GEOSTATISTICAL INVESTIGATION OF GRAIN SIZE AND HEAVY MINERALS OF STREAM SEDIMENTS FROM AGUNJIN AREA, KWARA STATE

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ABSTRACT

Sediment samples were obtained from different streams in Agunjin town within latitudes $8^0 26^1 28^{11}$N to $8^0 30^1 00^{11}$N and longitudes $4^0 57^1 30^{11}$E to $5^0 00^1 00^{11}$E. These samples were analysed using a sieve set of mesh with shaker, Gravity method and Binocular microscope for grain size distribution, geostatistical relationships and heavy mineral identification. The result of mean, standard deviation, skewness and kurtosis were used to differentiate the depositional environment of the sediments ranging from well to poorly sorted; negatively skewed (high energy environment) to positively skewed (low energy environment); platykurtic to leptokurtic. The heavy minerals (such as ultrastable: Zircon, Tourmaline and Rutile) were identified as well as metastable mineral and opaque minerals. The ultrastable minerals in T_1Ag_5 indicate that sand may have been sourced from reworked sediments. Ultrastable (ZTR) Index was computed which ascertains the mineralogical maturity index as mineralogically matured sediments and sub-mature and immature and no identification in T_1Ag_5, T_6Ag_{15} and T_8Ag_{18}, T_4Ag_{12}, T_3Ag_{11} and T_7Ag_{17}, T_2Ag_6 and T_5Ag_{14} respectively. Results relating the number of counts with different minerals are presented.

INTRODUCTION

Grain size analysis is done to obtain the size of different particles that form unconsolidated sedimentary deposit, sedimentary rock and others. This enables the determination of the type of environment and energy associated with the transport mechanism at the time of deposition. Particle size analysis is important because the rate of reaction of chemicals are exposed, potential of dissolution of particles are known (fine particles dissolve faster) and packing density is known (large particles are going to pack more poorly than small ones). If the particle size packing density is improved, voidage or unoccupied volume is reduced. A poorly graded soil will have better drainage than a well graded soil. Very poorly sorted to extremely poorly sorted indicate that the energy of deposition was not sufficient enough to enhance the degree of sorting to separate the sand fractions into different classes (Samyand, 2013). The quantity of finer near-mesh size particles actually determines sieving efficiency (Royse, 1970). 40g of sandy sediment as the maximum load for 8-inch diameter sieves is recommended (Twenhofel and Tyler, 1941). The sieves sort material is according to size, shape and roundness of the particles (Kennedy *et al*., 1985).

The classes of particle size are boulders, pebbles, sand, silt and clay. Particle sizes may be deposited by means of transport (Opreanu *et al*., 2007). Particle size influences how fast or slow water or other fluid moves through the soil. Characterizing the physical properties of sediment helps to investigate sedimentary environments and geologic history. The energy of the depositing medium can be described as either turbulent or calm by the nature of the sediments accumulated and relative percent of either coarse or fine (Okon and Essien, 2015). Suspended sediments have been shown to cause stress and gill damage in fish. Sediment characteristics also provide information about source materials, the depositional environment and other physical and chemical factors. When rocks are broken down into fragments either through mechanical means of weathering or chemical reactions, the fragments are called sediment.

The use of statistical parameters obtained from grain size analysis for environmental reconstruction help to distinguish ancient environments (Folk and Ward, 1957). Textural parameter such as kurtosis may have no significance in environmental diagnosis (Moiola and Weiser, 1968) but skewness is an environmental indicator (Awasthi, 1970).

A placer deposit is the result of flowing water like streams and rivers causing the accumulation of mechanically segregated minerals. The erosion of weathered rocks and minerals results in the concentration of the more resistant and higher specific gravity (density) minerals (Gandhi and Raja, 2014). Minerals having density more than 2.89 g/cm^3 are seen as dense or heavy minerals. These minerals are both opaque and non-opaque in character (Singh, 2012). Heavy minerals are defined as high density minerals with specific gravities greater or equal to 2.9 g/cm^3 (Muller, 1997). The heavy mineral assemblage in sediments reflects their parent rocks as well as their origin (Raiswell and Anderson, 2005).

The aim was to identify the non-opaque heavy minerals assemblage of the surficial and subsurficial sediments in Agunjin in an attempt to refer them to their origin.

