

# Depositional Processes and Provenance Determination Using Grain Size Analysis and Heavy Mineral Assemblages of Surficial Sediment and Stream Sediment Samples from Iwere-Ile and Its Environs

Okon, Emmanuel Etim and Essien, Nse Udo

**ABSTRACT** - The sedimentological study of surficial sediments (colluviums and stream sediments) was carried out around Iwere-Ile and its environs in part of southwestern Nigeria. Twenty-six (26) samples of which 11 were stream sediments and 15 were colluvial deposits were collected. The samples were subjected to grain size analysis and heavy mineral studies using standard procedures and the data obtained were subjected to statistical analysis from where the textural parameters and mineralogical characteristics were derived.

Results show that the textural characteristics of these sediments range from coarse grained to fine grained, with inclusive graphic mean values ranging from 0.37-1.93. 81% of the sediments were poorly sorted while 13% and 6% of the sediments were moderately sorted and moderately well sorted respectively, kurtosis values of these sediments range from very platykurtic (0.3 $\Phi$ ) to very leptokurtic (1.64 $\Phi$ ).

A total of 2289 heavy minerals were counted in the study area with about 1137 non-opaque minerals whose properties were studied. The dominant mineral in the area studied was zircon (22.4%) which was followed by Tourmaline (18%) and then Rutile (13.1). The ZTR index of the study area was calculated and seen to range from 52% to 70% among the samples analyzed. The heavy minerals assemblage includes opaque minerals, zircon, tourmaline, rutile, hornblende, biotite, garnet, glaucophane, staurolite, apatite and kyanite. These assemblages indicate that the igneous and metamorphic rocks of the Nigerian Basement complex are the source for these sediments. Most of the heavy minerals are almost euhedral and retain their original habit while some others are sub-angular indicating short distance of travel from source. The deductions from the bivariate plots are consistent with the environmental regime responsible for the transport of these sediments since they all point to fluvial environment.

**Keywords:** fluvial environment, grain size, heavy minerals, surficial sediments.

## 1 INTRODUCTION

Iwere-Ile is a town in Iwajowa LGA, Oyo state, south western Nigeria and it is located within the southwestern Nigerian Basement Complex. The Basement geology is characterized by distinct lithologies and mineralizations. The map area is bounded by longitude 3°00'E and 3°06'E, and latitude 7°50'N and 8°00'N, located with Igangan Sheet (1:100,000) and covers an aerial extent of about 198 km<sup>2</sup> surrounded by basement rocks. The area is almost divided into two parts by the River Oyan which flows throughout the map area from north to south forming the major drainage of the area. The sediment load of the river is predominantly those derived from the weathering of the surrounding basement rocks.

Not much has been done on the grain size analysis and heavy mineral assemblages of Iwere-Ile and its environs. Since grain size analysis is amenable to the characterization of depositional processes as well as mechanisms recorded in the sediment texture and composition; this paper incorporates both the grain size and heavy mineral analysis from sediments taken from Iwere-Ile and its environs to determine their provenance and depositional environment.

## 2 PREVIOUS WORK

The use of the statistical parameters derived from detailed analysis of grain size for environmental reconstruction, though suffers certain limitations, have proven to be very useful in distinguishing ancient environments [1], [2], [3], [4], [5], [6]. The energy of the depositing medium can be diagnosed as either being turbulent or calm by the nature of the sediments accumulated and the relative percent of either the coarse - or fine - tail. Moiola and Weiser [7] have pointed out from textural parameters that the values of kurtosis has no significance in environmental diagnosis, however, [8] has shown the importance of skewness as an environmental indicator. The study of heavy mineral begun over 100 years ago and the enthusiasm of early researchers as they looked for and identified heavy minerals refined the methods used initially and allowed for proliferation of publications (e.g. [9], [10], [11], [12], [13]. There was however, a decline in the study of heavy minerals when it became obvious that hydraulic effects caused selective sorting according to size, shape and density, and the realization that other phenomena may affect heavy mineral assem-

blage [14]. The study of heavy minerals once again gained interest after the work of researchers (e.g. [15], [16], [17], [18] contributing greatly to the factors that were seen to be important in modifying the heavy mineral suite and thus providing more sophisticated interpretations. The combined use of grain size and heavy mineral assemblages has proven to be an invaluable tool for sedimentological works, most especially in poorly preserved sediments [19].

