DEPOSITIONAL HISTORY AND PALEOENVIRONMENTAL CONDITIONS OF SEDIMENTARY ROCKS IN UHIERE VILLAGE, BENIN FLANK, NIGERIA

Supported by tetfund

E.G. Maju-Oyovwikowhe[1] and Osahon Ukpebor[2]
[1]Department of Geology, Faculty of Physical Sciences, University of Benin, Benin City, Nigeria
[2]Department of Geoscience, Faculty of Science, University of Lagos, Lagos State, Nigeria
Corresponding author Email: efetobore.maju@uniben.edu
Received: May 11, 2019 **Accepted: July** 18, 2019

Abstract

This study investigates the depositional history and environmental conditions of sedimentary rocks exposed in Uhiere village, located in the Benin flank of Nigeria. Grain size analysis, heavy mineral analysis, and palynomorph assemblage studies were conducted on selected samples from the outcrop to gain insights into the formation of these sedimentary rocks. Grain size analysis showed that the sediments range from very fine-grained to medium-grained with poor sorting, indicating deposition by low to moderate velocity currents alternating with quiet depositional regimes during which shales were deposited. Heavy mineral analysis and morphoscopic studies indicated an igneous and metamorphic source for the sediments and proximity to the source area. Palynomorph assemblage studies revealed an Eocene age for the sediments and suggested that they were deposited in a swampy or brackish environment. The lithological characteristics and palynomorph assemblage were consistent with the Ameki Formation, which represents the surface equivalence of the subsurface Agbada Formation in the Anambra Basin. The findings of this study contribute to the understanding of the depositional history and environmental conditions that led to the formation of these sedimentary rocks. The results suggest that the sediments were deposited in a paralic environment with alternating sand and shale units. The presence of heavy minerals and the proximity to the source area indicate a local sediment source. The Eocene age and palynomorph assemblage suggest a warm and humid climate with abundant vegetation. These findings are relevant for the exploration and exploitation of hydrocarbon resources in the Niger Delta sedimentary basin and provide insights into the paleoenvironmental conditions of the region.

Keywords: Sedimentary rocks, Depositional history, Paleoenvironmental conditions, Grain size analysis, Heavy mineral analysis, Palynomorph assemblage, Niger Delta Sedimentary basin

Introduction

The concept of interpreting rocks in terms of modern processes dates back to the 18th and 19th centuries (the present is the key to the past). The nature of sedimentary material is very varied in origin, size, shape and composition (Maju-Oyovwikowhe and Lucas, 2019). The study of sedimentary rocks and their depositional history is crucial in understanding the geological and environmental conditions of a region. A depositional environment describes the combination of physical, chemical and biological processes associated with the deposition of a particular type of sediment and therefore the type of rock that forms after lithification. Therefore environment at any point on the land or under the sea can be characterized by the physical and chemical processes that are active there and the organisms that live under those conditions at that time (Maju-Oyovwikowhe and Lucas, 2019).

In the Niger Delta sedimentary basin, sedimentary rocks are known to contain vast reserves of hydrocarbon resources, making their study of great importance for the petroleum industry. The Niger Delta sedimentary basin is a major petroleum-producing region in Nigeria and is believed to contain significant reserves of hydrocarbons. Sedimentary rocks, which are the primary source of oil and gas in the region, are thus of great importance to the petroleum industry. The study of these rocks and their depositional history can provide insights into the location, quantity, and quality of hydrocarbon reserves in the basin, as well as the potential environmental and geological hazards associated with exploration and production activities.

Previous studies have established the lithostratigraphy of the Niger Delta sedimentary basin, including the Ameki Formation, which is the focus of this study. The Ameki Formation has been found to be rich in hydrocarbon deposits and has been extensively studied for its depositional history and paleoenvironmental conditions (Orajaka, 2016; Onuoha and Ukaegbu, 2018).

The fieldwork carried out in this study follows a standard procedure used in previous works, including the determination of the lateral and vertical extent of the outcrop and the detailed lithologic description of the various facies based on rock types, color of the sediments, and grain size (Orajaka, 2016; Onuoha and Ukaegbu, 2018). The use of palynomorph analysis as a tool for age determination and paleoenvironmental reconstruction has also been previously established (Obaje and Wehner, 2014).

Most works which contain information on the Benin Flank along with the study area are those carried out on a more regional level involving the geology of South Western Nigeria, the Niger Delta sedimentary basin as well as those on the geology of southern Nigeria. The mineral survey of southern Nigeria between 1905 and 1908, and Reyment (1965) carried out work on the geology of south western Nigeria. The first detailed works were carried out by Shell Darcy (now Shell Petroleum Development Corporation Nigeria Limited) 1908. Adegoke (1969) wrote on the Eocene stratigraphy of southern Nigeria. Jones and Hocky (1964) carried out the geology of parts of south western Nigeria. Stratigraphy and paleontology of Afowo – 1 was carried out by Fayose, 1970. Other workers who have included descriptions either parts or whole of the Benin flank in their works include; Reyment (1965) who published a work on the 'Aspects of the Geology of Nigeria' and formalized the Ameki Formation. Murat (1972) wrote on the stratigraphy and paleogeography of the cretaceous and lower tertiary sequence in southern Nigeria. Kogbe (1974) attempted the description of the cretaceous and paleocene sediments of southern Nigeria. Ogbe et. al. (Unpublished report) wrote on the cenozoic stratigraphy, southern Nigeria, the Ameki formation. However, detail studies of the statigraphy of this location section has not fully discussed with a view to correlating with well-established rock units in the basin.

The scope of this study includes a detailed analysis of the sedimentary rocks exposed in the study area, with a focus on their grain size distribution, provenance, age, and paleo-environmental conditions. Grain size analysis will be carried out to determine the size distribution of the sediments, while heavy mineral analysis will be used to identify the source of the sediments. Diagnostic palynomorphs recovered from palynological analysis will be used in conjunction with lithological characteristics of the sediments to determine their age and paleo-environmental conditions. The results of this study will be used to enhance correlation with well-established units in this part of the basin and contribute to the existing body of knowledge on the geology of the Niger Delta sedimentary basin.

Overall, this study contributes to the existing body of knowledge on the Ameki Formation and the depositional history of sedimentary rocks in the Niger Delta sedimentary basin, with implications for the exploration and exploitation of hydrocarbon resources in the region.