Location and Geology of the Study Area

The study area (Agunjin) is located in the north easten part of Kwara State, Nigeria within latitude $8^0 26^1 28^{11}$N to $8^0 30^1 00^{11}$N and longitude $4^0 57^1 30^{11}$E to $5^0 00^1 00^{11}$E (Figure 1). The area is characterized by two distinct seasons: rainy (April to October) and dry (November to March). In the north eastern part of Abunjin is Abayan which is situated on the main road, about 5.5m Oke – Ode. The minor roads connect several villages to the town and assisted in the outcrop mapping of the area as well as the stream sediments collection. The climate is tropical and the vegetation type is Guinea Savannah. The vegetation type comprises tall grasses, scattered tall trees and shrubs. The topography is slightly undulating with the height of 230m to 351m above sea level. The elevation increases towards the north eastern region with the highest value (351m) around Abayan. The major river is River Ogun. Streams flow towards the south eastern part of the area to the river. The general drainage pattern in which a river flows from a common source and trellis drainage pattern was also observed indicating the subsequent streams from right to left at right angle to the direction of the river flow. The Precambrian Basement Rocks are the migmatitic gneiss, quartzite, marble and fine to medium grained granite. Migmatitic Gneiss is the most widespread in the basement rocks (Odewumi *et al*., 2015; Rahaman, 1988).

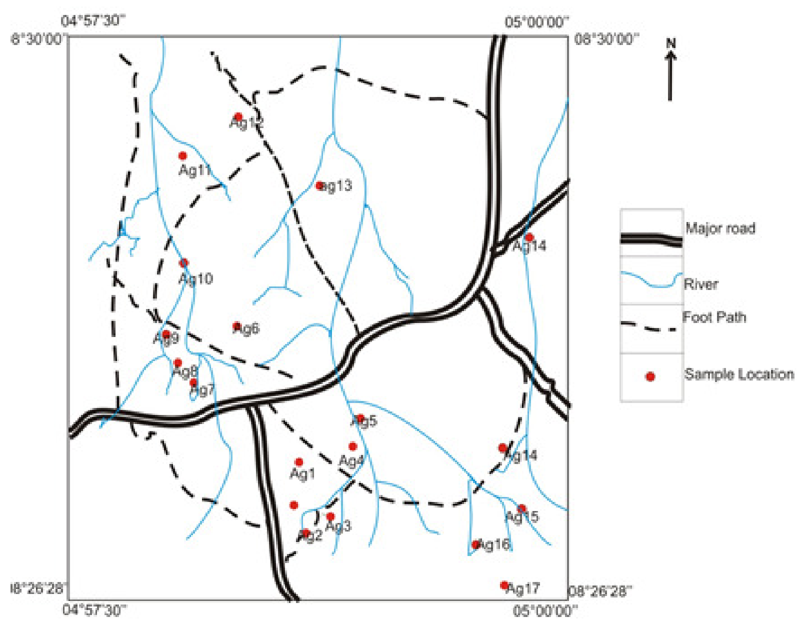

Figure 1: Locations of the study area

THEORY

The statistical parameters such as graphic mean, standard deviation, skewness and kurtosis are requirements for grain size and statistical distribution (Akintola *et al*., 2013). The formulae used to obtain these parameters are as follows:

Graphic Mean, M (Average size of the sediment):

$$M = \frac{\varphi_{16} + \varphi_{50} + \varphi_{84}}{3} \quad (1)$$

Median divides the population into two equal parts such that the intercept at 50 percentile give the value. The Wentworth scale is used for interpretation.

Standard Deviation, SD:

$$SD = \frac{\varphi_{84} - \varphi_{16}}{4} \quad (2)$$

Sorting, S_r

$$S_r = \frac{\varphi_{84} - \varphi_{16}}{4} + \frac{\varphi_{95} - \varphi_5}{6.6} \quad (3)$$

Skewness, S_k

$$S_k = \frac{\varphi_{84} + \varphi_{16} - 2\varphi_{50}}{2(\varphi_{84} - \varphi_{16})} + \frac{\varphi_5 + \varphi_{95} - 2\,\varphi_{50}}{2(\varphi_{95} - \varphi_5)} \quad (4)$$

Kurtosis, K

$$K = \frac{\varphi_{95} - \varphi_5}{2.44(\varphi_{75} - \varphi_{25})} \quad (5)$$

(Folk and Ward, 1957; Gandhi and Raja, 2014).