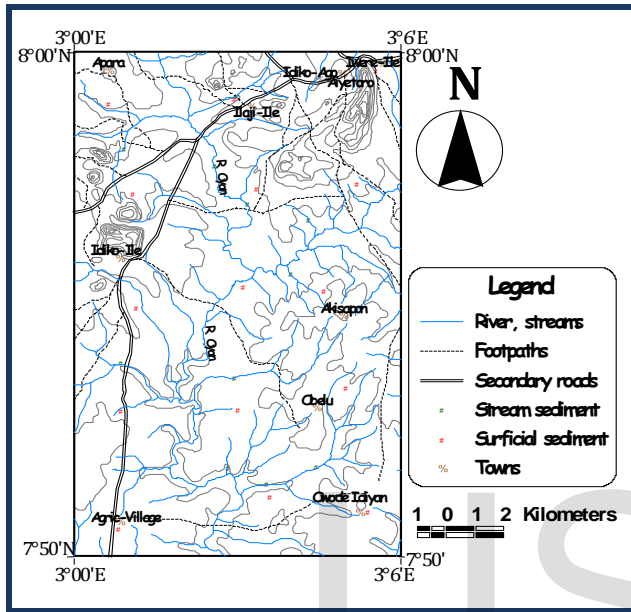


Fig. 1. Topographic map of the study area showing the sampling points

## 2.1 Geological Setting

Nigerian geology comprises of Precambrian – Early Proterozoic Basement rocks and Cretaceous – Recent sedimentary basins (Figure 2: Simplified geologic map of Nigeria). The sedimentary basins occupy about 50% of the aerial extensive surface of the country overlying the basement rocks. The sediments are Cretaceous to Recent in age and they are exposed at the four corners of the country and dominantly along the Y-arm of the Niger-Benue drainage system down to the southern Niger-Delta. There are about seven sedimentary basins in Nigeria (Sokoto, Bida, Dahomey, Borno, Benue Trough (Upper, Middle and Lower), Anambra and the Niger Delta, although recent studies have included the Calabar Flank into this list as a separate basin from the Lower Benue Trough, [20]. This is based on the premise that even though its origin is tied to the prevalent tectonics that initiated the Benue Trough, the Calabar Flank is more of a marginal basin underlain by horsts and graben structure that originated from vertical crustal movements.

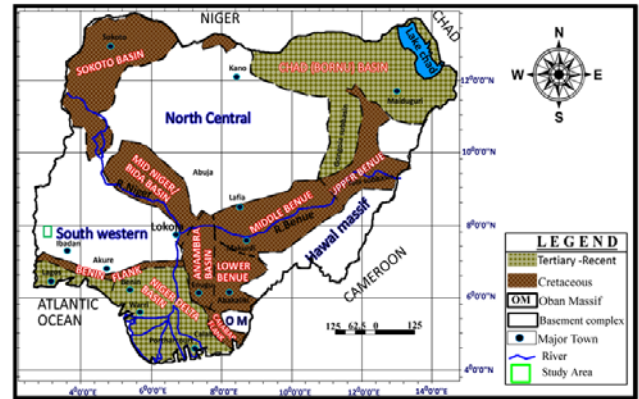


Fig. 2. Sketch of the geologic map of Nigeria showing the study area.

The Nigerian Basement Complex lies to the south of the Tuareg shield and within the Pan African Mobile belt (Fig. 3). The Pan-African province of West Africa lies between two cratons of Archean to Lower Proterozoic age (the West African Craton and the Congo Craton to the southeast). The Pan-African province extends northwards through Hoggar Massif in the central Sahara to be truncated by the Alpine fold belt in North Africa [21]. The Basement rocks consist mainly of Igneous and metamorphic rocks and they cover about fifty percent of Nigeria.

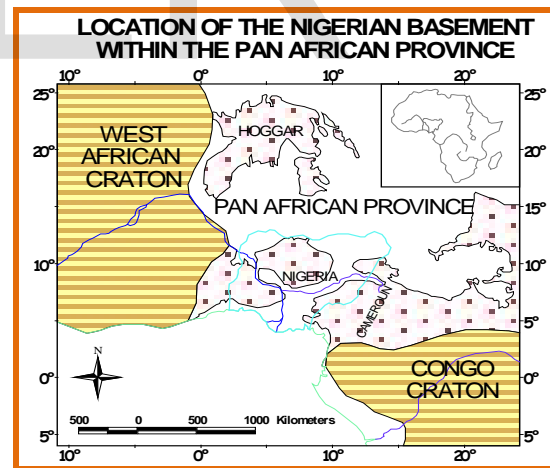


Fig.3. Location of Nigerian Basement Complex within the Pan-African Mobile belt (modified after [21]).

The study area lies in the region affected by the Late Precambrian to Early Proterozoic orogenies, more precisely to the east of the West African craton. The Nigerian Basement Complex extends westwards and is continuous with the Dahomeyan of the Dahomey – Togo – Ghana region, to the east and the south, Mesozoic-Recent sediment complex. The rocks of the Basement Complex bear evidence of an exceedingly long history;

they've generated heat and stress in the crust of the earth, they have been folded and crumpled, raised into mountain ranges and worn down by the agents of denudation to the gentle relief that most areas now have.