Materials and Methods

Study area and Location

The exposed outcrop section, which forms the basis of this study, is situated along the Benin-Akure road, approximately 250 meters from Uhiere Village in Edo State. The study area lies within the Benin flank of the Niger Delta basin, with coordinates between latitudes $6^0 – 7^0$N and longitude $5^0 – 6^0$ (as shown in Figure 1). The outcrop has a considerable lateral extent of approximately 200 meters, and a vertical extent of about 27 meters. The location and extent of the outcrop provide an ideal opportunity for a detailed study of the sedimentary rocks and their depositional history in the region.

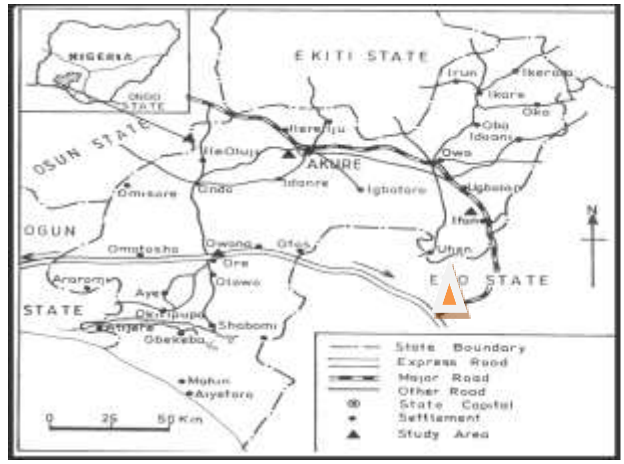


Figure 1 Map of the study area

Aim and scope of study

The aim of this project work is to make a detailed study of the stratigraphic section exposed in the study area. This involves:

(a) The determination of the grain size distribution of the sediments using grain size analysis.
(b) The determination of the provenance of the sediments using heavy mineral analysis.
(c) The determination of the age and paleo-environment of the sediments using diagnostic palynomorphs recovered from palynological analysis as well as lithological characteristics of the sediments. This would enhance correlation with well-established unit in this part of the basin.

Stratigraphy of the Benin flank of Niger Delta Basin

This represents the northwestern boundary of the Tertiary Niger Delta basin. The oldest rocks in the region are the Upper Cretaceous post Santonian rocks (largely Maestrichtian), which consist mainly of coarse-grained clastics and are known as the Abeokuta Formation. The Abeokuta Formation rests unconformably on the Basement Complex and is overlain by the Imo shale, which was deposited during the Paleocene Transgressive phase. The Imo shale is the up-dip or surface equivalent of part of the subsurface Akata Formation. The rocks of the Ameki Formation were deposited during the Eocene Regression and consist of deltaic sands and shallow marine clastics. The Benin Formation represents the youngest rocks in the region and consists mainly of yellow and white, coarse-grained, gravely, locally fine-grained, poorly sorted, sub-angular to well-rounded, sometimes cross-bedded sandstone with occasional intercalations of clays and lignite in the upper part (Figure 2).

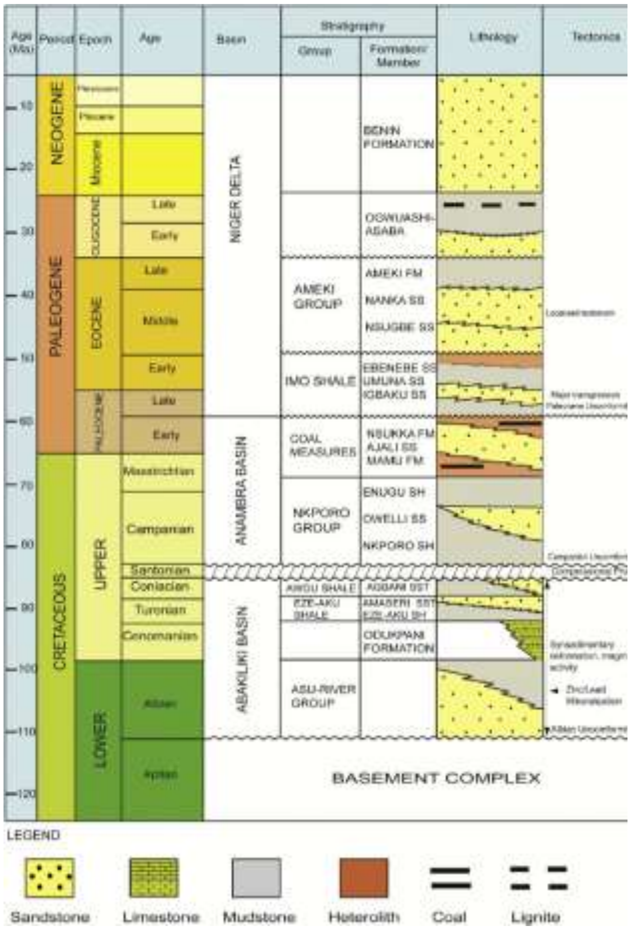


Figure 2 Stratigraphic succession in the Anambra Basin and Niger Delta (redrawn and modified from Short and Stauble, 1967; Nwajide, 2005).

Field survey

A comprehensive field study of the described outcrop was conducted during the early part of the year. The fieldwork was carried out with minimal difficulties, as the outcrop had been previously located, thus obviating the need for a search. To ensure a standardized approach, a procedural method was adopted in the study of the outcrop. Initially, the outcrop was identified on a map of Ifon and the surrounding area. Subsequently, the lateral and vertical extent of the outcrop was ascertained, and a detailed lithological description was made based on factors such as rock type, sediment color, grain size, and variations, among others. Any structures were also noted and their dips and strikes were taken where necessary. Additionally, the thickness of each bed was measured. Finally, a sketch of the outcrop was made, accompanied by an exhaustive lithological description of each bed. Fresh samples, amounting to approximately 25, were collected from the various beds for laboratory analysis.

Laboratory Work

Upon collection from the study outcrop, the samples underwent rigorous laboratory analysis to obtain valuable insights into their characteristics. These analyses included the determination of grain size distribution using the mechanical sieve method, general morphoscopic description of the sediments, heavy mineral analysis, and palynological analysis. The grain size distribution was obtained through the use of mechanical sieving techniques, while the general morphoscopic description of the sediments involved a detailed examination of the sediment's physical characteristics. The heavy mineral analysis was carried out to identify and quantify the presence of heavy minerals in the samples. Additionally, palynological analysis was carried out to study the organic material present in the samples. These laboratory analyses provided crucial data for the interpretation of the depositional environment and geological history of the outcrop.

