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Granulometric and Petrographic Studies of Agbani Sandstone Outcrops within Ihuokpara and Environs, Southern Benue Trough, Nigeria.

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ABSTRACT

Detailed Granulometric and petrographic analysis of the Agbani Sandstone outcrops were carried out within Ihuokpara, Southern Benue Trough, Nigeria. The aim was geared towards deciphering provenance and reconstructing the paleo-environment of deposition. The study area is underlain by Agbani Sandstone and Awgu Shale. They are Coniacian in age. A total of twelve (12) sandstone samples were collected and used for analysis. Out of the twelve sandstone samples, two (2) was deployed for thin section petrographic analysis, while ten (10) was deployed for grain size analysis. The petrographic results from two (2) sandstone samples from different locations reveal dominance in quartz (60% – 65%), feldspar (10%-13%), mica (10%-10%), limonite (15%-8%) with clay matrix and rock fragment less than 3% framework components of the sandstones respectively. These sandstones are mineralogically and texturally sub-mature and have been classified as lithic arkose on the basis of QFR diagram. Quartz in these sandstone samples is monocystalline in nature and feldspars are represented mainly as plagioclase. Provenance of the sandstone deposits within the study area was inferred to be from Abakaliki folded belt or Cameroun Basement Complex, due to the amount of detrital clay and degree of sorting. The textural parameters from the ten (10) samples show that the Agbani Sandstone are moderately to well sorted, medium grained, very negatively skewed and very leptokurtic grains in nature and suggest that the sand was deposited in a fluvial environment.

Introduction

The study area lies within latitudes $6^\circ\ 15^{1}\ 0^{11}$N and $6^\circ\ 20^{1}\ 0^{11}$N, and longitudes $007^\circ\ 38^{1}\ 0^{11}$E and $007^\circ\ 42^{1}\ 0^{11}$, with an area extent of about 69.2km^2 in Nkanu East Local Government Area, Enugu State, Nigeria (Figure 1). It is bounded by some surrounding communities like Obodo-Ene, Ndubunagu, Amangene, Amagunze, Amafor, Mputa-Uzam, Osu, Onueke, Okeani and Ndidinagu-Uzam. It can be accessed through Agbani-Akpugo-Amagunze road from Nkanu West Local Government Area. The towns are accessible mostly through untarred road networks, foot paths and bush paths. The villages are also connected by wooden bridges. Benue Trough is a linear, northeast trending depression in the eastern part of Nigeria. It tectonically evolved through transcurrent faulting in an axial fault system, where local compressional and tensional regimes resulted in basins and basement horsts (Benkhelil, 1989). The trough contains up to 6000meters of Cretaceous – Tertiary sediments of which those predating the mid-Santonian have been compressionally deformed, faulted, and uplifted in several places (Obaje, et al, 1999). Sedimentation in the Southern Benue Trough commenced with the marine Albian Asu River Group, although some pyroclastics of Aptian – Early Albian ages have been sparingly reported (Ojoh, 1992). Many researches have been on the Southern Benue Trough mainly because of the basin's mineral potentials and interesting geological features (Okonkwo and Ezeh, 2012; Cotsworth, 1949; Ezepue, 1984; Nwachukwu, 1972). Because of the basin's prospect for hydrocarbons and solid minerals, there is need for proper documentation of its stratigraphy and depositional framework. The diversity in rock lithology and stratigraphic heterogeneity occur as a result of many different depositional environments in which they are deposited. This paper tends to study the mineralogical and textural characteristics of the sandstone in the study area in other to decipher provenance and reconstruct the paleo-depositional environment.

Aim and Objectives

The aim of this research is to carry out the granulometric and petrographic analysis of Agbani Sandstone in other to decipher provenance and reconstruct the paleo-depositional environment. The objectives are as follows:

- Procurement of topographic base map of Ihuokpara and environs on the scale of 1:25,000
- Carry out detailed geological field mapping in other to locate outcrops/exposures.
- Collection and Description of rock samples. Fresh samples will be collected.
- Production of geologic map to show the rock distribution in the study area.
- Carry out textural and petrographic analysis on the rock samples.
- Production of thin section slides.
- Computation of textural parameters.
- Decipher provenance and paleo-environmental reconstruction.

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Geology

The geologic succession of the study area falls within can be correlated the Southern Benue Trough of Nigeria (Figure 2). Locally, it consists of an upper Agbani Sandstone unit underlain by a lower Awgu Shaley unit. The Sandstone facies has a limited lateral expanse within the scope of study, consisting of medium to coarse grains, white to reddish in colour, and moderately to highly consolidated bands. The Shale unit comprises of bluish grey, clayey, fissile shale with brownish stain of iron oxide. It is a low level land area in which majority of the out crops are well exposed along the stream/river channels. About two units were observed in the field, the shale unit A and consolidated sandstone unit B (Figure 3).

UNIT A: It comprises of bluish grey, clayey, fissile shale with brownish stain of iron oxide with so observable fossil remain.

UNIT B: It comprises of mainly white to reddish, medium to coarse, poorly sorted sandstone with presence of sedimentary structures such as; fractures, joints, laminations and bedding as well as plant imprint.

Materials and Method

Geological field mapping

The outcrops within the study area can be located mainly along the river channels and roadsides (foot paths). The outcrops encountered in the field were studied and described on the basis of the textures, structures and distinctive characteristics evident on the rock. The study area also consists of the following rock types, sandstone, mudstone, clay stone, and shale.

Laboratory work

A total of twelve rock samples were collected from different locations. Ten of the samples were used for sieve analysis while the other two was used for petrography in order to determine the paleo-environment of deposition and mineralogical component respectively. The study involved the detailed petrographic description of sandstone units within the study area and 12 outcrop locations were studied and sampled for petrographic and granulometric analysis. Two indurated sandstone samples from locations EET/2020/008 and EET/2020/013 were cut into thin sections for petrographic analysis while a total of 10 samples were studied for textural analysis. The thin section petrographic analysis involved the determination of the texture and mineral/framework element compositions of the sandstones through point counting of few constituent sandstone grains. The texture and framework elements of the sandstones are indicative of the depositional environments. The classification of the sandstone samples was also done based on the framework elements composition of (Folk *et al.*, 1970 and Folk, 1980). The granulometric analysis involves examination of the univariate parameters; mean, sorting, skewness and kurtosis (Table 1). Bivariate plots and multivariate parameters have evaluated ranges which indicate certain depositional environments. The bivariate plots derived from the form indices, which are environment indicators are used to determine the influence of some processes that are characteristic of certain environments of deposition.

Results and Discussion

Petrography

The results from the petrographic analysis show that the mineral compositions of all the rock samples include quartz, plagioclase felspar, Mica, limonite, clay matrix and rock fragment.

Mineralogical Maturity

The Mineral Maturity Index (MMI) is calculated using the mineralogical maturity index (Table 2) proposed by Nwajide and Hoque (1985), Igwe, et al, (2013).

The $MMI$is expressed as

$$MMI = \frac{\textbf{Proportion of Quartz}}{\textbf{Proportion of Fsp} + \textbf{Proportion of R.F}}$$

For Ndubunagu sandstone =

$$\text{MMI} = \frac{60}{10+10+2} = 2.72$$

For Amagene sandstone

$$\text{MMI} = \frac{65}{13+10+2} = 2.82$$

The Mineral Maturity Index (MMI) values for both sandstone ranges from 2.72 to 2.82, from Table 1, the sandstones are immature.

