Tropical Built Environment Journal. Volume 9, No. 3, 407-416, 2023 www.tbejournal.com
ISSN: 1118-1790

ANALYSIS OF THE PARTICLE-SIZE CHARACTERISTICS OF EBENEBE SANDSTONE FOR INFERENCE ON THE PREVALENT ENVIRONMENTAL HAZARD IN AREAS UNDERLAIN BY THE FORMATION

D. C. Onuoha* and O. G. Ogbo

Department of Environmental Management, Nnamdi Azikiwe University, Awka, Nigeria
*Corresponding Author: dc.onuoha@unizik.edu.ng

Abstract

This study conducted an analysis of the particle-size characteristics of Ebenebe Sandstone with a view to using the result to make inference on the prevalent environmental hazard in area under study being underlain by the formation. The sieve method of particle size analysis was used to determine the grain size distribution of the rock samples in the area. Sample was collected from two locations at Ekwueme Square and behind the State Secretariat which are currently being plagued by gully erosion. From the result of the analyses of the two samples collected, it was found that the Ebenebe sandstone has a coefficient of uniformity of 2.7 and therefore is well graded. It was also found that the sandstone formation is predominantly sandy with low fine content, highly friable and easily deflocculated. The study therefore proposed some interventions and measures which could slow down or stop the current erosion, such as, grouting, geotechnical and geochemical remediation, reforestation, regular monitoring and assessment; among others. These may serve as means of saving the area from continued gullying and preserving this formation and the history embedded in it.

Keywords: Ebenebe Sandstone, Environmental Hazard, Erosion, Formation, Particle Size Analysis

Introduction

Background to the study

Grain size analysis is a vital tool in geosciences for assessing siliciclastic sedimentary rocks, providing insights into hydrodynamic conditions, paleo environmental features, and ancient sedimentary transport histories (Srivastava *et al.,* 2012). Grain size distribution, a key sediment property, reveals hydrodynamic energy and transportation processes, offering crucial evidence of sedimentary conditions and aiding in textural classification (Blott *et al.,* 2001; Edwards, 2001). Researchers emphasize distinct particle size features in different sedimentary environments (Srivastava *et al.,* 2012; Goswami and Ghosh, 2011). The method's significance lies in its environmental indication based on transporting medium, duration, and depositional conditions (Stanley-Wood & Lines, 1992). Various techniques, such as direct sieving and point counting under a microscope, cater to different research purposes (Friedman, 1979). In cases where sedimentary particles cannot be separated, alternative methods must be employed (Stanley-Wood and Lines, 1992; Baiyegunhi *et al*, 2020).

Soil erosion is a well-known environmental problem in South Eastern Nigeria. It is the removal of soil particles from the surface of the Earth by natural processes, transportation and deposition of the particles by the action of wind, heat and water. Onyegbule (2005) described soil erosion as the process whereby the surface layer of the soil is detached and carried by agents of denudation and a lower layer in the soil is exposed leaving a topographic roughness on the resulting landscape.

The Ebenebe Sandstone Formation is composed of sandy sediments that were deposited during the Cretaceous period, approximately 100 million years ago. It is also a member of the Imo shale. The formation, however, is under threat and undergoing alterations to its structure due to ongoing erosion of its sediments. The erosion is being caused by a combination of natural and human factors such as deforestation, weathering, infrastructure development, agricultural practices, water erosion and others. These factors have led to the loss of biodiversity, potential loss of some of Earth's history and also poses significant safety risks. The loss of the formation will therefore, have significant negative impacts on the environment and its resources. The report provides an overview of the erosion affecting the Ebenebe Sandstone Formation.

The Ebenebe sandstone formation which is located on the Anambra Basin of Nigeria has been heavily affected by erosion. The formation has been exposed and weathered by rainfall and wind, leading to the formation of deep gullies and valleys. In addition, the surrounding landscape has undergone extensive denudation, leading to large amounts of sand and clay being deposited in the rivers and streams. This erosion has had a profound effect on the formation as well as the surrounding environment. This study therefore was conceived with the goal of analysing the particle size characteristics of the Ebenebe sandstone formation and relating same to the prevalent environmental hazard of gully erosion. Through this study, environmentalists in the area will be armed with the information of the characteristics of the formation and be able to marshal out modalities of effectively, efficiently and sustainably tackling gully erosion menace in the area and the sedimentary and stratigraphic history embedded in this formation.