Based on the work done so far on the structural, lithological, tectonostratigraphical and geochronological data, the evolution of the Basement Complex of southwestern Nigeria is believed to have occurred within four orogenic events [22], they are;

- Liberian 2800 ± 200 m.y.
- Eburnean 2100 ± 200 m.y.
- Kibaran 1100 ± 250 m.y.
- Pan – African 600 ± 150 m.y.

However, based on the classification scheme of [22], [23], [24], and some others who have carried out detailed work of the lithological units in the southwest, the rock suites are described as follows:

Lithologically, it is composed of five major rock units viz:

The first group comprises Migmatite and granite gneiss with quartzite rocks: This group is the most widespread in the southwestern Nigerian basement and comprises gneisses, quartzites, calc-silicate rocks, biotite-hornblende schist and amphibolites.

The second group is the slightly migmatized to unmigmatitic metasediments schists and metaigneous rocks: these consist of pelitic schists, quartzites, amphibolites and talcose rocks, metaconglomerates, marble and calc-silicate rocks.

The Charnockitic, gabbroic and dioritic rocks constitute the third group

Members of the Older Granite suite comprising rocks varying in composition from granodiorites to true granites and potassic syenites belong to the fourth group.

And finally the unmetamorphosed dolerites dykes believed to be the youngest [25].

The study area is characterized by both igneous and metamorphic rocks [26]. The metamorphic rocks constitute sericite phyllites and muscovite granite gneisses. Although no radiometric dating was attempted, the relationship between the rock units and existing publications has to a great extent enabled the relative dating of the rock units within the area.

From the mineralogical composition of these rocks, they seem to have formed from reworked sediments of the Older metasediments and are members of the Migmatite-Gneiss-Quartzite complex. They are rich in muscovites (sericite – fine grain muscovites found in rocks) and quartz. The rocks are foliated and fractured. The regional trend of these rocks is to the NE-SW direction and shows minor folds. The quartzofeldspathic materials found filling/healing the fractures and/or joints are younger than the rocks themselves. Their bedded nature makes them more likely to be of sedimentary origin but have been migmatized and metamorphosed to their present state. They constitute the oldest rock series with the muscovite

granite gneiss being older than the sericite phyllites that occur with quartzites.

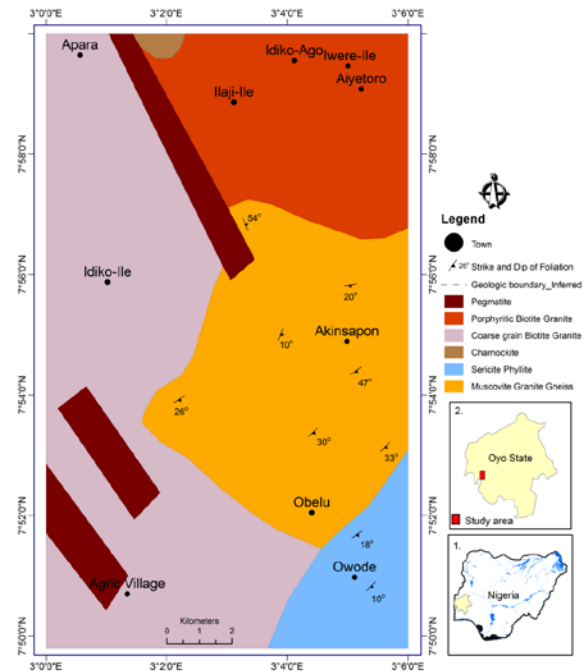


Fig.4. Geological map of the study area [26]

The next rock units of prominence in the study area are the granitoids of the Older Granite suite. The Charnockite present in the study area are believed to have been emplaced prior to the emplacement of the Older Granite during the Pan-African Event. The porphyritic biotite granites are believed to have been emplaced by “stopping mechanism” into the already existing rock units as this is evidenced by the presence of xenoliths found all around the rock mass. As earlier stated the emplacement of the charnockite is thought to be earlier than the Older Granite suite. It occurs as low-lying boulders within the study area in the far northwestern part near Apará, it is flanked to the west by a pegmatite trend and about 2.3km north of our study area is an isolated conical hill of Charnockitic rock which was observed along the course of the River Oyan. The River Oyan being highly structurally controlled and meanders through the approximate boundary of the pegmatite and the porphyritic biotite granite.

Rocks of the Older Granite suite consist of granodiorites; these rocks however have not been shown on the map distinctly because their size was not large to be mappable to the scale of the map and their boundary was indistinguishable. This was flanked by coarse grained muscovite-biotite granite around Idiko-Ile and Apará town, and porphyritic biotite granite to the northeast around Iwere-Ile. These rocks were followed by pegmatite intrusions and later quartzofeldspathic veins healing most of the joints associated with the emplacement of the

Older Granite during the Pan-African Orogeny.