Table 2. Maturity scale of sandstone: Limiting % of Q and (F + RF) MI and maturity stage (Nwajide and Hoque, 1985; Igwe et al., 2013)

Q =≥ 95% (F + RF) = 50%	MI = ≥ 19 supper mature
Q =95-90% (F + RF) = 5-10%	MI = 19 - 9.0 sub mature
Q = 90-75% (F + RF) =10-25%	MI =9.0-3.0 sub mature
Q =75-5O% (F + RF) = 25-50%	MI =3.0-1.O immature
Q = < 50%	MI ≤ 1
(F + RF) > 50%	Extremely immature

The results of the petrographic study (Table 1) of the two sandstone samples from Ihuokpara indicates on average; 62.5% quartz, 11.5% plagioclase feldspar, 10% mica, 11.5% iron, and 2.5% clay matrix and 2% rock fragment. The high quartz and feldspar content classify the sandstone as lithic arkose. Lithic arkoses are rich in feldspar and are mineralogically submature due to little transport from the parent rock (provenance). Lithic arkose are generally formed as the result of rapid uplift, erosion, and high rates of deposition. Most lithic arkose are deposited as fluvial, deltaic, coastal plain and shallow marine sandstones, interbedded with great thicknesses of shale. The high amount of feldspar in the sandstone is an indicative of chemical weathering in a relatively unaltered state. Hoque, and Ezepue, (1977) also observed that sandstone of the first and third sedimentary cycle Albian and Santonian are more feldspartic than those of the second tectonic cycle (Turonian) which is usually with little or no feldspar. Therefore, the overall results indicate that both sandstone samples studied were deposited during the third sedimentary cycle. The provenance of the sandstone can be determined by carrying out geochemical analysis of the sandstones obtained from an area. Madukwe et. al, (2014) noted that the provenance of Lokoja sandstone suggest felsic source rock because of low ratios of Ni/Co, Cr/Ni, Cr/Th, Cr/Sc, Th/Sc, La/Co and Th/Co. Provenance studies of sandstone near Igbile southwestern Nigeria using trace and minor elements reveal deposition in orogenic recycling and oxidizing environment and felsic provenance derived from upper continental crust (Ikhane et al, 2014). Provenance consideration of data acquired for mineral–chemical stratigraphy enables significant insight into provenance (Hurst and Morton, 2013). Heavy mineral assemblages have a relationship with the composition of source terrain but they can also provide insight into more subtle aspects of provenance that are related to processes in alluvial and marine sedimentary basins (Hurst and Morton, 2013). In most depositional environments, the bulk of coarse-clastic sediments are derived from the erosion of weathered and/or mechanically-modified sediments in drainage basins. Sediments derived from drainage basins are transported down-dip into alluvial basins where sediments compositions are modified by weathering. The sediments storage capacity of the basin and time is collectively termed residence (Hurst and Morton 2001). Due to the amount of detrital clay and degree of sorting, provenance of the study area is inferred to be Abakaliki Folded Belt or Cameroun Basement Complex, but further geochemical analysis is needed for a conclusive study.

Grain Size Analysis

Univariate Parameters:

The univariate results of the studied sandstone units-derived from cumulative probability (Figure 7 - 16) curves have been summarized in (Table 4). The average mean size (1.863) result shows that the sandstones are dominantly medium grained. The average standard deviation (Sorting) result (0.7879) shows that the sandstone exposures are moderately well sorted. The average skewness and kurtosis (-0.3595 and 2.76) respectively shows that the sandstone is very negatively skewed and very leptokurtic.

Bivariate Parameters

Bivariate plots of textural parameter have been found useful in differentiating adjacent environment of deposition as described by Friedman (1961) and Moiola and Weiser (1968). Plots of mean size against standard deviation (sorting), and skewness against standard deviation (sorting) was used to differentiate river deposit (fluvial) from beach deposits.

Multivariate Parameter

It was basically the works of Sahu (1964) that was used in this study for paleoenvironment discrimination. Sahu's function was used. The computed results for the multivariate parameters are shown in (Table 6).

Paleo-Environment of Deposition

The sandstone sediments within the study area are predominantly medium grained and moderately well sorted sandstones which indicate an evidence of stable flow. The skewness is very negatively skewed which implies a low energy transport medium distribution, where wave surges do not disturb bottom sediments. The kurtosis is very leptokurtic which indicates strongly peaked curves. The bivariate plots skewness and mean size against standard deviation shows that sediments are of fluvial origin (Figure 17). The multivariate parameter (Table 6) obtained from Y_1: Aeolian/Beach, Y_2: Beach/Shallow Marine and Y_3: Shallow marine/Fluvial analysis indicate that the scatter plot of Y_1 and Y_2, majority of the beach sediments fall within the Beach/Shallow marine, while only one of the sample fall in the Aeolian/Shallow marine environment. The scatter plot of Y_2 and Y_3 (Figure 18), Indicate that about 75% of the samples were deposited in shallow marine, while the other 25% are fluvial derived.

Conclusion

This study has shown that the Agbani Sandstone are deposited by fluvial dominated processes, with the interaction of beach processes. The energy process discriminant functions of the sediments indicate that they were deposited predominantly by beach, shallow marine depositional environment. The high quantities of quartz and feldspar classify the Agbani Sandstone as lithic arkose. Lithic arkoses are rich in feldspar content and mineralogically submature. The percentage of the feldspar content in the sandstone is indicative of chemical weathering in a relatively unaltered state with little transportation from the provenance. Due to the amount of detrital clay and degree of sorting, provenance of the Agbani Sandstone was inferred to be Abakaliki Folded Belt or Cameroun Basement Complex.

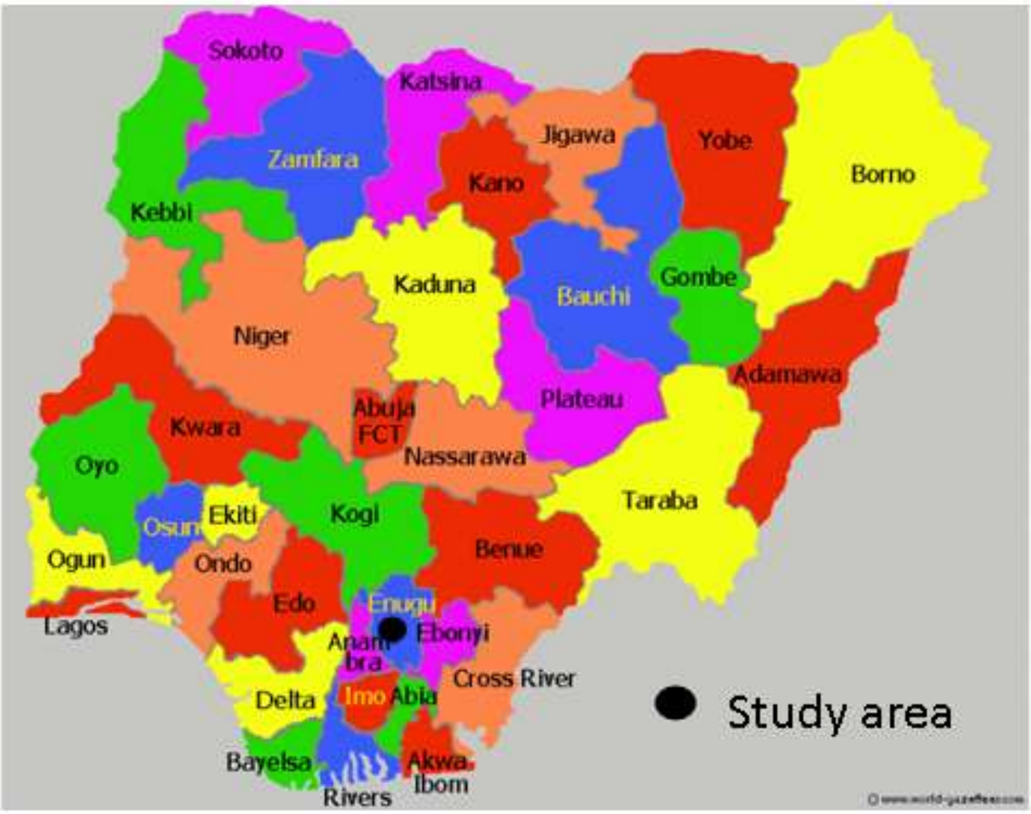

Figure 1. Map of Nigeria showing the location of the study area (World Gazatte maps, 2011)