Aim and objectives

The aim of this study is to analyse the Particle-Size Characteristics of Ebenebe Sandstone with a view to using the result to make inference on the prevalent environmental hazard in area under study being underlain by the formation.

To achieve this, aim the following procedure were observed:

1. Discussing the origin and characteristics of the formation.
2. Collection of samples and preparation of same for grain-size analyses.
3. Conducting the laboratory analysis and collating the data from same to plot the graph of the particle size.
4. Interpretation of the resultant data as represented in the graph and using that to make inference.

Geology of the Ebenebe sandstone formation

Origin of the formation

The Ebenebe sandstone geological formation is a sedimentary rock that’s found in the eastern part of Anambra State, Nigeria. It is a part of the Anambra Basin, which was formed by a series of tectonic and sedimentary events in the early Cretaceous period around 130-115 million years ago. The formation itself is thought to have been formed from sediments deposited by rivers that flowed into a shallow marine basin. Overtime, the sediments were compacted and cemented together to form the sandstone. The

sandstone spans through several towns such as Umunze, Ufume, Ajali, Ezira, Nawfija and Ihite in Anambra State (Anizoba, Orakwe and Chukwuma, 2020).

Description of the formation

The Ebenebe sandstone is one of the three constituent sandstone members that make up the Paleocene Imo formation which is the oldest Paleogene lithostratigraphic unit of the Niger Delta basin; the other two members are the Igbada sandstone and Umuna sandstone (Odumodu, 2013). The sandstone of Ebenebe outcrops at Ugwuoba, Umuogbuefi-Ebenebe and Isiagu respectively (Ohwona and Okoro, 2022). They consist of fine-coarse grained sandstone, coarse fine grained sandstone, mudstone and siltstone. It's believed that the erosion of the Ebenebe formation began in the Quaternary period, which started around 2.6 million years ago. As this was a time of dramatic climate changes, including the transition from a wet and humid climate to a drier and cooler climate, the changing climate is thought to have led to increased erosion, as well as the deposition of windblown loose sediments on top of the formation. The erosion has likely been accelerated in more recent times due to human activities etc.

Depositional environment

According to Ohwona *et al*. (2022), there has been contradictory interpretations of the depositional environment of the Ebenebe sandstone. Anyanwu and Arua (1990) depicts the depositional environment of the Ebenebe sandstone to be the Delta front facies. Oboh-Kuenobe *et al*. (2005), depicts the environment of deposition of the Ebenebe Sandstone to be fluvial channel of the estuarine lithic fill while Ekwenye *et al*. (2014), depicts it as large sand waves deposited in a tidally offshore to shore face settings respectively but the stratigraphic succession indicates that the sandstone is enclosed in shallows marine shale.

From the work of Acra, Etu-Efeotor and Omoboriowo (2014), it stated that the univariate, bivariate, multivariate, pebble morphometry and sedimentary structures indicates that the sandstones were deposited in a variety of depositional setting such as fluvial, lagoonal, tidal and shallow marine environments. Petrographic and paleo current results show that the sediments are derived from two sources namely, the basement area and from pre-existing sedimentary terrain which exist east and northeast of the study area.

Characteristics of the formation

Physical characteristics

The physical characteristics of the formation under study is summarized as follows:

i. Composition: The Ebenebe sandstone formation is primarily composed of sand-sized grains, which are typically well-sorted and well-rounded.
ii. Stratigraphy: It is part of the Anambra Basin. Within this basin, the Ebenebe formation is found in the upper part of the basin's succession. The formation is stratified into layers that vary in thickness from a few millimeters to several centimeters.
iii. Color and texture: The sandstone often exhibits various shades of red, brown and yellow, which is indicative of iron oxide content, it varies depending on the amount of iron minerals present. They are medium coarse grained, mainly moderately sorted and subrounded.
iv. Depositional Environment: The sandstone formation was likely deposited in a shallow marine environment, suggesting the presence of an ancient sea or shoreline.
v. The sandstone has a moderate porosity

Chemical characteristics

The main Chemical characteristics of the formation are as highlighted below:

i. Mineral Composition: They are mainly quartz arenites with some feldspar and mica.
ii. They have a good to excellent reservoir quality and hence have the potential to accumulate hydrocarbons.
iii. The grains are held together by a silica cement which gives the rock its moderate degree of strength.
iv. The sandstone may contain varying amounts of clay minerals which can affect properties like permeability.