### 3 STUDY METHODS

Surficial sediments (15) and stream sediments (11) spread across the study area (see Fig 1) were sampled in different areas with the aim of understanding the process leading to their accumulation and the source of the sediments

#### 3.1 Grain size analysis

The fifteen surficial sediment samples collected from the field were subjected to grain size analysis after air-drying them, disaggregating and removing all the roots and plant materials that may be included in the sample. 100g of each sample was weighed out using a weigh balance and the sample was emptied onto the top sieve of a nest of sieves that ranged from very coarse sand size to smaller than very fine sand size (pan). The sieve was capped and the stack set on an Endocotts sieve shaker for a constant time of 15 minutes. The weight retained in each sieve and the pans were obtained by subtracting the weight of the empty sieve/pan from that with sediments, then the weight was recorded. The cumulative weight percentages were determined and tabulated.

#### 3.2 Heavy mineral separation

Five stream sediments and one surficial sediment sample were selected for heavy mineral analysis judging by their distribution throughout the study area.

The selected samples were disaggregated and all roots and plant remains were picked out. 50g was taken for washing with water and decanting all clay – very fine silt (usually <0.01mm) materials after which the sample is boiled for half an hour in dilute HCl to remove all carbonates and to set the grains free and detached. The sample was again washed after acid digestion with distilled water to neutralize the effect of the acid. The sample is dried and screened through 3Φ sieve mesh for ease of identification and good representation of diversity of species [27], and only 5g of the residue that passed through the sieve was taken for the heavy mineral separation. Bromoform is the only available heavy liquid that could be used (although it is a toxic liquid and must be used with caution; a more environmental friendly and non-toxic liquid, sodium and lithium polytungstate is here recommended). The bromoform was held up in a separating funnel which was already set-up on a retort stand. A beaker was held below the separating funnel which had a filter paper shaped in the form of a cone and held in a funnel to trap the heavy mineral as they are let out of the separating funnel. The tap of the separating funnel was initially closed, and the prepared sample was emptied into the separating funnel and stirred vigorously with a stirring rod. The quartz and other lighter minerals float while the minerals with specific gravity greater than 2.89g/cm<sup>3</sup> sink to the bottom of the funnel near the tap. The whole process follows the principle of gravity settling. After all the heav-

ies have settled, the tap is opened to allow the bromoform flush the heavy minerals out through the tap and collect in the filter paper and the tap is closed again. In this way, the bromoform can be recycled and used again. The residue in the filter paper was wetted with acetone to remove the bromoform and to quicken drying. The heavy mineral concentrates was then mounted on slides using DPX mountant. The prepared slides was left on a hot plate for fifteen seconds and then viewed under the microscope for mineral identification and counting. Mineral counts using the 'Ribbon' technique [28] was used in this study.

### 4 RESULTS AND DISCUSSION

From the results obtained from the sieve analysis, ogives (cumulative curves) and histograms were generated following standard procedures. Grain sizes corresponding to the 5<sup>th</sup>, 16<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup>, 84<sup>th</sup> and 95<sup>th</sup> percentiles were obtained (Table 1) and used to compute the graphic mean, median, mean, standard deviation (sorting), inclusive graphic skewness and graphic kurtosis. The formulae proposed by [1] were used for the calculation.

TABLE 1: PHI (Φ) VALUES OBTAINED FROM THE CUMMULATIVE CURVES

Φ EQUIVALENT Sample No	Φ5	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95
C001	-0.90	-0.65	-0.45	0.15	0.90	1.30	2.30
C002	-0.95	-0.80	-0.68	-0.35	-0.05	0.30	1.50
C003	-0.75	-0.20	0.15	0.95	1.60	1.90	2.75
C004	-0.75	-0.25	0.10	1.20	2.15	2.50	3.65
C005	-0.70	-0.05	0.58	1.43	2.03	2.35	3.00
C006	-0.83	-0.45	-0.15	0.90	1.60	1.90	2.35
C007	0.15	1.30	1.45	1.85	2.18	2.35	2.85
C008	-0.75	-0.20	0.25	1.65	2.55	3.25	4.05
C009	-0.10	1.25	1.90	2.40	2.80	3.15	3.70
C010	-0.75	-0.20	0.25	1.40	2.25	2.50	3.35
C011	-0.80	-0.40	-0.08	0.85	1.70	2.15	2.90
C012	-0.70	-0.05	0.75	2.20	2.75	3.25	4.00
C013	-0.88	-0.60	-0.40	0.50	2.00	2.40	3.20
C014	-0.80	-0.35	0.00	1.30	1.95	2.40	3.55
C015	-0.85	-0.55	-0.30	0.95	2.00	2.40	3.45

#### 4.1 Univariate Analysis

Grain size statistical parameters can be related to different environments of deposition ([1], [6], [29]). Such grain size parameters are very useful in environmental interpretation especially when they are integrated with other parameters such as sedimentary structures and geological settings. In situations where the characteristics of a single statistical parameter define a depositional process, univariate analysis is implied. For instance, translated in terms of energy, the mean size indicates the average kinetic energy (velocity) of the depositing agent [30]. However, the average size is also dependent upon the size distribution of the available source materials. In the study



area, it ranged from fine grains (2.67) to coarse (-0.28), having an average size in the medium grain (1.14) class.