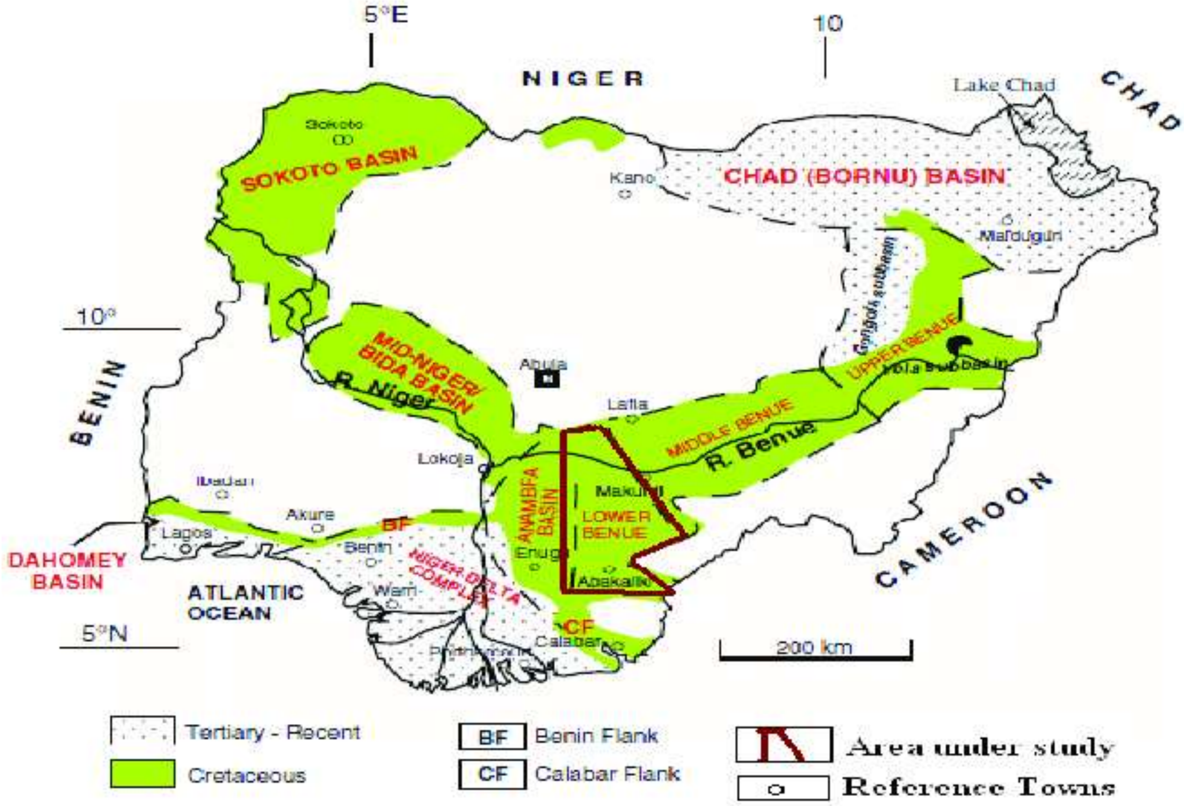

Figure 2. Map of Nigeria showing segments of Benue Trough with Southern Benue Trough formerly known as Lower Benue Trough (Bolarinwa, et al, 2019).

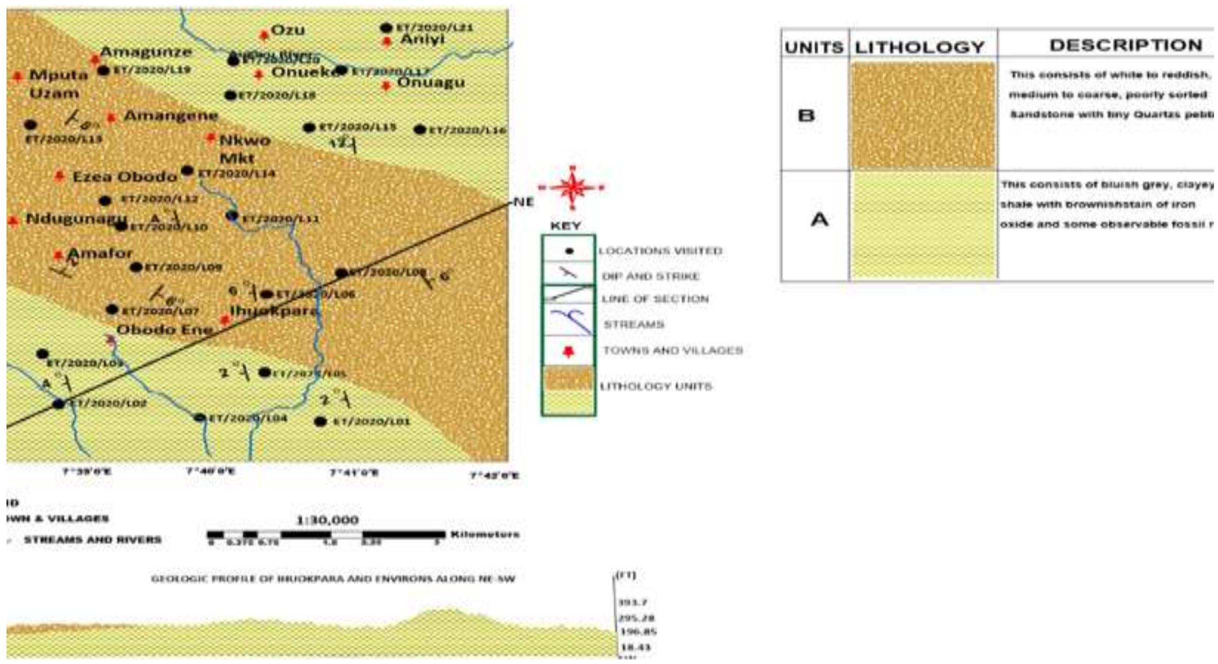

Figure 3. Geologic Map of the study area.