Literature Review

Ohwona and Okoro (2022) carried out a study on depositional facies analysis of the Ebenebe sandstone outcropping in Ugwuoba, Umuogbuefi-Ebenebe and Isiagu area of the South Eastern Nigeria. The method adopted for this study was field study and textural analysis. The field observations showed that lithofacies of the Ebenebe sandstone consists of fine-coarse grained sandstone, coarse-fine grained sandstone, mudstone and siltstone, and size lithofacies typically of tidally-dominated shelf setting and tidal current processes characterized the Ebenebe sandstone. The result from the grainsize analysis showed that the mean grain size of the Ebenebe sandstone is medium-coarse grained, moderately well sorted, coarsely skewed to near symmetrical, and the kurtosis values ranging from platykurtic to leprokurtic. The study recommends that further studies should be carried out on the Ebenebe sandstone since fewer studies have been done on the area.

Acra, Etu-Efeotor and Omobiorowo (2014) carried out a study on the sedimentological attributes and stratigraphic architecture of Ebenebe formation, Anambra State, Nigeria. The method used for this study included field work sampling, graphic logging and also made use of twenty lithologic outcrop units. From the study, the univariate, bivariate, multivariate, pebble morphometry and sedimentary structures indicate that the sandstones were deposited in a variety of depositional settings such as fluvial, lagoonal, tidal and shallow marine environment. Petrographic and paleocurrent results show that the sediments are derived from two sources namely, the basement area and from pre-existing sedimentary terrain which exist east and northeast of the study area. The stratigraphic architecture shows various facies associations such as the tidally influenced channels, braided fluvial channels, flood plains and fluvial channels. The sands are medium-coarse grained mainly moderately sorted, subrounded, negatively to positively skewed and leptokurtic in distribution. These sands are mainly quartz arenites with a good to excellent reservoir quality hence, have the potential to accumulate hydrocarbons. The study recommends a new mode of a tide dominated depositional system based on integrated ichnological and sedimentological data.

Anizoba, Orakwe and Chukwuma (2020) studied on the assessment of groundwater potential of Imo formation (Ebenebe Sandstone) in Anambra State, Nigeria. The objective of the study was to provide data on groundwater prospect considering the subsurface geophysical conditions of Imo formation (Ebenebe Sandstone) to enhance the availability of clean water source. Vertical Electric Sounding (VES) method was used for the study. The results revealed that the subsurface section consists of five geo-electrical layers namely: top soil/laterite, clayey sand, dry sandstone, water saturated sand and shale.

Description of Analytical Process

Sieve analysis/ grain size analysis

The grain size analysis test is performed to determine the percentage of each size of grain that is contained within a soil sample, and the results of the test can be used to produce the grain size distribution curve. This information is used to classify the soil and to

predict its behaviour. The two methods generally used to find the grain size distribution are:

i. Sieve analysis which is used for particle sizes larger than 0.075 mm in diameter and
ii. Hydrometer analysis which is used for particle sizes smaller than 0.075 mm in diameter

Sieve analysis is a method that is used to determine the grain size distribution of soils that are greater than 0.075 mm in diameter. The sieve analysis is done to know the particle sizes of sediments and to know what soil types are suitable for agricultural and engineering purposes. It is usually performed for sand and gravel but cannot be used as the sole method for determining the grain size distribution of finer soil. The sieves used in this method are made of woven wires with square openings.

Sample collection

The soil samples used for the sieve analysis were obtained within the study area (Awka) at Ekwueme square (the back of State secretariat). The samples were collected from two different points within the erosion site. Two samples were collected and were put in different containers. After collection, the samples were taken home and air dried in other to get rid of any moisture content, deflocculated and made ready for the sieve analysis experiment.

Step by step process of the sieve analysis:

i. We clean the sieves with a brush to remove any particles stuck between the sieve openings and set them according to their sieve sizes in descending order from the biggest to the smallest with the tray as the last
ii. We take the scale in order to make sure the plates measurement is insignificant and weigh out 500 grams each from our two samples. The doors should be closed in order to get an accurate measurement on the weigh scale due to its sensitivity to air
iii. A mechanical sieve shaker is used to shake and sieve the two samples for 5-10 minutes each at different intervals
iv. After sieving, we scale each of the samples left on the different sieve sizes on the weighing scale and record the values. While doing this, the plate should always be tarred so as to make sure its measurement is insignificant (0).
v. Each of the sample sizes are recorded on the mass retained column. After recording, we sum up all the values. The difference in the summation should not be more than 1% of the original measurement.
vi. We calculate the percentage mass retained by dividing each value of the mass retained by 500 and multiplying by 100.
vii. Next, we calculate the cumulative percentage retained by adding the first number of our percentage mass retained with the next number, this continues to the last number. The final value on this column should be 100.
viii. We calculate our percentage finer/passing by subtracting each of the numbers gotten in our cumulative percentage retained from 100.
ix. We add up all the values gotten from our cumulative % retained and divide by 100, this will give us our fineness modulus.