Sieve Analysis

The grain size analysis of the sediment samples collected from the study outcrop was conducted using both wet and dry sieving methods. To begin with, 50g of each of the 18 samples were weighed and soaked in water with two drops of ammonia solution added for proper dispersion of the grains. After standing overnight for 24 hours, wet sieving was carried out using a 75µm mesh size to separate and determine the amount of fines in the samples. Both the fines that passed through the mesh and the larger-grained sand fraction were collected, dried and weighed.

Next, dry mechanical sieving was carried out on the sand fraction to determine the size distribution of the sand particles. The sand fraction was sieved using a set of sieves arranged in decreasing order of size: 2.36mm, 1.18mm, 600µm, 300 µm, 150 µm, and 75 µm. The weight of the sand fraction left in each sieve after sieving with the aid of a mechanical shaker was recorded, and their weight percentages, cumulative percentages, and percentage passing were calculated.

Cumulative curves for each sample were then plotted from which statistical parameters of the sediments were derived. These parameters included mean size (Mz), standard deviation, skewness (Sk), and kurtosis (k). These statistical parameters were used to deduce the hydrodynamics of sedimentation. Overall, this grain size analysis provided valuable information about the sedimentary characteristics of the outcrop and the depositional environment.

Heavy Mineral Analysis

The heavy mineral analysis of the collected samples involved the use of bromoform (S.G. = 2.85) as a heavy liquid to separate the heavy mineral fractions retained on the 75-micron mesh sieve. A total of 15 suitable samples were selected for this analysis. The apparatus used included a separating funnel, a filtering funnel with filter papers, a collecting flat bottom flask, and a retort stand. The procedure involved partly filling the separating funnel with bromoform and introducing the first sediment sample into it. The mixture was then stirred until the heavy fractions were no longer observed sinking to the bottom of the flask. The stopper was gently opened to allow the heavy minerals to flow out and collect in the filter paper in the filtering funnel. The bromoform liquid drained into the flask under the funnel. Afterwards, the flat bottom flask containing the accumulated bromoform was replaced with another, and the heavy minerals obtained were washed several times with methylated spirit and set aside to dry. The dried heavy minerals were then mounted on glass slides using canada balsam and examined under a petrographic microscope to determine the distribution of heavy minerals in the samples. The results of the analysis were then used to infer the source area of the sediments.

Palynological Analysis

Palynological investigation was carried out on shale samples collected from the study outcrop. Standard preparation techniques were used to isolate and prepare the palynomorphs for study. The samples were first air-dried in the laboratory and then crushed. 20g of each sample was weighed and placed in a labeled 100ml plastic beaker. To loosen and isolate the palynomorphs, suitable reagents were added to the sample. The first step involved adding 40% hydrofluoric acid (HF) to overflow the sample and dissolve or break the silicates and silica bonds. The samples were then left overnight for 24 hours. After this step, the hydrochloric acid (HCl) was carefully decanted, and the residue was washed with distilled water into a clean Pyrex glass beaker. The undissolved residue was discarded.

The next step involved adding hot concentrated hydrochloric acid (HCl) to the sample in the beaker, stirring properly, and then topping with water. This step eliminated the carbonates. Afterward, hot nitric acid (HNO_3) was added to the sample and stirred thoroughly. The solution was then topped with water and allowed to settle, after which it was decanted. This step was carried out to oxidize the samples and concentrate the palynomorphs. To neutralize humic acids, hot sodium hydroxide (NaOH) was added to the sample and stirred. The solution was then topped with water and allowed to settle, after which it was decanted. 0.5% HCl was then added to the sample and transferred into 10ml centrifuge tubes and decanted.

To separate the mineral debris from the macerate, heavy liquid flotation was carried out using zinc bromide (ZnBr) with a specific gravity of 2.2. The solution was separated and kept in properly labelled 10cc centrifuge tubes. 0.5% HCl was then again added to the organic residue centrifuge and then decanted. The organic residue was kept in properly labeled phials, and a few drops of glycerine were added to the organic residue to preserve them for mounting on slides. Palynomorphs recovered from the analysis were used to interpret depositional environment as well as the age of sediment deposition.

Results and Discussion

Grain size analysis

The results obtained from the grain size analysis performed on the sands are displayed in Tables 1 to 18. The compilation of data on the weight of sand retained in each sieve mesh, along with their corresponding weight percentages, cumulative percentages, and percentages passing are presented

Table 1 Sample A1
Sample initial weight = 50g
Final weight = 46.06g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.00	0.00	0.00	100
1.18mm	-0.25	0.29	0.58	0.58	99.42
600μm	0.75	4.09	8.18	8.76	91.24
300 μm	1.75	17.75	35.50	44.26	55.74
150 μm	2.75	18.67	37.34	81.60	18.40
75 μm	3.75	5.26	10.52	92.12	7.88

Table 2 Sample A3
Sample initial weight = 50g
Final weight = 45.23g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.59	1.18	1.18	98.82
1.18mm	-0.25	2.39	4.78	5.96	94.04
600μm	0.75	10.88	21.76	27.72	72.28
300 μm	1.75	16.24	32.48	60.20	39.80
150 μm	2.75	8.66	17.32	77.52	22.48
75 μm	3.75	6.47	12.94	90.46	9.54

Table 3 Sample A4
Sample initial weight = 50g
Final weight = 44.15g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.41	0.82	0.82	99.18
1.18mm	-0.25	2.26	4.52	5.34	94.66
600μm	0.75	9.46	18.92	24.26	75.74
300 μm	1.75	17.81	35.62	59.88	40.12
150 μm	2.75	9.67	19.34	79.22	20.78
75 μm	3.75	4.54	9.08	99.30	11.70

Table 4 Sample A7
Sample initial weight = 50g
Final weight = 29.29g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	-	-	-	100.00
1.18mm	-0.25	0.10	0.20	0.20	99.80
600µm	0.75	0.75	1.50	1.70	98.30
300 µm	1.75	1.95	3.90	5.60	94.40
150 µm	2.75	6.93	13.86	19.46	80.54
75 µm	3.75	19.56	39.12	58.58	41.42

Table 5 Sample A8
Sample initial weight = 50g
Final weight = 40.51g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	1.47	2.94	2.94	97.06
1.18mm	-0.25	5.72	11.44	14.38	85.62
600µm	0.75	12.09	24.18	38.56	61.44
300 µm	1.75	14.91	29.82	68.38	31.62
150 µm	2.75	3.22	6.44	74.82	25.18
75 µm	3.75	3.10	6.20	81.02	18.98