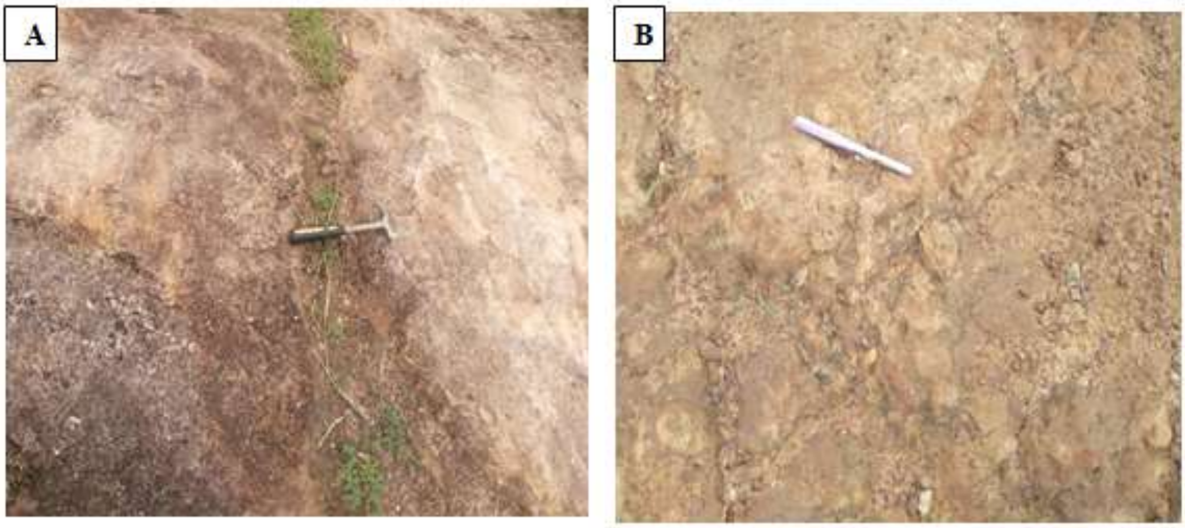

Plate 1. Sandstone outcrops at locations A (2020/L08) and B (2020/L13)

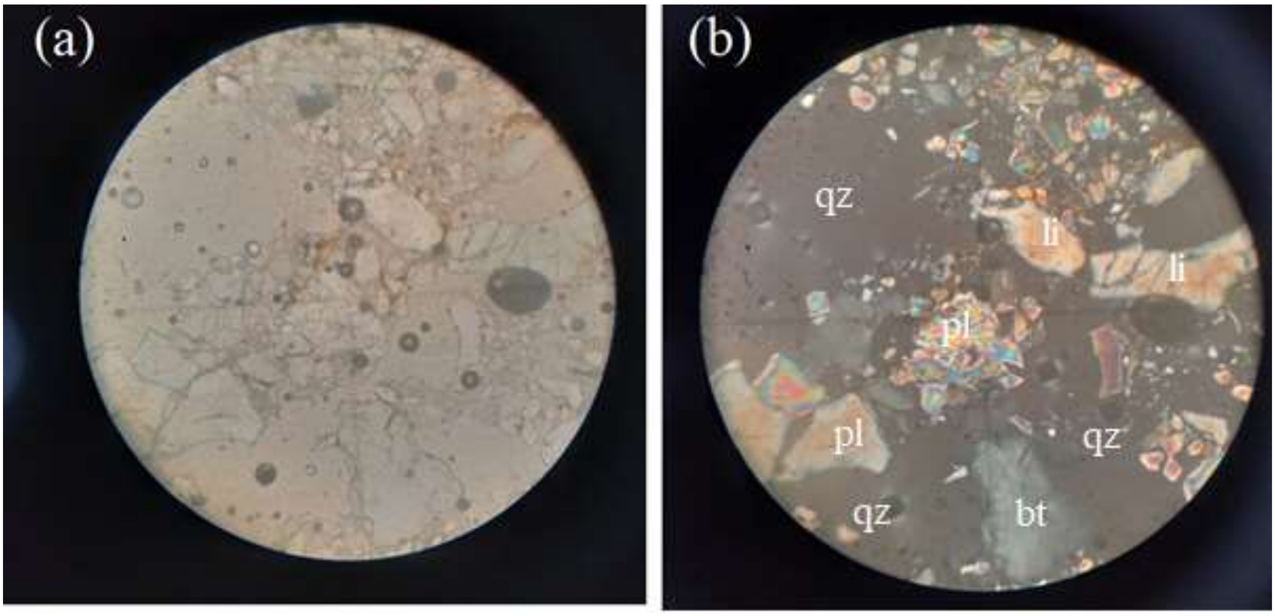

Figure 4. Petrography of Ndubunagu sandstone (2020/L08) under (a) plane polar (b) cross polar. The minerals identified are quartz (qz), plagioclase (pl), biotite (bt) and limonite (li).

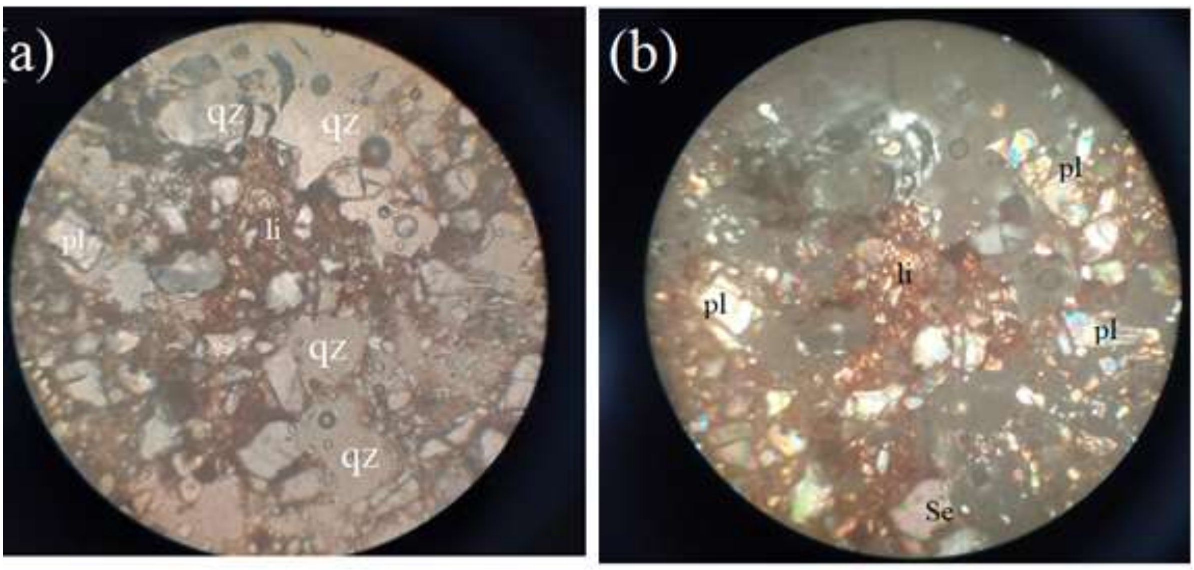

Figure 5. Petrography of Amangene sandstone (2020/L13) under (a) plane polar (b) cross polar. The minerals identified are quartz (qz), plagioclase (pl), Secrite (Se) and limonite (li).