The standard deviation measures the sorting of the sediments and indicates the fluctuation of the kinetic energy (velocity) conditions of the depositing agent about its average velocity. Sorting has an inverse relation to standard deviation, so if sufficient materials of different sizes are not available to the depositing agent, all the fluctuation in velocity cannot be recorded geologically. In the study area, on the average the sediments are poorly sorted (1.18) but they range from poorly sorted (1.65) to moderately well sorted (0.64). Thus the size distribution of the source material also to a certain extent control the sorting of the sediments.

The range of values for skewness in this study is from strongly fine skewed (0.52) to near symmetrical (-0.03); the average being near symmetrical (0.033), while kurtosis, a measure of the peakedness of the frequency curve, fell below unity for most samples except sample C003 which attained unity (normal distribution). On the average the samples are describes as mesokurtic, while they range from very platykurtic to very leptokurtic.

The table below (Table 2) summarizes the univariate analysis for the individual samples from the study area. Due to the fact that in some cases there are usually overlap between different sedimentary environments for values of any single parameter, the results from the univariate parameters have been plotted (scatter plots) to produce bivariate charts [29]. Although these overlaps were not completely eliminated, they were greatly reduced and since all the plots of [29] for distinguishing river and beach sands have not shown any difference between each other, two of such plots are used in this work.

TABLE 2: RESULTS FOR STATISTICAL PARAMETERS

SAMPLE NO	MEAN (Mz)	SORTING ( $\sigma$ )	SKEWNESS (SKi)	KURTOSIS (K <sub>G</sub> )
C001	0.47	0.97	0.52	0.97
C002	-0.28	0.64	0.35	1.59
C003	0.88	1.06	-0.03	1.00
C004	1.15	1.35	0.03	1.24
C005	1.24	1.16	-0.12	1.05
C006	0.78	1.07	-0.12	0.74
C007	1.83	0.67	-0.15	0.30
C008	1.57	1.65	-0.04	0.86
C009	2.67	1.05	-0.26	1.64
C010	1.23	1.30	-0.12	0.53
C011	0.98	1.20	0.23	0.85
C012	1.80	1.54	-0.30	0.96
C013	0.77	1.37	0.42	0.70
C014	1.12	1.34	-0.07	0.91
C015	0.93	1.39	0.07	0.46

### 4.2 Bivariate Analysis

When two statistical parameters are combined to interpret the depositional environment, we describe the analysis as bivariate analysis. This has successfully being used by [4] and [6].

Notice that all the points fall on the river sands field of the plot

(Fig 5), this goes to confirm the Univariate analysis that the sediment are from a fluvial environment. From the field relationship, within the Basement Complex the only medium of transportation of the sediments weathered from the rocks is the river and surface run-offs predominantly, less of wind and dune mechanism maybe present

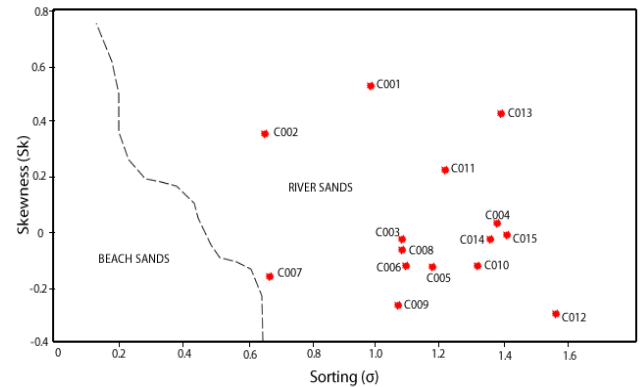


Fig 5: bivariate plot of Skewness (SKi) vs Sorting ( $\sigma$ ), after [29]

This plot of the mean sizes against the sorting shows the point all clustering in a particular area except samples 2 and 9 (Fig 6). This shows that the same mechanism of deposition was common to all the samples for them to plot in like fields. Every environment can be seen to have its characteristic energy conditions and fluctuation through space and time [30], the preservation of these fluctuations is subject to availability of sufficient amount of source materials (sediments) of all sizes; only then can the size distribution help accurately to indicate environment of deposition.