Table 6 Sample A9
Sample initial weight = 50g
Final weight = 41.03g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	1.72	3.44	5.44	96.56
1.18mm	-0.25	5.26	10.52	13.96	86.04
600µm	0.75	11.82	23.64	37.60	62.40
300 µm	1.75	15.23	30.46	68.6	31.94
150 µm	2.75	3.84	7.68	75.74	24.26
75 µm	3.75	3.16	6.32	82.06	17.94

Table 7 Sample A10
Sample initial weight = 50g
Final weight = 32.05g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	-	-	-	100.00
1.18mm	-0.25	1.88	3.76	3.76	96.24
600µm	0.75	11.94	23.88	27.64	72.36
300 µm	1.75	14.23	28.46	56.10	43.96
150 µm	2.75	1.05	2.10	58.20	41.80
75 µm	3.75	2.95	5.90	64.10	35.90

Table 8 Sample A14
Sample initial weight = 50g
Final weight = 40.68g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	-	-	-	100.00
1.18mm	-0.25	0.54	1.08	1.08	98.92
600µm	0.75	2.76	5.52	6.60	93.40
300 µm	1.75	12.59	25.18	31.78	68.22
150 µm	2.75	16.00	32.00	63.78	36.22
75 µm	3.75	8.79	17.58	81.36	18.64

Table 9 Sample A15
Sample initial weight = 50g
Final weight = 39.64g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.80	0.16	0.16	99.84
1.18mm	-0.25	2.47	4.94	5.10	94.90
600µm	0.75	4.84	9.68	14.78	85.22
300 µm	1.75	8.20	16.40	31.18	68.82
150 µm	2.75	8.82	17.64	48.82	51.18
75 µm	3.75	14.51	29.02	77.84	22.16

Table 10 Sample A1'
Sample initial weight = 50g
Final weight = 45.70g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	-	-	-	100.00
1.18mm	-0.25	0.28	0.56	0.56	99.44
600μm	0.75	4.00	8.00	8.56	91.44
300 μm	1.75	18.15	36.30	44.86	55.14
150 μm	2.75	17.87	35.74	80.60	19.40
75 μm	3.75	5.40	10.80	91.40	8.60

Table 11 Sample A3'
Sample initial weight = 50g
Final weight = 43.95g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.61	1.22	1.22	98.78
1.18mm	-0.25	2.24	4.48	5.70	94.30
600μm	0.75	9.20	18.40	24.10	75.90
300 μm	1.75	16.90	33.80	57.90	42.10
150 μm	2.75	10.50	21.00	78.90	21.10
75 μm	3.75	4.50	9.00	87.90	12.10

Table 12 Sample A4'
Sample initial weight = 50g
Final weight = 45.41g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.62	1.24	1.24	98.76
1.18mm	-0.25	2.42	4.84	6.08	93.92
600μm	0.75	10.53	21.06	27.14	72.86
300 μm	1.75	15.84	31.68	58.82	41.18
150 μm	2.75	8.92	17.84	76.66	23.34
75 μm	3.75	7.08	14.16	90.82	9.18

Table 13 Sample A7'
Sample initial weight = 50g
Final weight = 28.91g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	-	-	-	100.00
1.18mm	-0.25	0.10	0.20	0.20	99.80
600μm	0.75	0.80	1.60	1.80	98.20
300 μm	1.75	2.05	4.10	5.90	94.10
150 μm	2.75	7.12	14.24	20.14	79.86
75 μm	3.75	18.84	37.68	57.82	42.18

Table 14 Sample A8'
Sample initial weight = 50g
Final weight = 42.84g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.27	0.54	0.54	99.46
1.18mm	-0.25	5.27	10.54	11.08	88.92
600μm	0.75	14.39	28.78	39.86	60.14
300 μm	1.75	14.84	29.68	68.54	31.46
150 μm	2.75	4.84	9.68	79.22	20.78
75 μm	3.75	3.32	6.46	85.68	14.32

Table 15 Sample A9'
Sample initial weight = 50g
Final weight = 43.03g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.32	0.64	0.64	99.36
1.18mm	-0.25	5.42	10.84	11.48	88.52
600μm	0.75	14.42	28.84	40.32	59.68
300 μm	1.75	15.03	30.06	70.38	29.62
150 μm	2.75	4.66	9.32	79.70	20.30
75 μm	3.75	3.18	6.36	86.06	13.94

Table 16 Sample A10ⁱ
Sample initial weight = 50g
Final weight = 32.13g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	-	-	-	100.00
1.18mm	-0.25	1.70	3.40	3.40	96.60
600µm	0.75	12.30	28.00	28.00	72.00
300 µm	1.75	14.23	56.46	56.46	43.54
150 µm	2.75	1.15	58.76	58.76	41.24
75 µm	3.75	2.75	64.26	64.26	35.74

Table 17 Sample A14ⁱ
Sample initial weight = 50g
Final weight = 40.29g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	-	-	-	100.00
1.18mm	-0.25	0.55	1.10	1.10	98.90
600µm	0.75	2.56	5.12	6.22	93.78
300 µm	1.75	13.03	26.06	32.28	67.72
150 µm	2.75	15.86	31.72	64.00	36.00
75 µm	3.75	8.29	16.58	80.58	19.42

Table 18 Sample A15ⁱ
Sample initial weight = 50g
Final weight = 40.87g

Sieve Diameter	pHi (ø) Value	Weight of Sample Retained (g)	Weight Percentage	Cumulative Percentage	Percentage Passing
2.36mm	-1.25	0.95	1.90	1.90	98.10
1.18mm	-0.25	2.32	4.64	6.54	93.46
600µm	0.75	5.03	10.06	16.60	83.40
300 µm	1.75	8.26	16.52	33.12	66.88
150 µm	2.75	9.16	18.32	51.44	48.56
75 µm	3.75	15.15	30.30	81.74	18.26

Graphical Mean

The statistical analysis of the sieve values obtained indicates that the sediment's mean size range, as depicted by the graphic mean, ranges from 1.53 to 3.32, which corresponds to a medium-grained to very fine-grained sediment classification. The average size of the sediment particles is 2.06, which implies that the sediment is predominantly composed of fine-grained materials.

Table 19 is a table of statistical values for different sediment samples. It includes the graphic mean, standard deviation, skewness, and kurtosis for each sample. These values provide information about the size distribution, sorting, and shape of the sediment particles in each sample. By analyzing these values, it is possible to infer the mode of sediment transport and the environment of deposition.