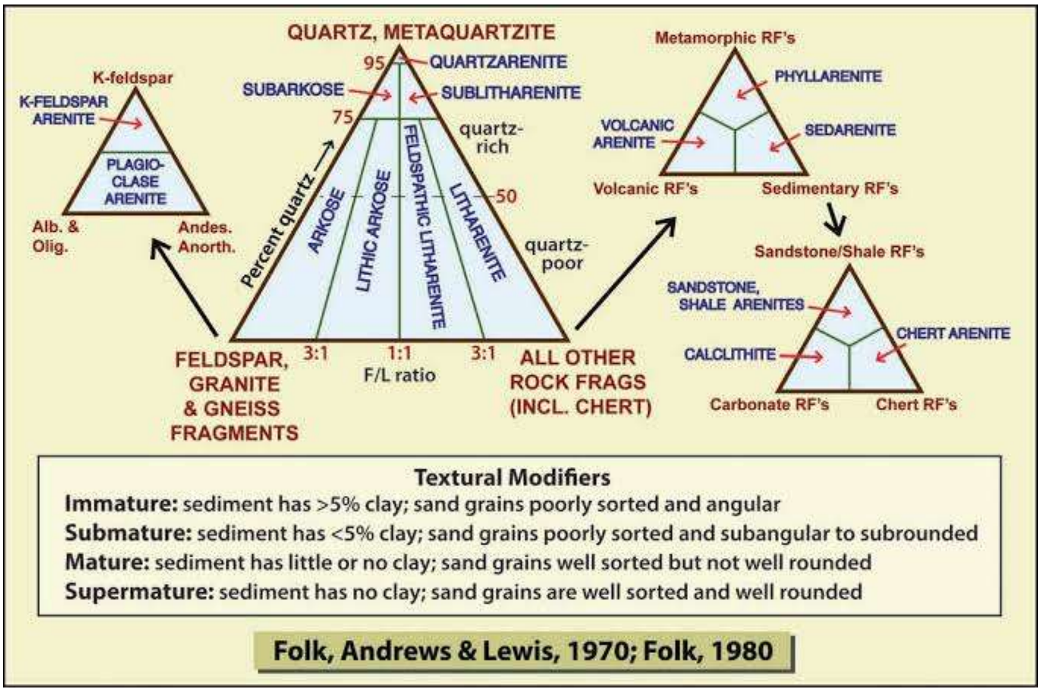

Figure 6. Classification for sandstones based on the relative abundances of quartz (Q), feldspars (F), and rock fragments (R); (Folk *et al.*, 1970 and Folk, 1980).