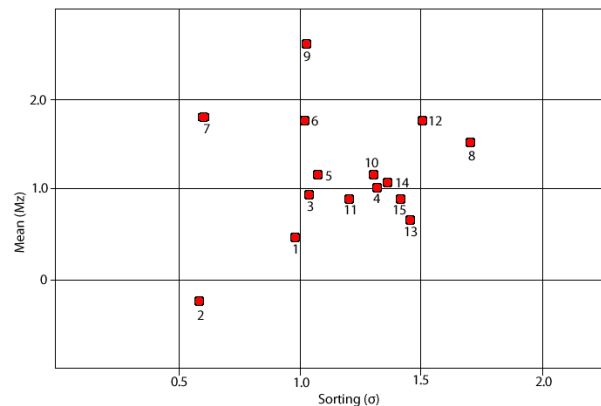


Fig 6: Bivariate plot of mean (Mz) vs. sorting ( $\sigma$ )

The result for heavy mineral analysis is presented in Table 3; the results show dominance in some ultrastable grains and opaque minerals, the grains (opaque and non-opaque minerals) were counted using the ribbon technique of [28]. Figure 7 shows the distribution of these minerals using pie charts.

TABLE 3: HEAVY MINERALS IDENTIFIED WITHIN THE STUDY AREA

Sample No	S002	S003	S004	S005	C006	S010
Zircon	26	98	29	25	33	44
Tourmaline	38	85	35	35	25	57
Rutile	20	32	21	13	22	41
Hornblende	11	27	7	7	5	26
Biotite	-	28	8	4	1	17
Garnet	13	42	9	9	7	-
Glauconite	-	16	3	-	-	-
Staurolite	3	9	7	1	-	13
Apatite	6	44	9	4	10	10
Kyanite	3	10	-	-	3	-
Others	5	34	34	12	10	8

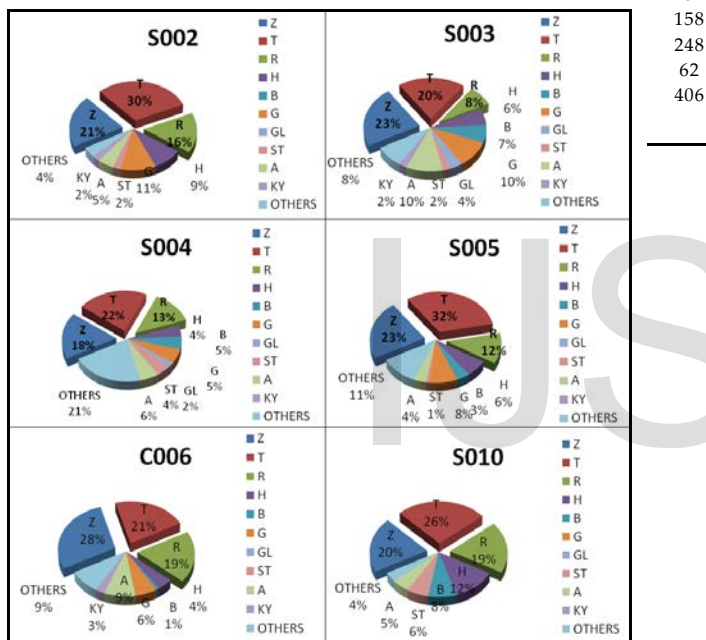


Fig 7: Pie charts illustrating the distribution of heavy minerals per slide. (Z=zircon; T=tourmaline; R=rutile; H=hornblende; B=biotite; G=garnet; GL=glauconite; S=staurolite; A=apatite; KY=kyanite)

### 4.3.1 Heavy mineral description

- Zircon:** Appears mostly as sub-rounded prismatic crystals, colourless to pale yellow, characterized by strong birefringence, positive elongation and parallel extinction. The dominantly show variation of three colours pleochroism.
- Tourmaline:** Mostly euhedral and well formed crystals commonly in a wide range of colours such as pink, brown, black and green varieties; it has strong birefringence, negative elongation and parallel extinction, the minerals is present every in good proportion.
- Rutile:** Appears as elongate to sub-rounded to sub-angular prismatic grains, occasionally greenish and yellowish, with extreme birefringence, positive elongation and parallel extinction.

- Hornblende:** occur generally as green to brownish-green elongate cleavage grains with strong birefringence, moderate pleochroism and positive elongation; inclined extinction about 5°.
- Biotite:** occurs as brown crystals exhibiting platy habit, with parallel extinction, straight cleavage and occasionally prismatic, terminating at one end in the shape of a prism.
- Garnet:** occurs as deep red to pink, colourless in some cases, with irregular form, the surface shows a pebbled, etched dodecahedron appearance. They are isotropic.
- Glauconite:** occurs as bluish violet grains, moderately birefringent and highly pleochroic, they tend to be elongate in the direction of the main crystallographic axis.
- Staurolite:** they occur as straw yellow irregular grains, crudely prismatic, lacks pleochroism, almost showing conchoidal fracture, and moderate birefringence.
- Apatite:** occur as dull white sub-rounded prism, lacks pleochroism.
- Kyanite:** appear as colourless fragments being sub-rounded to prismatic with cleavage traces at right angle, grains show moderate birefringence, positive elongation and inclined extinction (extinction angle =27 - 30°).