This classification is necessary to know the nonexistence material within the range studied. Also to know how many sediment types with characteristic bedding features occur on the bar in constant stratigraphic order, with the coarsest at the base. Table 1 shows the degree of sorting while Table 2 shows the Kurtosis values.

Table 1: Classification of the degree of sorting (Folk and Ward, 1957)

S/N	Sorting Coefficient	Characterization
1	> 4	extremely poor
2	2 – 4	very poor
3	1 - 2	poor
4	0.71 - 1	moderate
5	0.50 - 0.71	moderately well
6	0.35 - 0.5	well
7	< 0.35	very well

Table 2: Classification of kurtosis values (Folk and Ward, 1957)

S/N	Value	Classification	Explanation
1	< 0.67	very platykurtic	very flat frequency distribution
2	0.67 - 0.90	platykurtic	flat
3	0.90 - 1.11	mesokurtic	not especially peaked, normal
4	1.11 - 1.50	leptokurtic	highly peaked
5	> 1.50	very leptokurtic	very highly peaked

Heavy minerals may be opaque or non-opaque minerals. Opaque minerals usually predominate in a heavy mineral suite (Friedman and Sanders, 1978). Non opaque could be ultrastable or metastable minerals. Suites of heavy minerals and their source rocks are presented in Table 3.

Table 3: Heavy minerals and their source rocks (Feo-Codecido, 1956)

S/N	Minerals	Source rocks
1	Rutile, Topaz, Zircon, Apatile	Acid Igneous rocks
2	Garnet, Topaz, Tourmaline, Monzonite, Cassiterite	Granite, Pegmatite
3	Augite, Magnetite, Chronite, Hypersthene, Diopside	Basic Igneous rocks
4	Topaz, Garnet, Andalusite, Ziosite, Corundum	Contact Metamorphic rock
5	Epidote, Garnet, Kyanite, Silimanite, Staurolite	Regional, Metamorphic rock
6	Zircon, Rutile, Tourmaline	Reworked Sediment

Considering the ZTR index, the focus is on minerals such as Zircon, Tourmaline and Rutile (ZTR). The index is to ascertain the mineralogical maturity so as to know how mature, sub-mature, immature and no identification of these minerals in a sample.

$$\text{ZTR Index} = \frac{Zircon + Tourmaline + Rutile\ (100\%)}{\sum non-opaque\ minerals} \quad (6)$$

ZTR $< 75\%$ implies immature to sub-mature. ZTR $> 75\%$ indicates mineralogically matured sediments (Hubert, 1962; Suleiman *et al.*, 2015).

METHODOLOGY

The materials used include: hammer, chisel, German Standard Sieve of sizes, sample bags (for collection of stream sediments), measuring tape, paper tape, marker (labeling for easy identification), GPS (for location), compass clinometer, Weighing balance, digital camera (to capture the stream sediments collected), electrical vibratory machine, hand lens and topographical map.

The procedure for the analysis involves disaggregation of eight samples by soaking in water for 24 hours to obtain individual grains and was exposed to sun for two days to ensure the samples are free of water. Weighing balance was used to measure 100g of each dried sample and poured into the German Standard Sieve of sizes: 2.00mm, 1.00mm, 0.85mm, 0.71mm, 0.60mm, 0.50mm, 0.30mm, 0.25mm, 0.112mm, 0.09mm, 0.075mm, 0.063mm and less than 0.063mm. It carries a pan at the bottom to collect the less than 0.063mm fractions. The set up was set linked to an electrical vibratory machine (sieve shaker) for 10 minutes to facilitate the grains separation. The fraction retained on each sieved pan was weighed, recorded and used for statistical calculation.
Heavy minerals were separated from other minerals of lower density by gravity method. Light density fractions float while high density ones sink after allowing for 7 hours. Both fractions were washed with Bromoform (Tribromommethane) and allowed to dry. The grains of the heavy mineral were placed on the microscope slide for identification and subsequently counted.

RESULT AND DISCUSSION

The percentage of the aggregates was estimated. Cumulative weight retained in percentage was obtained. The 5th, 16th, 25th, 50th, 75th, 84th and 95th percentiles were deduced from each cumulative curve (Figures 2 to 9). These were used to investigate the statistical and textural parameters such as Graphic Mean (M), Standard Deviation (SD), Sorting (S_r), Graphic Kurtosis (K) and Graphic Skewness (S_k). The equations employed for calculations are 1 to 5. The results are presented in Table 4, textural interpretation in Table 5.