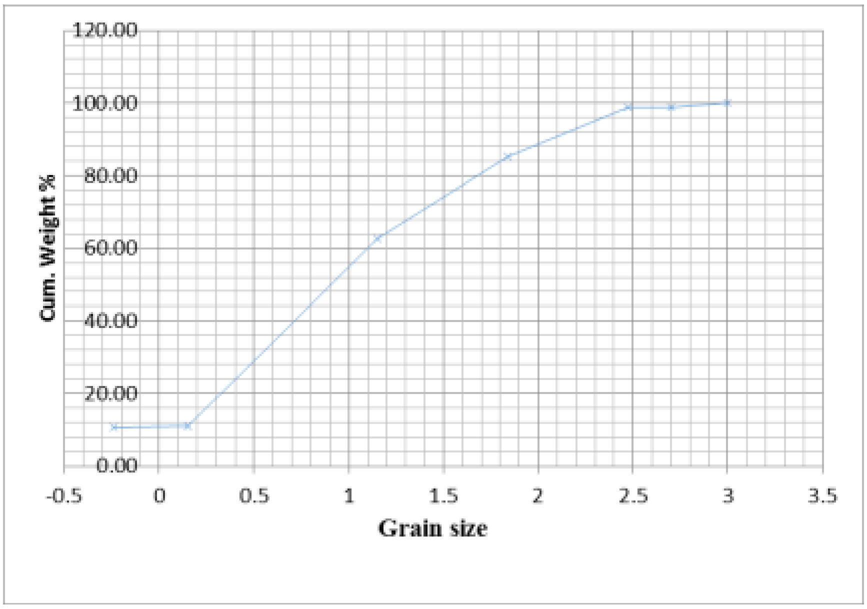

Figure 7. Particle size distribution curve at EET/2020/007

Particles size distribution curve

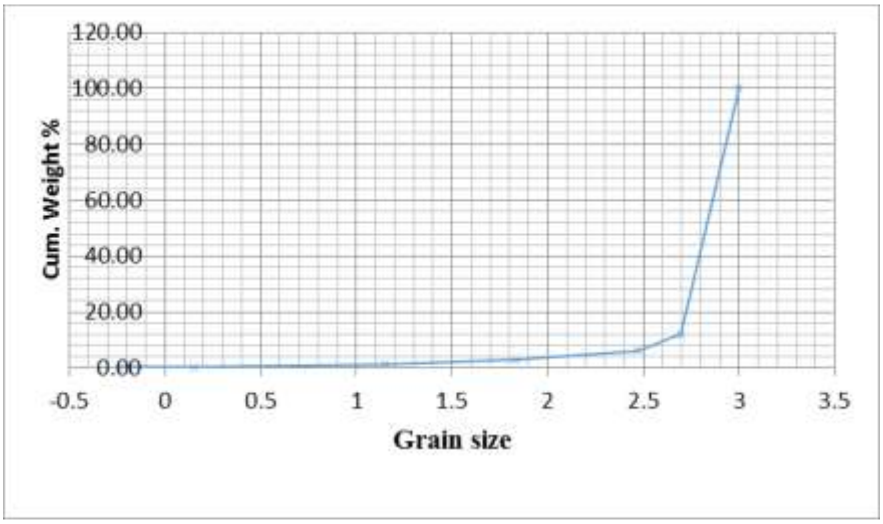

Figure 8. Particle size distribution curve at EET/2020/007

Particles size distribution curve

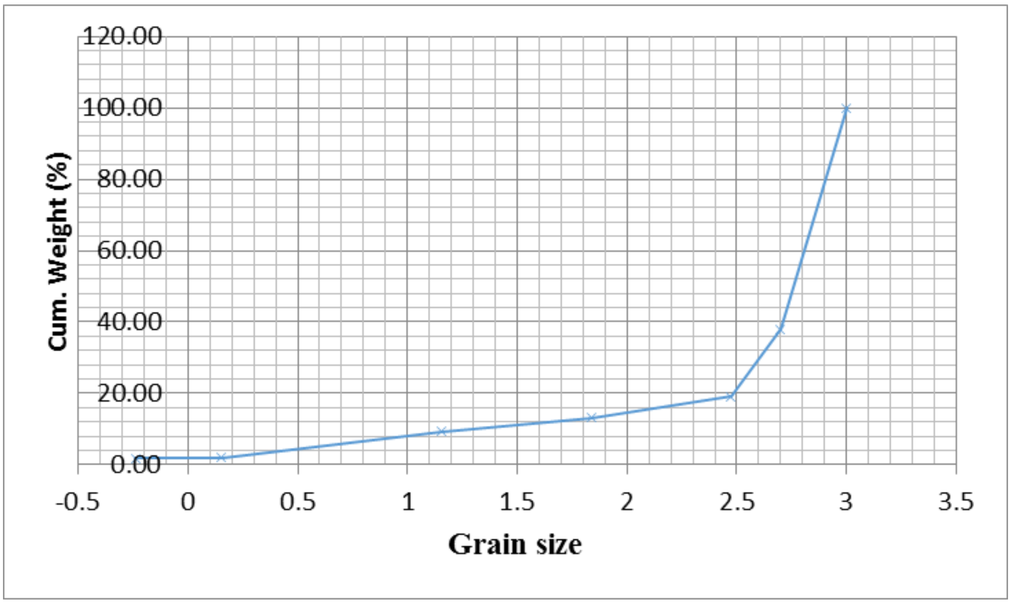

Figure 9. Particle size distribution curve at EET/2020/007

Particles size distribution curve

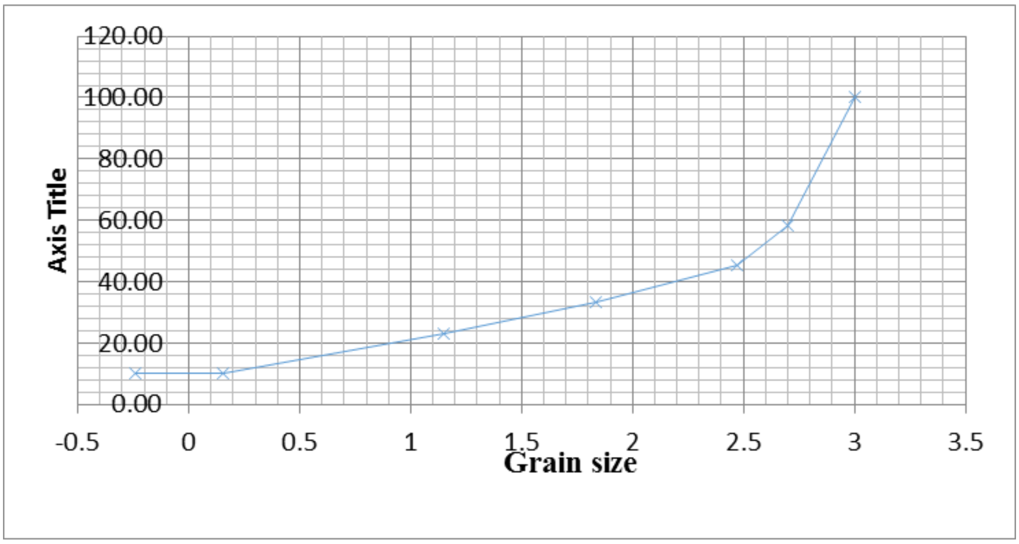

Figure 10. Particle size distribution curve at EET/2020/009

Particles size distribution curve

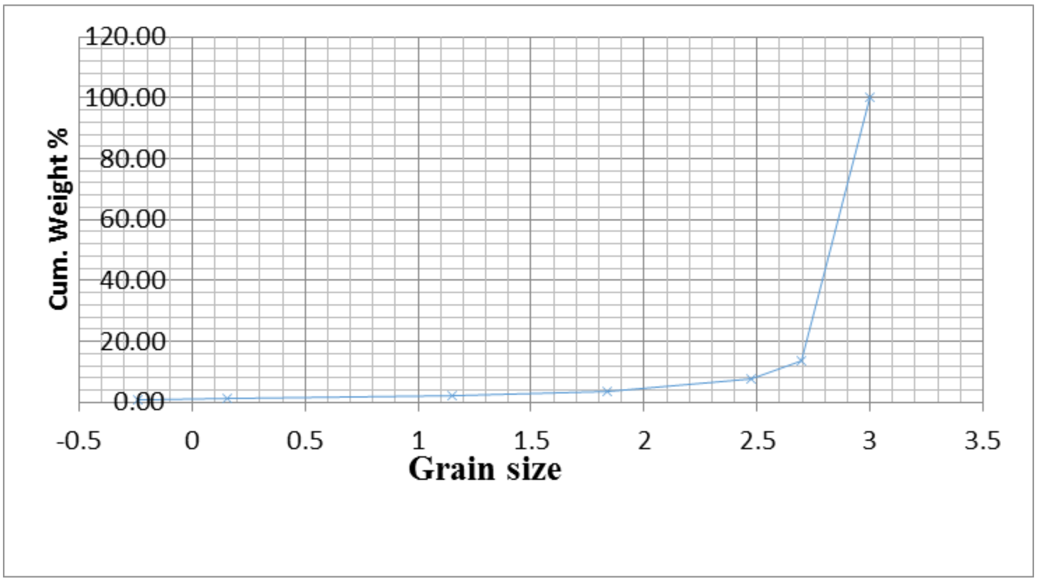

Figure 11. Particle size distribution curve at EET/2020/016