The photomicrograph of some of the slides is shown in figure 8, while some of the grains were zoomed out and represented in figure 9 below. The significance of heavy minerals to solving geologic problems associated with provenance and stratigraphic horizon discrepancies cannot be over-emphasized. A total of about 2289 heavy minerals were counted in the study area with a total of 1137 non-opaque minerals whose properties we studied. The dominant mineral in the area studied was zircon (22.4%) which was followed by Tourmaline (18%) and then Rutile (13.1%).

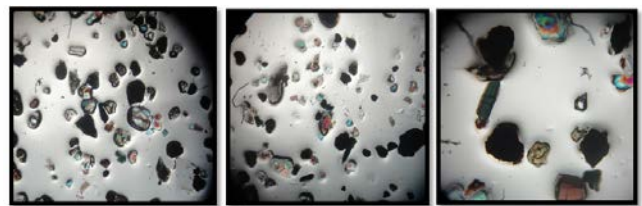


Fig 8: Photomicrograph of the heavy mineral slides (Mag x10) (a) grains of zircon (colourless), tourmaline (green and pink varieties), hornblende, kyanite, and opaque grains (black) (b) a collection of zircon, garnet, tourmaline, apatite and opaque grains; (c) the provenance diagnostic tourmaline and zircon grains are depicted here.

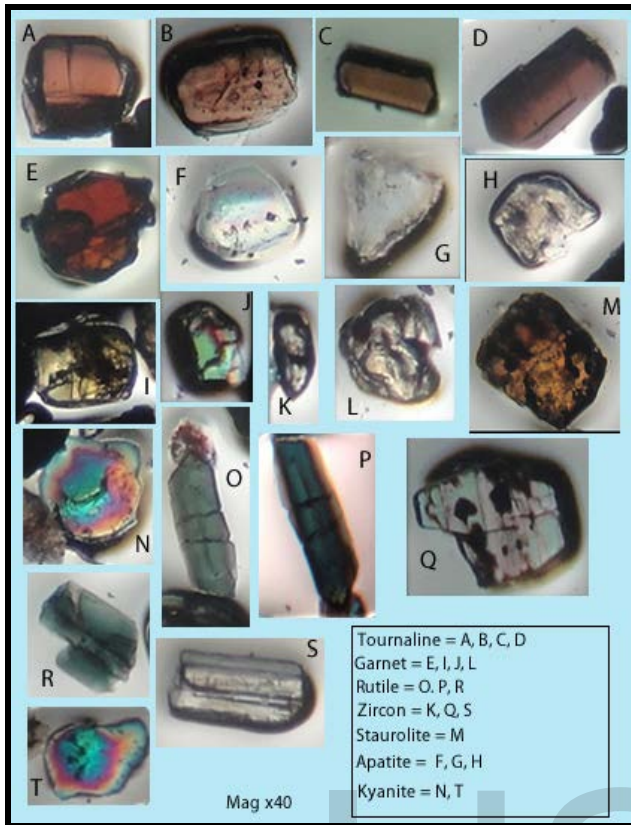


Fig 9: Individual heavy minerals selected under higher magnification

These three minerals incidentally are regarded as the ultrastable heavy minerals and hence because of this [17] successfully used them to determine the maturity of sandstones based on their indices. The ZTR index of the study area was calculated and seen to range from 52% to 70% among the samples analysed. The ZTR index was determined using the relationship given below:

$$\text{ZTR Index} = [(Z+T+R)/\text{Non-opaque}]$$

A ternary diagram (Figure 10) having zircon–tourmaline–rutile as apices was plotted and it had all the samples plotting in the same field indicating the same environmental conditions affecting them, and that there are from the similar source.

The maturity of sandstones can be determined with the combined studies of quartz crystals which was not analyzed in our study (i.e. the relative percentage of quartz with respect to other rock forming minerals is an indication of the maturity of sandstones), however, from the values obtained, it shows that the samples although they have not travelled far from their source, they are at the verge of attaining maturity. This was adjudged from the relative abundance of ultrastable minerals in the composition. Although this may not be conclusive in itself because of the effect of hydraulic sorting, whose effect can be checked when a variety of grain sizes are compared

with respect to the retention of the mineral assemblages or a depletion of same. Kyanite and glaucophane were the least represented in the counts, but their presence combined with the predominance of zircon (a mineral that occurs in both igneous and metamorphic terrain) and tourmaline, points to the rocks of the Basement Complex as the source of these clastics and judging from the well formed crystals and sub-angular crystals observed, it can be said that the grains have not travelled too far from their source (i.e. the provenance can be traced to the vicinity of the rocks of the basement complex). Feo-codecido (1955) presented a table (Table 4), that characterizes the heavy mineral suite one may likely find in certain environments