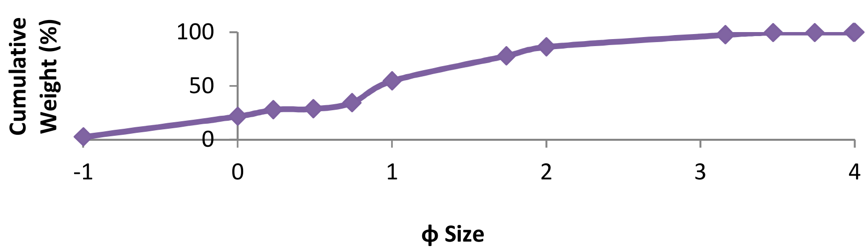

Figure 2: Cumulative curve of sample Ag5

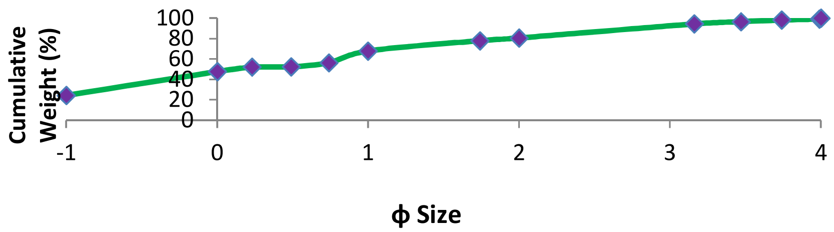

Figure 3: Cumulative curve of sample Ag15

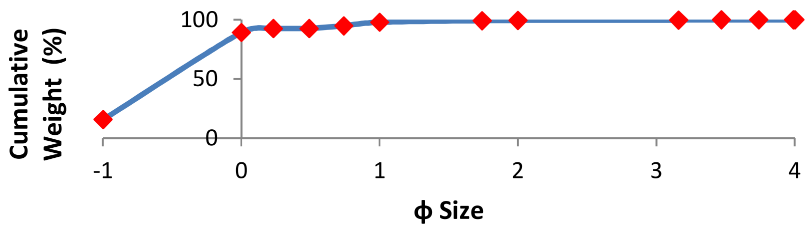

Figure 4: Cumulative curve of sample Ag17

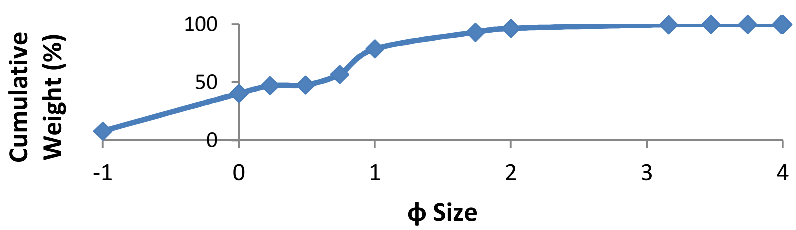

Figure 5: Cumulative curve of sample Ag6

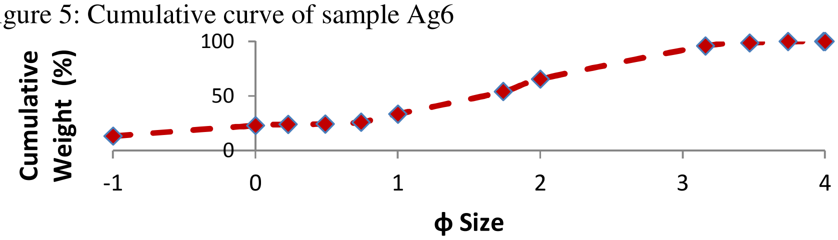

Figure 6: Cumulative curve of sample Ag18

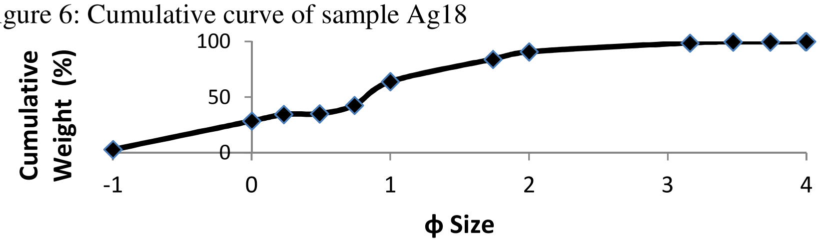

Figure 7: Cumulative curve of sample Ag11

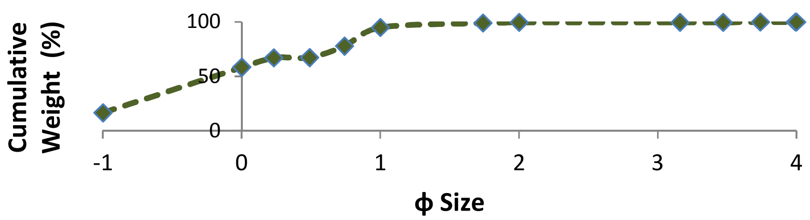

Figure 8: Cumulative curve of sample Ag14

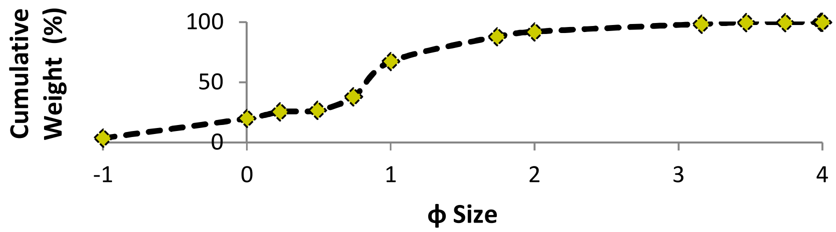

Figure 9: Cumulative curve of sample Ag12

DISCUSSION

Stream sediments varied for sorting ranging from well sorted (T_3Ag_{11}), moderately sorted (T_4Ag_{12}, T_7Ag_{17}, T_8Ag_{18}) to poorly sorted (T_1Ag_5, T_2Ag_6, T_5Ag_{14}, T_6Ag_{15}). These may be due to the prevalence of wave convergence and fine size of the sediments; the addition of sediments of different grain size from the reworking of stream ridges or alluvial action and the prevalence of strong wave convergence throughout the year; quick deposition such as storm beds or from viscous flow respectively. It varies for skewness as negatively skewd (high energy environment) for T_4Ag_{12}, T_5Ag_{14}, T_6Ag_{15}; positively skewed (low energy environment) for T_2Ag_6, T_3Ag_{11}, and nearly symmetrical for T_1Ag_5, T_7Ag_{17}, T_8Ag_{18}. Kurtosis obtained shows platykurtic for T_2Ag_6, T_7Ag_{17}, mesokurtic for T_1Ag_5, T_3Ag_{11}, T_4Ag_{12}, T_6Ag_{15} and Leptokurtic for T_5Ag_{14}, T_8Ag_{18}.