This fineness modulus is what helps us know the classification of our sample, whether it is fine, medium or coarse grained. The ranges are: 3.1-3.7: coarse sand, 2.3-3.0: medium sand, 1.6-2.2: fine sand, 0.7-1.5: super fine sand. So after getting the final value, we check what category our sample falls under

and record. If it is a higher value, it means it's very coarse.



Figure 1: Sample weighing instrument for sieve analysis process

Results and Discussion

Results of analyses of the collected samples

The resultant data from the analyses of the samples collected are presented in tables 1 and 4.

Table 1: Measurement results for sample 1

S/N	Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cumulative % Mass Retained	% finer/ % passing
1	2.00	33.1	6.62	6.62	93.38
2	1.18	42.8	8.56	15.18	84.82
3	0.85	28.3	5.66	20.84	79.16
4	0.60	56.5	11.3	32.14	67.86
5	0.425	91.3	18.26	50.4	49.6
6	0.30	123.6	24.72	75.12	24.88
7	0.15	93.9	18.78	93.9	6.1
8	0.075	23.1	4.62	98.52	1.48
9	Tray/pan	7.4	1.48	100	0
	Total	499.9		492.72	

Fineness Modulus= 492.72\100=4.9. Therefore, our sample 1 is a very coarse sand.

In Table 2, the x variables are the sieve size figures and the y variables are the percentage finer values. These variables were used for the plotting of the graph in Figure 2.

Table 2: Sieve sizes and percentage finer figures for sample 1

x	y
2	93.38
1.18	84.82
0.85	79.16
0.6	67.86
0.425	49.6
0.3	24.88
0.15	6.1
0.075	1.48

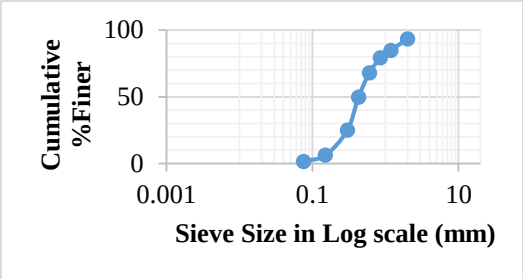


Figure 2: Graph of cumulative percentage finer against sieve size

Table 3: Percentage soil grades

Gravel	0.00%
Sand	98.52%
Fine (silt & clay)	1.48%

From the Table 3, it shows that the soil is predominantly sandy and has a low fine content of 1.48%.

Table 4: Measurement results for sample 2

S/N	Sieve Sizes (mm)	Mass Retained (g)	% Mass Retained	Cumulative % Mass Retained	% finer/ % passing
1	2.0	32.5	6.5	6.5	93.5
2	1.18	46.1	9.22	15.72	84.28
3	0.85	31.4	6.28	22	78
4	0.60	56.6	11.32	33.32	66.68
5	0.425	89.6	17.92	51.24	48.76
6	0.30	120.8	24.16	75.4	24.6
7	0.15	92.3	18.46	93.86	6.14
8	0.075	22.2	4.44	98.3	1.7
9	Tray/pan	8.4	1.68	99.98	0.02
	Total	499.9		496.32	

Table 4 shows that Fineness Modulus= 496.32\100= 4.96. Therefore, sample 2 is a very coarse sand.

Table 5: Sieve sizes and percentage finer figures for sample 2

x	y
2	93.5
1.18	84.28
0.85	78
0.6	66.68
0.425	48.76
0.3	24.6
0.15	6.14
0.075	1.7

In Table 5, the x variables are the sieve size figures and the y variables are the percentage finer values. These variables are to be used for the plotting of the graph.

Table 6: Percentage soil grades

Gravel	0.00%
Sand	98.30%
Fine (silt & clay)	1.70%

The Table 6 shows that the soil is predominantly sandy and has a low fine content of 1.70%.

Applying engineering geology

Engineering geology was used to classify the soil samples. The shape of the grain size distribution curve indicates the type of soil. Therefore, uniformly or poor graded soil will be represented by nearly vertical lines, and a well graded soil by a line of a uniform slope passing through all sizes.

Coefficient of uniformity and coefficient of curvature

In order to describe the shape of the grain size distribution curve with a single number, two coefficients are generally used.