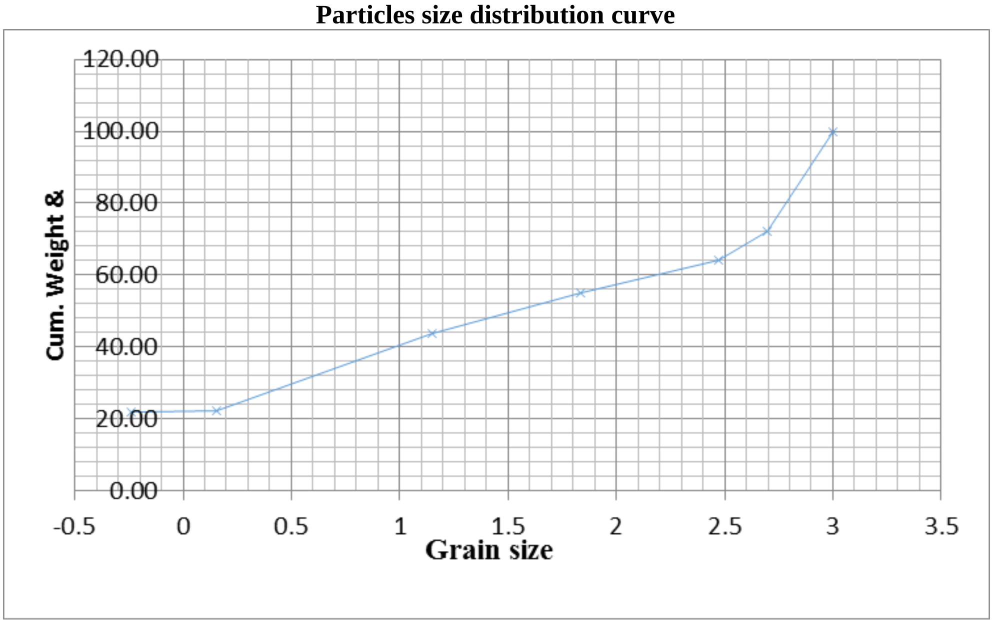

Figure 12. Particle size distribution curve at EET/2020/009

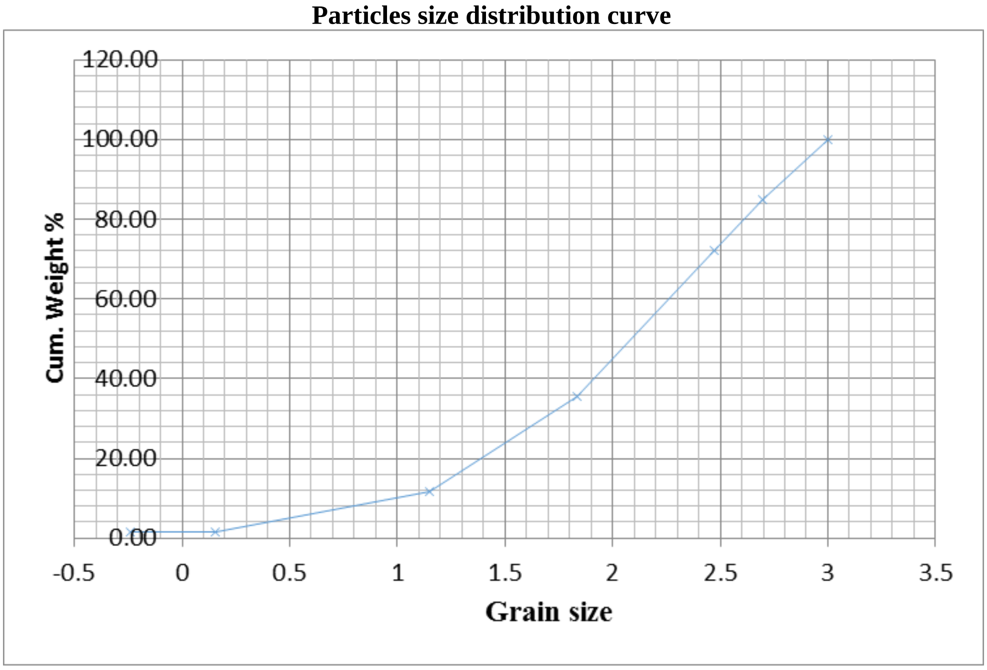

Figure 13. Particle size distribution curve at EET/2020/009

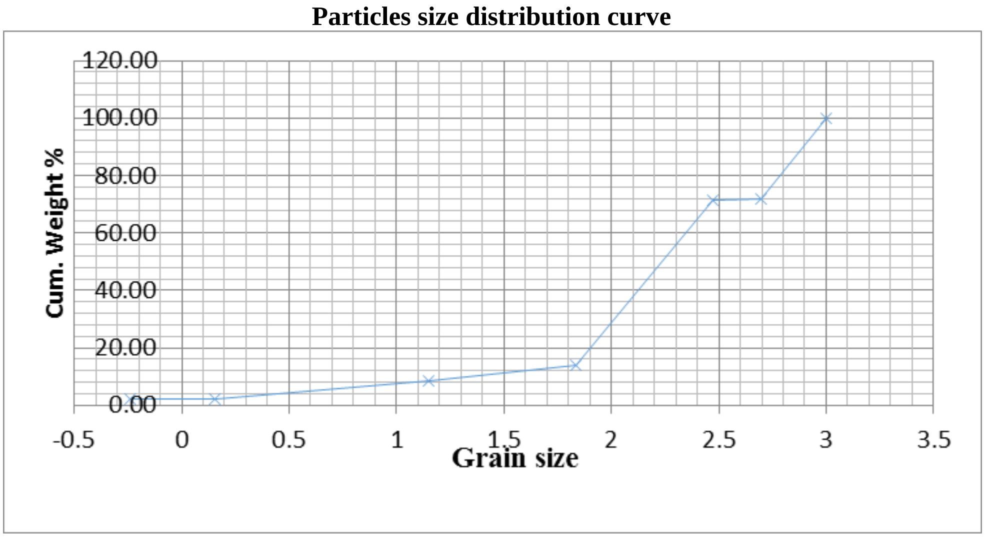

Figure 14. Particle size distribution curve at EET/2020/016

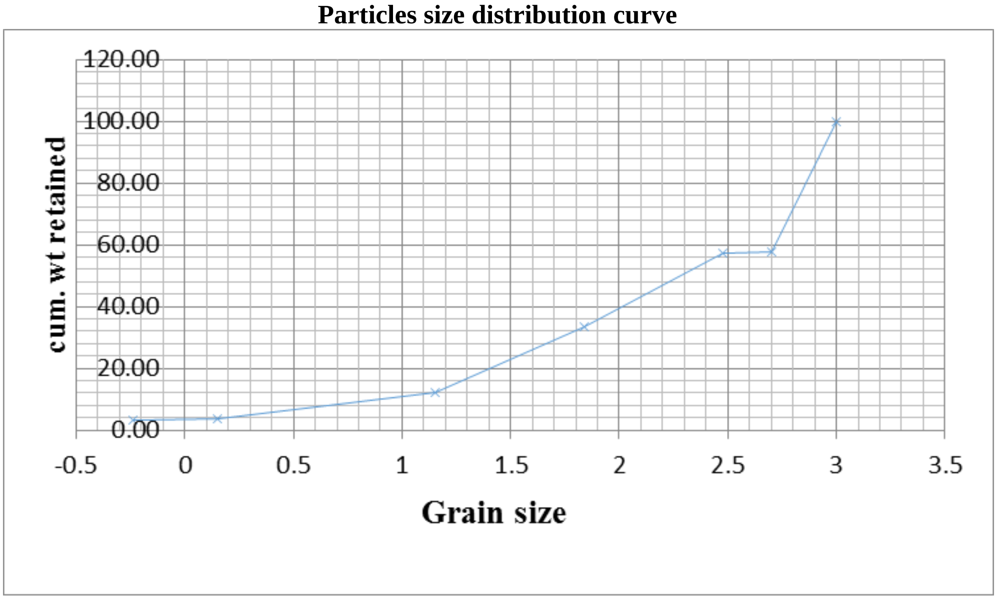

Figure 15. Particle size distribution curve at EET/2020/010

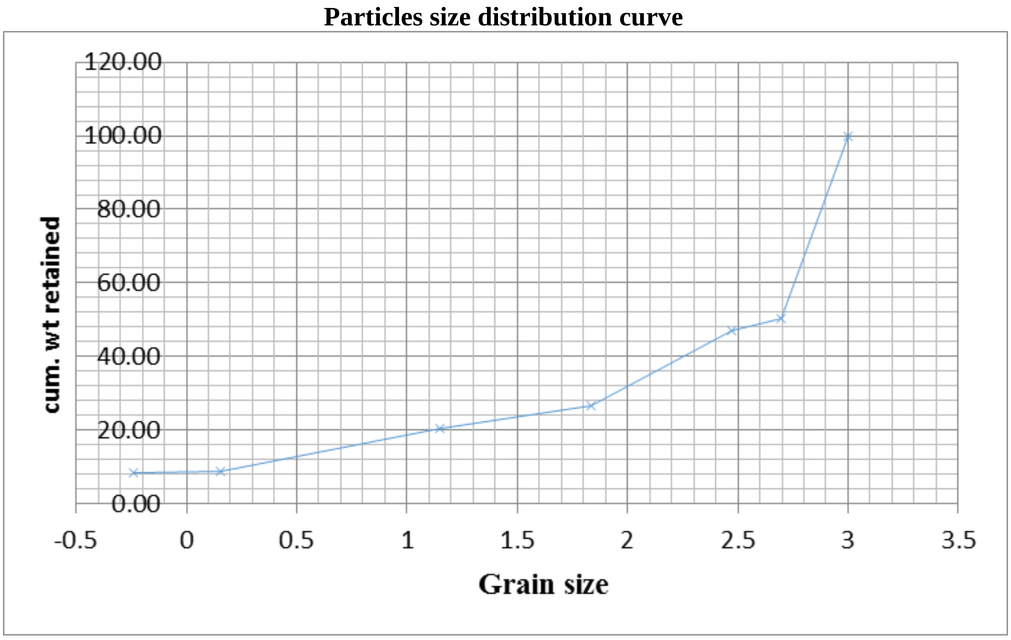

Figure 16. Particle size distribution curve at EET/2020/011

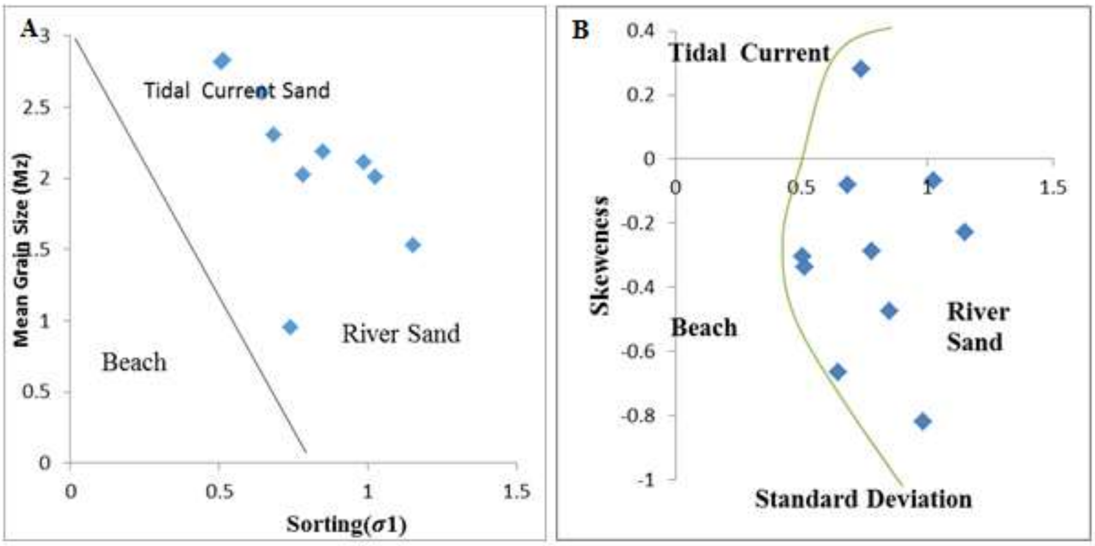

Figure 17. Bivariate plots of (A) Mean size versus sorting (Moiola and Weiser 1968); (B) Skewnesses versus sorting (Friedman 1961).