The heavy minerals identified consist of opaque and non-opaque minerals. Our focus is on non-opaque minerals such as Zircon, Tourmaline and Rutile (ultrastable); others are Garnet, Epidote, Topaz, Sphene (or Titanite), Enstatite, Piemontite and Muscovite (metastable). The count of each mineral is presented in Table 6. T_8Ag_{18} contains Tourmaline, Topaz and Zircon. This is an indication that sand could have been sourced from both acid igneous rocks and reworked sediments. T_7Ag_{17} contains Rutile, Epidote and Sphene which is higher than others. This indicates that the minerals may have been from regional metamorphic rocks and were reworked from older sediments. T_4Ag_{12} identified Rutile, Topaz, Zircon and Sphene; shows they are from acid igneous rocks. T_2Ag_6 has Tourmaline, Rutile, Sphene, therefore should be from reworked sediments and acid igneous rocks. T_5Ag_{14} identified Enstatite and piemontite which are both from igneous rocks and metamorphic rocks. T_1Ag_5 shows Tourmaline, Rutile, Zircon which indicates from reworked sediments. T_5Ag_{15} contains Garnet, Tourmaline, Zircon. This indicates minerals may be from Granite, Pegmatite, regional metamorphic rocks, reworked sediments and acid igneous rocks. T_3Ag_{11} contains Rutile, Zircon, Muscovite which is from reworked sediments. Moreso, ultrastable mineral (ZTR) index is a quantitative definition of mineralogical maturity index. Results relating the number of counts with different minerals are presented in figures 9.0 to 10.0. These show that the minerals are mature (or mineralogically matured sediments) in T_1Ag_5, T_6Ag_{15}; sub-mature in T_8Ag_{18}, T_4Ag_{12} and T_3Ag_{11}; immature in T_7Ag_{17} and T_2Ag_6; minerals are not found in T_5Ag_{14}.