$\mathbf{C_u}$ = coefficient of uniformity = $\frac{D_{60}}{D_{10}}$

$\mathbf{C_{cr}}$= coefficient of curvature = $\frac{D_{30}^2}{D_{60}.D_{10}}$

A uniformly or poorly graded soil will have its coefficient of uniformity (Cu) of less than 2.0 (nearly 1.0) and a well graded soil will have its coefficient of curvature (Ccr) more than 1.0, but less than 3.0. More so, Cu is greater than 4 for gravels and 6 for sands (USBR, 1960).

For sample 1 (Ebenebe Sandstone)

Cu = D60/ D10 = 2.7

Ccr = (D30)2 / D60*D10 = 1.13

This result shows that the Ebenebe sandstone based on the coefficient of uniformity at 2.7 is a well graded soil.

For sample 2

Cu = D60/ D10 = 3.5

Ccr = (D30)2 / D60*D10 = 1

This result shows that the Ebenebe sandstone based on the coefficient of uniformity at 2.7 is a well graded soil.

Discussion of findings

The result of the analyses of both samples collected indicate that the sandstone formation is predominantly sandy with low fine content and well graded. The sandstone was highly friable and easily deflocculated, as the disintegration during laboratory work was done with hands other than mortar and pestle.

This outcome is in line with the findings of Ohwona and Okoro (2022) and Acra *et al.* (2014), whose field observations showed that lithofacies of the Ebenebe sandstone consists of fine-coarse grained sandstone, coarse-fine grained sandstone, mudstone and siltstone, and size lithofacies typically of tidally-dominated shelf setting and tidal current processes characterized the Ebenebe sandstone. From the result of their grain-size analysis it was found that the mean grain size of the Ebenebe sandstone is medium-coarse grained. Their findings slightly disagreed with the result of this study in the area of their conclusion that Ebenebe Sandstone is moderately well sorted, coarsely skewed to near symmetrical, and the kurtosis values ranging from Platykurtic to leprokurtic (Ohwona and Okoro, 2022). Also that the sands are medium-coarse grained mainly moderately sorted, subrounded, negatively to positively skewed and leptokurtic in distribution (Acra *et al*, 2014). This is because the result of the grain-size analyses for both samples collected depicts a well graded sandstone. On the other hand, Anizoba *et al.* (2020) who applied geophysical method in their study utilizing VES (vertical electrical sounding), found the content to be of clayey sand.

The reason for the high erodibility can be attributed to the poor compatibility and high friability of the sandstone, hence it easily to deflocculates. This was observed during the preparation of the sample for laboratory analysis.

Some predictable causes of erosion of the formation, may include:

i. Physical and chemical weathering of rocks due to exposure to wind, rain and temperature fluctuations overtime weaken the structure of the sandstone.
ii. Surface runoff especially during periods of heavy rainfall contribute to the erosion process. The force of the moving water can wear down the surface of the sandstone leading to gradual removal of the soil.
iii. Human activities such as construction, removal of vegetative cover etc., also accelerate soil erosion.
iv. Changes in the climate pattern such as shifts in precipitation for instance drought followed by heavy rainfall also influence erosion rates.
v. The geologic composition also influences the rate of erosion.

vi. Tectonic activities and geologic processes such as faulting and folding naturally weakens the structure.
vii. Since erosion can occur naturally over long periods of time, overtime, the combined environmental factors leads to gradual alterations of the sandstone formation.

Conclusion and Recommendation

The result of the analyses of the two samples collected shows that the Ebenebe sandstone based on the coefficient of uniformity at 2.7 is a well graded. It was also found that the sandstone formation is predominantly sandy with low fine content, highly friable and easily deflocculated.

As stated in the discussion, the erosion of the Ebenebe sandstone formation is a serious threat to the environment and economy. This erosion is influenced by various natural and anthropogenic factors; however, there is still not much study on the erosion of the formation. In order to preserve the Ebenebe Sandstone Formation, it is important to adopt measures and interventions which are required to slow down and stop the current erosion affecting the formation. These measures include:

i. Advanced geotechnical and geochemical remediation techniques like grouting with eco-friendly and less impacting chemicals is recommended as the formation need to be compacted and lithified more to reduce erodibility.
ii. Further studies should be carried out on the causes and consequences of erosion in the formation and research works on the hydrocarbon potentials of the formation should be carried out in order to ascertain the petro-physical properties of the sandstone.
iii. Bioremediation and reforestation programs should be established in order to plant trees and other vegetation in the affected areas.
iv. Regular monitoring, geologic surveys and assessments should be conducted in order to monitor the rate of erosion, identify areas of concern and track the progress of intervention measures and their impacts.
v. Government and environmental bodies should sensitize the people on the causes, impacts and problems of soil erosion through public awareness campaigns, seminars and conferences.
vi. Funding programs should be established in order to support the implementations of these measures.