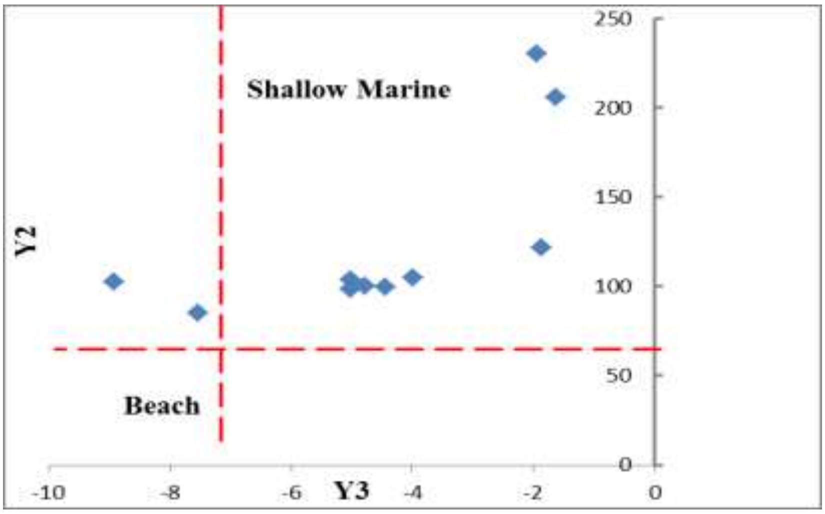

Figure 18. Multivariate plot of Y2 versus Y3

Table 1. Mineral Composition of petrographic analysis in the study area.

Framework element/Location	Quartz (%)	Plagioclase feldspar (%)	Mica (%)	Limonite (%)	Clay matrix (%)	Rock fragment (%)
L8	60	10	10	15	3	2
L13	65	13	10	8	2	2

Table 3. Descriptive Measures of Grain Size Distribution (Folk and Ward, 1957)

PARAMETER	FORMULAE	VERBAL TERMS
Mean (Mz)	$\frac{\Phi16+\Phi50+\Phi84}{3}$	1-1 = coarse sand 1-2 = medium sand 2-3 = fine
Standard Deviation (σ_1)	$\frac{\Phi84-\Phi16}{4}+\frac{\Phi95-\Phi5}{6.6}$	Very well sorted = < 0.35 Well sorted = 0.35-0.50 Moderately well sorted = 0.50 -1.0 Poorly sorted = 1.0 – 2.0 Very poorly sorted = 2.0 – 4.0 Extremely poorly sorted = >4.0
Skewness (S_{KI})	$\frac{\Phi16+\Phi84-2\Phi50}{2(\Phi84-\Phi16)}+\frac{\Phi5-\Phi95-2\Phi50}{2(\Phi95-\Phi5)}$	Very positively skewed = +0.3 to +1.0 Positively skewed = +0.1 to +0.3 Symmetrical = +0.1 to -0.1 Negatively skewed = -0.1 to -0.3 Very negatively skewed = -0.3 to -1.0
Kurtosis (K_G)	$\frac{\Phi95-\Phi5}{2.44(\Phi75-\Phi25)}$	Very platykurtic = < 0.67 Platykurtic = 0.67 - 0.90 Mesokurtic =0.9 – 1.1 leptokurtic = 1.11 – 1.50 very leptokurtic = 1.50 – 3.00 extremely leptokurtic = >3.00

Table 4. Summary of grain size characteristics of collected samples with interpretations

Location	Mean (M_Z)	Sorting (σ1)	Skewness (S_{KI})	Kurtosis (K_G)	Description
Sample No.1 EET/2020/007	0.957	0.740	0.280	0.903	coarse sand, moderately well sorted, very positively skewed, platykurtic
Sample No.2 EET/2020/007	1.962	0.507	-0.305	9.287	medium grain sand, moderately well sorted, very negatively skewed, mesokurtic
Sample No.3 EET/2020/007	1.258	0.645	-0.664	3.862	medium grain sand, moderately well sorted, very negatively skewed, extremely leptokurtic
Sample No.4 EET/2020/009	2.014	1.024	-0.680	0.928	fine grain sand, poorly sorted, very negatively skewed, mesokurtic
Sample No.5 EET/2020/016	2.831	0.512	-0.336	7.239	fine grain sand, moderately well sorted, very negatively skewed, mesokurtic
Sample No.6 EET/2020/009	1.53	1.152	-0.228	0.494	medium grain sand, poorly sorted, negatively skewed, platykurtic
Sample No.7 EET/2020/009	2.031	0.780	-0.287	1.221	fine grain sand, moderately well sorted, negatively skewed, leptokurtic
Sample No.8 EET/2020/016	1.739	0.684	-0.082	1.505	medium grain sand, moderately well sorted, symmetrical, leptokurtic
Sample No.9 EET/2020/010	2.192	0.849	-0.475	0.994	fine grain sand, moderately well sorted, very negatively skewed, mesokurtic
Sample No.10 EET/2020/011	2.116	0.986	-0.818	1.167	fine grain sand, moderately well sorted, very negatively skewed, leptokurtic

Table 5. Phi of the samples calculated

Samples	Φ5	Φ10	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95
1	0	0	0.25	0.415	0.82	1.47	1.801	2.325
2	2.1	2.53	2.714	2.768	2.821	2.9	2.93	2.991
3	0.5	1.215	2.152	2.56	2.74	2.87	2.922	2.987
4	0	0	0.61	1.411	2.52	2.72	2.911	2.964
5	2.1	2.554	2.71	2.731	2.832	2.9	2.95	2.985
6	0	0	0	0.274	1.77	2.721	2.82	2.948
7	0.5	0.94	1.287	1.561	2.12	2.514	2.687	2.84
8	0.57	1.24	1.868	1.948	2.232	2.75	2.82	2.945
9	0.41	0.8	1.287	1.58	2.4	2.8	2.89	2.96
10	0	0.25	0.75	1.81	2.699	2.85	2.9	2.96

Table 6. Multivariate Parameter and their Interpretation

Sample number	Y_1: Aeolian: Beach	Y_2: Shallow marine: Beach	Y_3: Shallow marine: Fluvial
ET/2020/007/B1	1.554 (Beach)	85.385 (Shallow Marine)	-7.536 (Shallow Marine)
EET/2020/007/B2	24.423 (Beach)	230.352 (Shallow Marine)	- 1.942 (Fluvial)
EET/2020/007/B3	11.301 (Beach)	121.514 (Shallow Marine)	- 1.856 (Fluvial)
EET/2020/009/B1	0.904 (Beach)	103.669 (Shallow Marine)	- 5.024 (Fluvial)
EET/2020/016	15.029 (Beach)	205.825 (Shallow Marine)	- 1.635 (Fluvial)
EET/2020/009/B2	0.816 (Beach)	102.658 (Shallow Marine)	-8.916 (Shallow Marine)
EET/2020/009/B3	0.037 (Beach)	100.441 (Shallow Marine)	- 4.791 (Fluvial)
EET/2020/016	1.182 (Beach)	98.532 (Shallow Marine)	- 5.022 (Fluvial)
EET/2020/010	-0.599 (Aeolian)	99.889 (Shallow Marine)	- 4.440 (Fluvial)
EET/2020/011	1.432 (Beach)	104.693 (Shallow Marine)	-3.976 (Fluvial)

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