Table 4: Result percentiles and their corresponding textural parameters

Locations	φ_5	φ_{16}	φ_{25}	φ_{50}	φ_{75}	φ_{84}	φ_{95}	M	SD	S_r	S_k	K
$T_1(AG_5)$	-0.9	-0.3	0.1	0.9	1.6	1.9	2.9	0.833333	0.550	1.125758	-0.01914	1.038251
$T_2(AG_6)$	-1.7	-1.3	-1	0.1	1.5	2.3	3.3	0.366667	0.900	1.657576	0.251111	0.819672
$T_3(AG_{11})$	-1.1	-1	-0.9	-0.5	-0.2	-0.1	0.7	-0.53333	0.225	0.497727	0.111111	1.053864
$T_4(AG_{12})$	-1.1	-0.7	-0.3	0.6	0.9	1.2	1.9	0.366667	0.475	0.929545	-0.25088	1.024590
$T_5(AG_{14})$	-1.7	-0.5	0.6	1.6	2.3	2.7	3.1	1.266667	0.800	1.527273	-0.34375	1.157184
$T_6(AG_{15})$	-0.9	-0.5	-0.1	0.9	1.4	1.7	2.6	0.700000	0.550	1.080303	-0.15065	0.956284
$T_7(AG_{17})$	-1.3	-1	-0.8	-0.2	0.7	0.8	1.0	-0.13333	0.450	0.798485	0.077295	0.628415
$T_8(AG_{18})$	-0.9	-0.2	0.2	0.8	1.2	1.6	2.5	0.733333	0.450	0.965152	-0.05556	1.393443

Table 5: Textural interpretation

Locations	M	SD	S_r/ Interpretation	S_k/ Interpretation	K/ Interpretation
$T_1(AG_5)$	0.833333	0.55	1.125758/ Poor	-0.01914/ Nearly Symmetrical	1.038251/ Mesokurtic
$T_2(AG_6)$	0.366667	0.9	1.657576/ Poor	0.251111/ Positively skewed (Coarse Skewed)	0.819672 Platykurtic
$T_3(AG_{11})$	-0.53333	0.225	0.497727/ Well	0.111111/ Positively skewed (Coarse Skewed)	1.053864/ Mesokurtic
$T_4(AG_{12})$	0.366667	0.475	0.929545/ moderate	-0.25088/ Negatively Skewed (fine skewed)	1.02459/ Mesokurtic
$T_5(AG_{14})$	1.266667	0.8	1.527273/ Poor	-0.34375/ Very Negatively Skewed (strongly fine skewed)	1.157184/ Leptokurtic
$T_6(AG_{15})$	0.7	0.55	1.080303/ Poor	-0.15065/ Negatively Skewed (fine skewed)	0.956284/ Mesokurtic
$T_7(AG_{17})$	-0.13333	0.45	0.798485/ Moderate	0.077295/ Nearly Symmetrical	0.628415/ Platykurtic
$T_8(AG_{18})$	0.733333	0.45	0.965152/ Moderate	-0.05556/ Nearly Symmetrical	1.393443/ Leptokurtic

Table 6: Number of counts of heavy minerals present

S/N	Heavy Mineral	Ag_{18}	Ag_{17}	Ag_{12}	Ag_{6}	Ag_{14}	Ag_{5}	Ag_{15}	Ag_{11}
1	Garnet							2	
2	Toumaline	8			7		6	3	
3	Rutile		3	4	10		2		3
4	Topaz	10		5					
5	Epidote		2						
6	Zircon	5		3			7	5	5
7	Sphene		2	2	30				
8	Enstatite					5			
9	Piemontite					4			
10	Muscovite								4
11	Opaque	20	8	22	10	4	30	17	20

CONCLUSION

Sediments were found to be well sorted in only one location, moderately and poorly sorted in other locations; platykurtic, mesokurtic and leptokurtic; negatively skewed, positively skewed and nearly symmetrical. These indicate high environment (downstream barrages) associated with high current velocity and low energy environment (upstream barrages) associated with a reduced current velocity. Heavy minerals such as ultrastable, metastable and opaque were identified with the ultrastable mineral index indicating that only two locations (T_1Ag_5 and T_6Ag_{15}) have matured sediments. The possible sedimentary rock formation could be chemical, biogenic and mostly detrital since they contain particles from preexisting rocks. The volume of minerals in these locations is recommended for economic value.

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