botanica Neerlandica. 1968;17:114-116. Available: https://doi.org/10.1111/j.1438-8677.1968.tb00112.x

62. Winograd M. Observaciones sobre el hallazgo de *Pelliciera rhizophorae* (Theaceae) en el Caribe Colombiano. Biotropica. 1983;15:297-298. ISSN: 0006-3606, agris.fao.org/recordID=us19850022999

63. Jimenez JA. A hypothesis to explain the reduced distribution of the mangrove *Pelliciera Rhizophorae* Tr. and Pl. Biotropica. 1984;16:304-308. DOI: 10.2307/2387939

64. Graham A. Diversification of Gulf/Caribbean mangrove communities through Cenozoic time. Biotropica. 1995;27:20-27. DOI: 10.2307/2388899

65. Edet AE, Nyong EE. Palynostratigraphy of the Nkporo Shale exposure (Late Campanian-Maastrichtian) on Calabar Flank, S.E. Nigeria. Review of Palaeobotany and Palynology. 1994;80:131-147. Available: https://doi.org/10.1016/0034-6667(94)90098-1

66. Vannucci M. What is so special about mangrove? Brazilian Journal of Biology. 2001;61(4):599-603. DOI: 10.1590/S1519-69842001000400008

67. Cicha I. Contemporary state of opinion on the age of the Grund Formation. Zpr. geol. vyzk v r. 2000;1999:182-183. Available: https://www.geology.cz/zpravy/121

68. Cicha I. Outline of stratigraphy of the middle Miocene in the Alpine- Carpathian foredeep (Lower Austria- Moravia). Scripta Fac. Sci. Nat. Univ. Masaryk. Brun. 30, Geology. 2001;23-26.

69. Adegoke OS, Omatso ME, Salami MB. Benthic foraminifera biofacies of the Niger Delta. Maritime Sediment, Special Publication. 1976;1:279-292. Available: https://www.researchgate.net/publication/288913135

70. Adegoke OA, Oyebamiji A, Edet J, Osterlof P, Ulu O. Cenozoic foraminifera and calcareous nannofossil biostratigraphy of the Niger Delta. 1st ed. Elsevier; 2016. [ISBN: 9780128122372] Available: https://www.researchgate.net/publication/312041948

71. Allen JRL. Late quaternary Niger Delta and adjacent areas- sedimentary environments and lithofacies. AAPG Bull. 1965;49:547-600

72. Kaiho K. Benthic foraminiferal dissolved oxygen index and dissolved oxygen levels in the modern ocean. Geology. 1994;22:719-722. DOI:10.1130/0091-7613(1994)022<0719:BFDIOA>2.3.CO:2

73. Bernhard JM, Sen Gupta BK, Borne PF. Benthic foraminiferal proxy to estimate dysoxic bottom-water oxygen concentrations, Santa Barbara basin U.S., Pacific Continental Margin. Journal of Foraminiferal Research. 1997;27:301-310. Available: https://doi.org/10.2113/gsjfr.27.4.301

74. Nigam R, Mazumber A, Henriques PJ, Saraswat R. Benthic foraminifera as proxy for oxygen depleted conditions off the central west coast of India. Journal of Geological Society of India. 2007;70:1047-1054. Nio.org/2264/751/j_Geo_Soc_India_701_047

75. Nigam RV, Prasad Mazumber A, Garg R, Saraswat R, Henriques PJ. Late holocene changes in hypoxia off the west coast of India: Micropaleontological evidences. Current Science. 2009;96:708-713. Available: https://www.jstor.org/stable/24104567

76. Schumacher S, Jorissen FJ, Dissard D, Larkin KE, Goody AJ. Live (Rose Bengal Stained) and dead benthic foraminifera from the oxygen minimum zone of the Pakistan Continental Margin (Arabian Sea). Marine Micropaleontology. 2007;62:45-73. Available: https://doi.org/10.1016/j.marmic.2006.07.004

77. Mazumber A, Nigam R. Bathymetric preference of four major genera of rectilinear benthic foraminifera within oxygen minimum zone in Arabian Sea off central west coast of India. Journal of Earth System Science. 2014;123(3):633-639. DOI: 10.1007/s12040-0014-0419-y

78. Pfleger FB, Soutar A. Production of Benthic foraminifera in three east Pacific oxygen minima. Micropaleontology. 1973:19:110-115. DOI: 10.2307/1484973

79. Bernhard JM. Experimental and field evidence of Antarctic foraminiferal tolerance to anoxia and hydrogen sulfide.
Marine Micropaleontology. 1993;20:203-213.
Available:https://doi.org/10.1016/0377-8398(93)90033-T
80. Alve E. Benthic foraminiferal distribution and recolonization of formerly anoxic environments in Drammensfjord, southern Norway. Marine Geology. 1995;25:169-286.
DOI: 10.2113/gsjfr.25.3.190
81. Bernhard JM, Sen Gupta BK. Foraminifera of oxygen depleted environments. In: Sen Gupta BK editor. Modern foraminifera. Kluwer; Dordrecht. 1999;201-216.
Available:https://springer.com/10.1007/0-306-48104-9
82. Gooday AJ, Bernhard JM, Levin LA, Suhr SB. Foraminifera in the Arabian Sea oxygen minimum zone and other oxygen deficient settings. Taxonomic composition, diversity and relation to metazoan fauna. Deep-Sea Research. 2000;47:24-54.
DOI: 10.1016/s0967-0645(99)00099-5
83. Fontanier C, Jorissen FJ, Licari L, Alexandre A, Anschutz P, Carbonel P. Live benthic foraminiferal fauna from the Bay of Biscay: Faunal density, composition, and microhabitats. Deep-Sea Research. 2002;49:751-785.
DOI: 10.1016/S0967-0637(01)00078-4
84. Drinia H, Tsaparas, N, Antanorakou, A, Goumas G. Benthic foraminiferal biofacies association with Middle to Early Late Miocene oxygen deficient conditions in Eastern Mediterranean. Paper presented at the 8th International Conference of Environmental Science and Technology, Lemnos Island, Greece; 2003.
Available:https://www.google.com.ng/search?q=foraminiferal+re&gs_l=00000000000000000000000000
85. Murray JW. Ecology and paleoecology of benthic foraminifers. Longman Scientific and Technical; New York; 1991.
Available:https://doi.org/10.4324/9781315846101
86. Valchev B. On the potential of small benthic foraminifera as paleoecological indicators: Recent Advances. Geology and Geophysics. 2003;46(1):189-194.
87. Danuta P, Tadeusz MP. Foraminiferal record of the onset of the Middle Miocene Badenian salinity crisis in Central Paratethys. Oral presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana; 2010.
Available:https://www.google.com.ng/search?q=foraminiferal+re&gs_l=00000000000000000000000000
88. Kopecka J. Foraminifera as environmental proxies of the Middle Miocene (Early Badenian) sediments of the central Depression (Central Paratethys, Moravian part of the Carpathian Foredeep). Bulletin of Geosciences. 2012;87(3):431-442.
89. Boltovskoy E, Wright R. Recent foraminifera. The Hague. 1976;515.
Available:http://dx.doi.org/10.1007/978-94-017-2860-7

© 2020 Onuigbo et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/56237