Furthermore, the data presented in table suggests that the sediment's particle size distribution is dominated by fine to medium-grained particles, indicating that the sediment deposition occurred under the influence of a low to moderate velocity current. These findings highlight the importance of carefully analyzing sediment properties to understand the depositional environment, which is critical for interpreting the geological history of the area.

Graphic Inclusive Standard Deviation

Based on the statistical analysis of the sieve values, the standard deviation values of the analysed samples indicate that the sediments are poorly sorted, with values ranging from 0.77 to 1.76, and an average of 1.34. This implies that there is a wide range of particle sizes present in the sediment, indicating that they have not undergone significant transport and sorting by water or wind currents. The poorly sorted nature of the sediment can also suggest a lack of significant energy or transportation mechanism to sort the particles effectively. Further studies would be needed to determine the exact cause and characteristics of the sediment's poor sorting.

Graphic Skewness

Based on the statistical analysis of the sieve values obtained, it can be observed that the graphic skewness values range from 0.43 to 0.32, indicating a range from strongly coarse skewed to finely skewed. However, the average graphic skewness value is 0.07, suggesting that the sediments are nearly symmetrical on average. This means that the sediments are not significantly skewed in either direction and have a relatively symmetrical distribution of grain sizes.

Graphic Kurtosis

This suggests that the sediment sample has a relatively flat distribution, meaning that it contains a larger proportion of particles with sizes close to the mean size, and fewer particles with larger or smaller sizes.

Table 19 Statistical values for different sediment samples.

Sample	Graphic Mean (Mz)	Standard Deviation (SD)	Skewness (SK)	Kurtosis
A1				
A3	Medium-grained	Poorly sorted	Fine Skewed	Mesokurtic
A4	Medium-grained	Poorly sorted	Fine skewed	Mesokurtic
A7	Very fine-grained	Moderately sorted	Strongly coarse skewed	Leptokurtic
A8	Medium-grained	Poorly sorted	Fine Skewed	Platykurtic
A9	Medium-grained	Poorly sorted	Fine Skewed	Platykurtic
A10	Medium-grained	Poorly sorted	Strongly coarse skewed	Very Platykurtic
A14	fine-grained	Poorly sorted	Near Symmetrical	Platykurtic
A15	fine-grained	Poorly sorted	Strongly coarse skewed	Platykurtic
A1^{I}	fine-grained	Poorly sorted	Fine Skewed	Mesokurtic
A3^{I}	Medium-grained	Poorly sorted	Fine Skewed	Mesokurtic
A4^{I}	Medium-grained	Poorly sorted	Fine Skewed	Platykurtic
A7^{I}	Very fine-grained	Moderately sorted	Strongly coarse skewed	Leptokurtic
A8^{I}	Medium-grained	Poorly sorted	Strongly coarse skewed	Platykurtic
A9^{I}	Medium-grained	Poorly sorted	Fine Skewed	Platykurtic
A10^{I}	Medium-grained	Poorly sorted	Strongly coarse skewed	Very Platykurtic
A14^{I}	fine-grained	Poorly sorted	Near Symmetrical	Platykurtic
A15^{I}	fine-grained	Poorly sorted	Strongly coarse skewed	Platykurtic

Table 20 Sediment analysis results for different samples

Sample	Graphic Mean (Mz)	Standard Deviation (SD)	Skewness (SK)	Kurtosis
A1	2.00	0.98	0.16	1.10
A3	1.63	1.39	0.19	0.93
A4	1.70	1.34	0.17	1.00
A7	3.32	0.77	-0.43	1.17
A8	1.55	1.76	0.24	0.84
A8^{I}	1.53	1.56	0.32	0.89
A10	1.92	1.57	0.28	0.55
A14	2.43	1.35	0.08	0.80
A15	2.48	1.38	-0.34	0.80
A1^{I}	2.00	1.03	0.15	1.00
A3^{I}	1.67	1.42	0.18	1.00
A4^{I}	1.68	1.39	0.13	0.89
A7^{I}	3.33	0.82	-0.54	1.15
A9	1.58	1.74	0.23	0.85
A9^{I}	1.48	1.55	0.30	0.86
A10^{I}	1.93	1.58	0.31	0.56
A14^{I}	2.42	1.20	0.03	0.79
A15^{I}	2.38	1.45	-0.4.	0.83

Table 20 summarizes the sediment analysis results for different samples, including the graphic mean (Mz), standard deviation (SD), skewness (SK), and kurtosis. It also provides information on the grain size and sorting of each sample. The results show that most samples are poorly sorted, consisting mostly of fine to medium-grained particles, and are skewed towards finer particles. The kurtosis values indicate that the sediments are generally platykurtic, but some samples are leptokurtic or very platykurtic. Overall, the table provides a detailed characterization of the sediment properties and can be used to infer the depositional environment and transport processes that shaped these sediments.

Table 21 summarizes the range and average values of different sediment parameters, including graphic mean, graphic standard deviation, skewness, and kurtosis. It also provides a verbal description of each parameter based on its average value.
According to the table, the sediment samples have a fine-grained texture with an average graphic mean of 2.06. The sediments are poorly sorted with an average graphic standard deviation of 1.35. The skewness of the sediments is nearly symmetrical with an average value of 0.06, and the kurtosis is platykurtic with an average value of 0.90.

Table 21 Summary of the range and average values of different sediment parameters