Reference

Acra, E. J., Etu-Efeotor, J. O. and Omoboriowo, A. O. (2014). Sedimentological attributes and stratigraphic architecture of Ebenebe formation, Anambra Basin, Nigeria. *International Journal of Science Inventions Today (IJSIT)*, 3(4), 346-364.

Anizoba, D. C., Orakwe, L. C. and Chukwuma, E. C. (2020). Assessment of groundwater potential of imo formation (Ebenebe Sandstone) in Anambra State, Nigeria using geo-electrical sounding data. *Journal of Engineering and Applied Sciences*, 16, 43-51.

Anyanwu, N. P. C. and Arua, I. (1990). Ichnofossils from the Imo formation and their palaeoenvironmental significance. *Journal of Mining and Geology,* 26(1), 1–4.

Baiyegunhi, C., Liu, K., Gwavava, O. (2017). Grain size statistics and depositional pattern of the Ecca Group sandstones, Karoo Supergroup in the Eastern Cape Province, South Africa. *Open Geosciences*, 9, 554–576. 10.1515/geo-2017-0042.

Baiyegunhi, T. L., Liu, K., Gwavava, O. and Baiyegunhi, C. (2020). 'Textural characteristics, mode of transportation and depositional environment of the Cretaceous sandstone in the Bredasdorp Basin, off the south coast of South Africa: Evidence from grain size analysis.' *Open Geosciences*, 12(1), 1512-1532. https://doi.org/10.1515/geo-2020-0135.

Blott, S. J. and Pye, K. (2001). Radistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms*, 26, 1237–1248.10.1002/esp.261.

Edwards, A. C. (2001). Grain size and sorting in modern beach sands. *Journal of Coastal Research*, 17(1), 38–52.

Ekwenye, O. C., Nichols, G. J., Collinson, M., Nwajide, S. C., and Obi, G. C., (2014). A paleogeographic model for the sandstone members of the Imo Shale, Southeastern Nigeria. *Journal of African Earth Sci*ences, 96, 190–211.

Friedman, G. M. (1967). Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. *Journal of Sediment Petrology*. 37, 327–54.

Friedman, G. M. (1979). Differences in size distribution of populations of particles among sands of various origin. *Sedimentology*. 26, 859–62.10.1111/j.1365-3091.1979.tb00979.x.

Goswami, B. and Ghosh, D. (2011). Understanding the transportational and depositional setting of Panchet formation, Purulia and Bankura districts of West Bengal, India - Evidence from grain size analysis. *Frontiers of Earth Science*, 5(2), 138–49. 10.1007/s11707-011-0169-y.

Oboh-ikuenobe, F. E., Obi., G. C. and Jaramillo, C. A., (2005). Lithofacies, palynofacies and sequence stratigraphy of palaeogene strata in Southeastern Nigeria: *Journal of African Earth Sciences*, 41, 79-102.

Odumodu, C. F. (2013). Facies granulometric analysis as proxies for the paleodepositional environment of the Imo formation, Southeastern Nigeria. *Journal of Environment and Earth Sciences*, 3(14), 55-70.

Ohwona, O. C. and Okoro, A. U. (2022). Depositional facies analysis of the Ebenebe sandstone in Ugwuoba, Umuogbuefi-Ebenebe and Isiagu area of the Southeastern Nigeria. *Global Scientific Journals*, 10(3), 7-29.

Onyegbule, P. O. (2005). Erosion and its consequences on soil and landscape degradation in the humid savannah of southeastern Nigeria. *Journal of Sustainable Development in Africa*, 7(4), 295-304.

Srivastava, A. K., Ingle, P. S., Lunge, H. S. and Khare, N. (2012). Grain-size characteristics of deposits derived from different glaciogenic environments of the Schirmacher Oasis, East Antarctica. *Geologos*, 18(4), 251–266. 10.2478/v10118-012-0014-0.

Stanley-Wood, N. and Lines, R. W. (1992). *Particle size analysis.* Cambridge: Royal Society of Chemistry, Special Publication. 101–103. 10.1039/9781847551627.