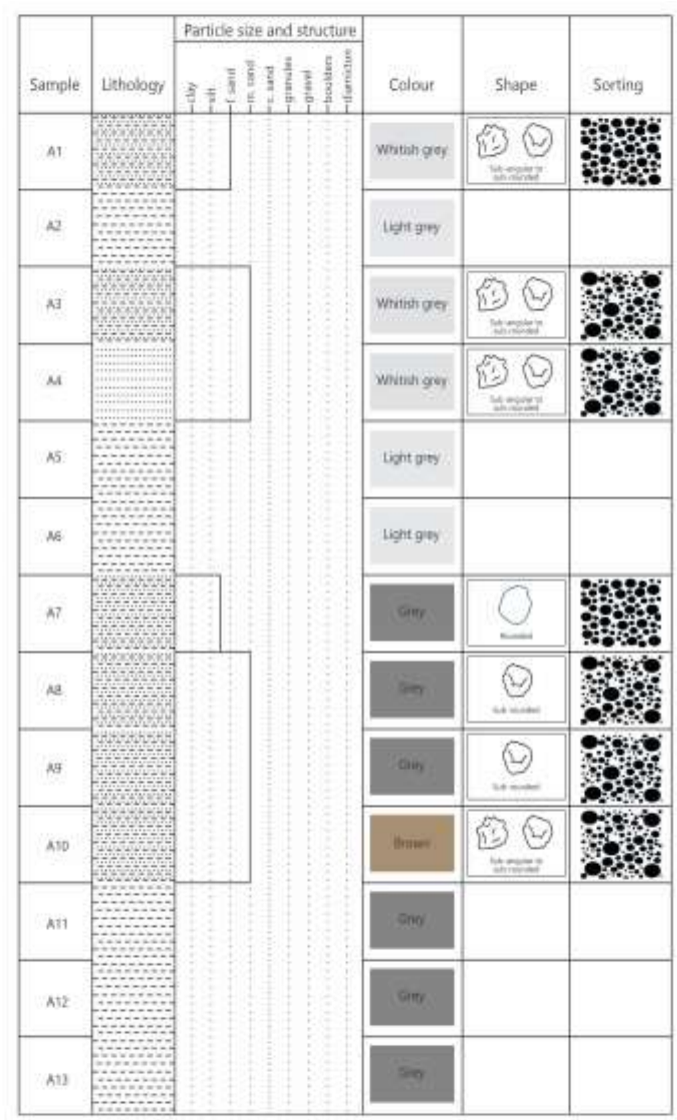
Parameter	**Range of Value ø**	**Average Value ø**	**Verbal Description**
Graphic Mean	1.53 – 3.33	2.06	Fine-grained
Graphic Standard Deviation	0.77 – 1.76	1.35	Poorly sorted
Skewness	-0.54 – 0.32	0.06	Nearly symmetrical
Kurtosis	0.55 – 1.17	0.90	Platykurtic

Sedimentology

The outcrop, which lies about 250m to Uhiere village and about 30km from Benin City along Benin – Akure road, is exposed by road-cut. It has a lateral extent of about 300m trending in the NE – SW direction and a vertical extent (height) of about 27m.

The first 11m is embanked by concrete concealing some beds of shale and sand. Above the embankment the sequence begins with a clayey sandstone bed. The thickness of the bed varies horizontally ranging from 1.5 to 3m. Overlying this bed is a shale unit. This layer is overlain by another clayey sandstone bed, which is cross-bedded, and about 2.0m thick. Above this layer is a shale/clay unit, light grey in color and about 0.5 thick. Overlying the shale/clay is a fine to medium grained sandstone bed. This unit consists of pockets of clays, which increases in thickness upward. The thickness of this unit is about 3.5m. Overlying this unit is a sandy clay bed, whitish in color and about 1.0m thick. The uppermost layer/unit consists of reddish brown sandstone with varying lateral thickness being thicker in the middle and thinner at the ends in response to the topography of the outcrop (Table 22).

After the description of the outcrop, a graphic log was plotted to represent the subsurface geology of the study area. The log was constructed using data from the sedimentological description of the outcrop (Figure 3). The log consists of a vertical representation of the different rock units encountered in the subsurface, along with their corresponding depths and lithological characteristics. The top of the log represents the surface of the earth, and the depth increases as one move down the log. The different rock units encountered in the subsurface are represented by different colors, patterns, or symbols. The lithological characteristics of each unit, such as grain size, color, and mineralogy, are also included in the log. This information can be used to better understand the subsurface geology of the area. Overall, the graphic log is an important tool for visualizing and interpreting the subsurface geology of an area. It provides a clear and concise representation of the different rock units encountered in the subsurface and their lithological characteristics, which can aid in geological interpretation and decision-making.



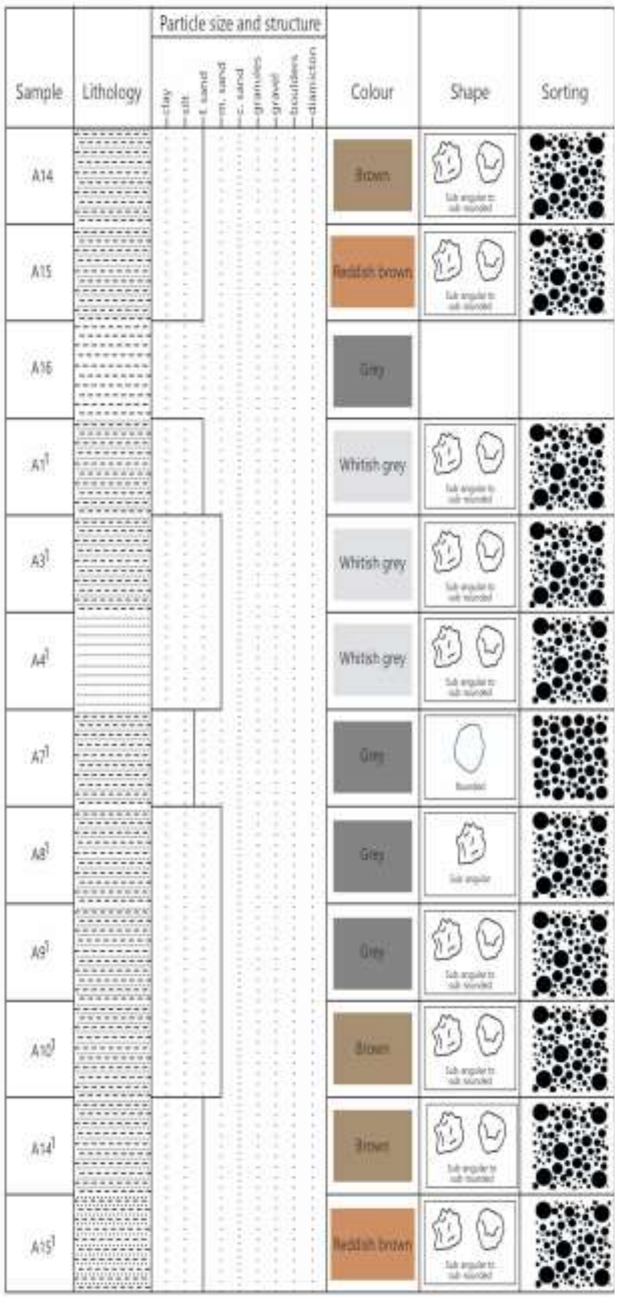


Figure 3 Graphic log of the outcrop

Heavy Mineral Analysis

Results of heavy mineral analysis revealed the presence of both opaque and non-opaque minerals in the sediments. The opaque minerals were found to be more abundant than the non-opaque minerals. The non-opaque minerals identified include zircon, rutile, sphene, hornblende, and tourmaline (Table 23).

Table 23 Heavy mineral analysis results

Mineral	Description
Opaque	Black to brownish, angular to rounded/tabular grains
Zircon	Pale yellow, elongate to sub-angular prismatic grains with bipyramidal terminations.
Rutile	Red-brown to yellow-brown, angular to sub-rounded grains.
Sphere	Pale yellow/brownish yellow euhedral grains. Pleochroism is weak, colourless to yellow.
Hornblende	Light brown in colour with strong pleochroism
Tourmaline	Deep brown, euhedral to sub-rounded grains, distinctly pleochric.

Palynological Constituents

Sediments are known to contain a significant amount of both particulate organic matter and dissolved organic matter, including amorphous organic matter. Through the use of transmitted light microscopy, various particulate palynological constituents and other forms of organic matter have been identified within these sediments. Such findings represent valuable insights into the composition and nature of sediments, providing researchers with a deeper understanding of the geological and environmental processes that have shaped our planet over time. It is therefore crucial to approach the analysis and interpretation of such data with the utmost professionalism and attention to detail, in order to ensure the most accurate and meaningful results possible.

Phytoclasts

The particulate organic matter found within sediment can be further characterized as being plant-based in origin, and is comprised of both structured and structureless components. These components may include a variety of plant-derived materials such as cuticles, epidermal cells, and root debris, among others. These materials are present in significant quantities within the sediment, and can originate from a range of terrestrial to marine plant sources. By carefully examining and analyzing the composition of these materials, researchers can gain valuable insights into the history and evolution of the ecosystems that produced them, as well as the broader geological and environmental context in which they exist. As such, it is important to approach the study of particulate organic matter in sediment with the utmost professionalism and scientific rigor, in order to ensure the most accurate and meaningful results possible.

Protistoclasts

In addition to the plant-derived components previously mentioned, sediment may also contain other types of organic matter, such as foraminiferal test linings and dinoflagellate cysts. These materials are typically pale to light brown in color and have been classified as marine palynomorphs, as documented by researchers such as Love (1987) and Gorin (1993). The presence of these marine palynomorphs in sediment can provide valuable information about the biological and ecological conditions present in the marine environment over time, as well as the broader geological and environmental context in which these conditions existed. To ensure accurate and meaningful interpretation of such data, it is important to approach the study of marine palynomorphs in sediment with appropriate professionalism and scientific rigor, employing appropriate analytical techniques and methods to extract as much information as possible from these materials.

Pollen Grains and Spores

Pollen grains and spores are important components of sediment that provide valuable information about the vegetation in and around the sedimentary basin. Pollen grains are the male reproductive bodies of flowering plants, which include both Gymnosperms and Angiosperms. Spores, on the other hand, are the reproductive bodies of non-flowering plants. The outer coat or exine of pollen and spores is composed of an organic material that is highly resistant to chemical reagents and physical forces such as high temperatures and pressures.

The presence of pollen and spores in a sediment sample can be used to identify the various plant species that were present in the environment when the sediment was deposited. This information can be obtained by analyzing the distinct sculptures, pores, scars (for spores), and colpus or colpi (for pollens) present on the surface of these particles. The relative abundance of pollen and spores in a sediment sample can also provide insights into the composition and diversity of the plant community in the surrounding area.

Table 24 presents the results of the analysis of pollen and spores found in a specific sediment sample, along with their relative abundance. These data can be used to reconstruct the vegetation and environmental conditions present at the time the sediment was deposited, and can provide valuable insights into the evolution of the ecosystem over time. As with any scientific data, it is important to approach the interpretation of these results with professionalism and scientific rigor, using appropriate analytical techniques and methods to ensure the accuracy and reliability of the findings.

Table 24 Occurrence and distribution chart of selected palynomorphs in sediments from study area

Species (Depth in meters)	*Spinozonocolpitesbaculatus*	*Dichtyvditesharassi*	*Ctenolophoniditescoastatus*	*Heterocolpiteslaevigatus*	*Spirosyncolpitesspiralis*	*Monoporatitesannualtus*	*Proxerpititescurcus*	*Ericpitessp*	*Proxerpetitesoperalatus*	*Acrostichumaureum*	*Retibrevitricolporitessp*	*Psilatricolporitescrassus*	*Dinoflagellate cysts*	*Forminiferal test lining*	AGE
24															
20															
16															
	X			X			X		X						
12	X		X	X			X	X	X	X	X	X			
	X	X		X	X	X	X	X	X	X	X	X			
8	X	X	X	X		X	X		X	X		X	X	X	
4															
0															

Based on the results of grain size analysis, heavy mineral analysis, and palynological analysis, the researchers were able to reconstruct the depositional environment, processes of conditions of deposition of the sediments, provenance, and age of the sediments.

The grain size analysis showed that the sediments consisted mostly of fine-grained materials, with mean size values ranging from 1.53ø – 3.32ø (medium-grained to very fine-grained) and an average of 2.06ø (fine-grained). This suggests that the sands were deposited by low to moderate velocity currents, alternating with quiet depositional regimes during which the shales were deposited. The standard deviation values ranged from 0.77 – 1.76 (moderately sorted to poorly sorted) with an average of 1.34, indicating that the sediments are poorly sorted, suggesting a short distance of transportation or proximity of sediment to the source.

The palynological analysis revealed the presence of Spinozonocolpitesbaculatus, Proxerpertitesoperculatus, Monoporatitesannulatus, Acrostichumaureum, Proxerportitecurcus, Heterocolpiteslaevigatus, Pssilatricolpitescrassus, Dichtyphyditesharassi, and Ericipitesspis. These species are indicative of a swampy or brackish environment (Germerald et al 1968), with Heterocolpiteslaevigatus and Spinozonocolpitesbaculatus being plants that are restricted to mangrove swamps or brackish environments (Germerald et al 1968). The

presence of lots of structured woody material supports the suggestion of a marshy or swampy environment. The presence of some marine fossils, such as foraminifera test lining and Dinoflagellatecycts, suggests a low degree of marine influence on the environment.
The age determination was based on comparing the palynomorph recovered from the sample with those already established forms from other areas. Works carried out by Jan du Chaena (1979), Germerald, Muller and Hopping (1978), SalardCheboldaeff (1978), and SPDC work on Niger Delta basin have indicated important marker species found in the rocks to the Paleocene – Eocene in age. The researchers found that the sediments contain important marker species found in rocks to the Paleocene – Eocene in age, including Spinozonocolpitesbaculatus, Proxerpertitesoperculatus, Heterocolpiteslaevigatus, Pssilatricolpitescrassus, Spirosyncolpitesspiralis, Retibrevitricolpitesspheroidite, Monoporitesannulatus, Dichtyphiditesharassi, Ctenolophoniditescostatus, Ericipites sp., Dinoflagellate cysts, and foraminiferal test linings.
The provenance of the sediment was determined based on the heavy minerals identified in the sediments, including zircon, rutile, sphene, hornblende, and tourmaline. Tourmaline is a metamorphic mineral, indicating a metamorphic source for the sediments, while zircon, rutile, sphene, and hornblende are igneous minerals, indicating an igneous source for the sediments. Therefore, the sediments could be said to have been derived from the weathering of the igneous and metamorphic rocks of the adjacent crystalline basement complex.
Based on the lithology and fossil content, the stratigraphic section exposed at km 30 along Benin-Akure road close to Uhiere village can be correlated with the Ameki Formation. The lithologies observed at Uhiere, including clayey sandstone, sandy claystone, sandstone and shale intercalations, are similar to those found in the Ameki Formation (Orajaka, 2016). Furthermore, the floral assemblages present in both the Uhiere outcrop and the Ameki Formation are also similar (Orajaka, 2016).
The rock sequence exposed at Uhiere can be inferred to be the lateral equivalent of the Ameki Formation, which is the up-dip or surface equivalent of the subsurface Agbada Formation of Niger Delta (Short and Stauble, 1967). This is supported by previous studies that have shown that the Ameki Formation is the lateral equivalent of the Agbada Formation, and both formations are characterized by similar lithologies and fossil content (Orajaka, 2016; Short and Stauble, 1967).
The correlation of the Uhiere outcrop with the Ameki Formation has important implications for the understanding of the geology of the Niger Delta region. It provides additional evidence for the lateral continuity of sedimentary units across the region and contributes to a better understanding of the stratigraphic framework of the area.

Conclusion

The study on the sedimentary rocks exposed at Uhiere village along the Benin-Akure road has provided important insights into the geology of the Niger Delta region. The sedimentary rocks are fine-grained, poorly sorted, and contain palynomorphs that indicate a swampy or brackish environment with a low degree of marine influence. The sediments were derived from the adjacent crystalline basement complex through weathering, as indicated by the heavy minerals identified in the sample. The lithology and fossil content suggest that the exposed rocks at Uhiere can be correlated with the Ameki Formation, which is the lateral equivalent of the subsurface Agbada Formation of Niger Delta.
The findings have significant implications for the understanding of the stratigraphic framework and lateral continuity of sedimentary units across the Niger Delta region. They also contribute to the knowledge of the paleoenvironmental conditions during the Paleocene-Eocene age. Possible future directions of research could include further analysis of the sedimentary rocks at Uhiere and their correlation with other formations in the Niger Delta region, as well as a more detailed investigation of the paleoenvironmental conditions during the Paleocene-Eocene age.

Acknowledgement

We acknowledge the technical assistance provided by Valz Bello who assisted in the research. We also appreciate the advice and support from Professor, W.O. Emofurieta who provided guidance.

Conflict of Interest

Authors declare that there are no conflicts of interest.

References

Adegoke, O.S. (1969). Eocene Stratigraphy of Southern Nigeria.Extrait de Memoire du B.R.G.M. No 69 – 1969

Fayose, E.A. (1970). Stratigraphy and Paleontology of Afowo – 1 Well Southern Nigeria. Jour. Nig. Min. Geol. Metal. Soc. 5 pp. 1-99.

Germeraad, J.H., Hopping, C.A. and Muller, J. 1968. Palynology of Tertiary Sediments from Tropical Areas. Review of Palaeobotany and Palynology, 6(1-4), pp.189-348.

Gorin, G.E., 1993. Dinoflagellate cysts in marine sediments: A brief review of their study and significance. Marine Geology, 113(1-2), pp.1-17.

Jan du Chene, R. 1979. Paleocene palynomorphs from the Gulf Coast and Atlantic Coastal Plain of North America. American Association of Stratigraphic Palynologists Contribution Series, 9, pp.1-39.

Jones, H.A. and Hockey (1964).The Geology of part of South Western Nigeria Geol. Surv.Nigeria Bull. 31.

Kogbe, C.A. (1974). The Upper Cretaceous sediments of Southern Nigeria Field.Vol. 39 No. 4.

Love, G., 1987. The application of palynology to the study of marine sediments: Recent developments and future directions. Palynology, 11(1-2), pp.151-160.

Maju-Oyovwikowhe, G.E. and Lucas, F.A., 2019. Depositional facies analysis using core samples from greater Ughelli Depobelt, Niger Delta Basin Nigeria. Journal of Applied Sciences and Environmental Management, 23(6), pp.1137-1146.

Murat, R.C. (1972). Stratigraphy and paleogeography of the cretaceous and lower tertiary sequence in southern Nigeria.Bull. Am. Assoc. Petrol. Geol. 56: 1979-1989.

Nwajide, C. S. (2005). The Niger Delta basin: stratigraphy, sedimentology and petroleum geology. Elsevier.

Obaje, N.G. and Wehner, H. (2014). Palynological and sedimentological analysis of the Ameki Formation, Southern Nigeria: implications for palaeoenvironmental reconstruction and hydrocarbon potential. J. Afr. Earth Sci. 90: 99-108.

Ogbe, F.G.A. (1972). Stratigraphy of strata exposed in the Ewekoro Quarry, Western Nigeria in Proc. Conferences on African Geology (T.F.J. Dessauvagie and A.J. Whiteman Eds). Ibadan University press.

Onuoha, K.M. and Ukaegbu, V.U. (2018). Sedimentology and sequence stratigraphy of the Ameki Formation, Niger Delta Basin, Southeastern Nigeria. J. Afr. Earth Sci. 143: 72-88.

Orajaka, I.P. (2016). Facies analysis, depositional environments and hydrocarbon potential of the Ameki Formation in part of the Anambra Basin, Southeastern Nigeria. J. Afr. Earth Sci. 117: 104-121

Reyment, R.A. (1965). Aspects of the Geology of Nigeria. Ibadan Univ. Press, Nigeria.

SalardCheboldaeff, M. 1978. Maastrichtian and Paleocene pollen and spores from the Aquitaine Basin, France. Pollen et Spores, 20(1), pp.5-72.

Short, K.C. and A.J. Stuable (1967).Outline of Geology of Niger Delta. Amer. Assoc. Petrol. Geol. Bull. 51(5) pp. 751- 779.