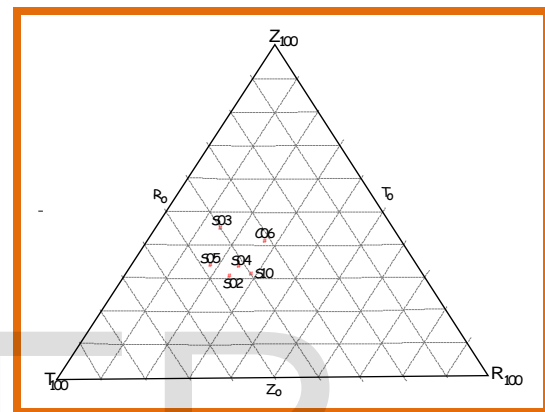


Fig 10: A ternary diagram of Zircon – Tourmaline – Rutile from the study area.

## 5 CONCLUSION

From the study it has been shown that the textural parameters

**TABLE 4**  
HEAVY MINERALS ASSOCIATIONS AND PROVENANCE

Associations	Source
Apatite, biotite, brookite, hornblende, monzonites, muscovite, rutile, titanite, tourmaline (pink variety), zircon	Acid Igneous Rocks
Cassiterite, dumortierite, fluorite, garnet, monazite, muscovite, topaz, tourmaline (blue variety), wolframite, xenotime	Granite pegmatites
Au-gite, chromite, diopside, hypersthene, ilmenite, magnetite, olivine, picotite, pleonaste	Basic igneous rocks
Andalusite, chondrodite, corundum, garnet, phlogopite, staurolite, topaz, vesuvianite, wollastonite, zoisite	Contact metamorphic rocks
Andalusite, chloritoid, epidote, garnet, glaucophane, kyanite, sillimanite, staurolite, titanite, zoisite, clinozoisite	Dynamothermal metamorphic rocks
Barite, iron ores, leucoxene, rutile, tourmaline (rounded fragments), zircon (rounded fragments)	Reworked sediments

After [16].



and mineralogical characteristics of surficial sands/sediments reflects the characteristics regarding the provenance and environment of deposition of the sediments. Textural parameters reveal that the sediments from the area under investigation is best described as being very fine to medium grained, poorly sorted, near symmetrical mesokurtic sands. This description is common to river sands whose energy is typical of the fluvial depositional environment. However, one of the critical drawbacks from textural studies of sediments is that of their source materials [31]. The size characteristic reflect the depositional process as well as the characteristic of the source materials, such that, in cases where the source constitute a beach deposit that accumulated several million years ago, the same will be misinterpreted even if it is now deposited by fluvial process. The availability of sedimentary structures can to a large extent enable proper environmental diagnosis. The source of the sediments is largely from mixed acid igneous rocks, granite pegmatite and metamorphic related rocks of the basement complex of southwestern Nigeria. The heavy mineral grains still retain their shapes and are well formed indicating that they have not travelled so far from their source while the results from the size analysis show that the depositing mechanism and the environment is fluvial.

## ACKNOWLEDGMENT

The authors wish to thank the postgraduate field school coordinators of the University of Ibadan for providing the platform upon which this study was conducted.

## REFERENCES

- [1] R.L. Folk, and W.L. Ward, "Brazus River Bar: A Study of the Significance of Grain Size Parameters". *Journal of Sedimentary Petrology* 27, pp 3-27, 1957.
- [2] R. Passega, "Texture as a characteristic of clastic deposition". *American Association Petroleum Geologists Bulletin*. 41, pp 1952 – 1984, 1957.
- [3] C.C. Mason and R.L. Folk, "Differentiation of Beach, Dune and Aeolian flat environments by size analysis". *Journal of Sedimentary Petrology* 28, pp 211 – 226, 1958.
- [4] G.M. Friedman, "Distribution Between Dune, Beach and River Sands from their Textural Characteristics". *Journal of Sedimentary Petrology* 31, pp 514-529, 1961.
- [5] D.W. Spencer, "The interpretation of grain size distribution curves of clastic sediments". *Journal of Sedimentary Petrology* 33, pp 180 – 190, 1963.
- [6] G.S. Visher, "Grain size distribution and depositional processes". *Journal of Sedimentary Petrology* 34, pp 1074 – 1106, 1969.
- [7] R.J. Miola, and D. Weiser. "Textural parameters: An evaluation". *Journal of Sedimentary Petrology* 38. pp 45 – 53, 1968.
- [8] A.K. Awasthi, "Skewness as an environmental indicator in the Solani River system, Roorkee (India)". *Sedimentary Geology* 4, pp. 177 – 183, 1970.
- [9] J. Thoulet, "Study of heavy minerals of Sahara". *Bull. Soc. Miner. France*. Vol 4; pp 262-268, 1881
- [10] W. Mackie, "The sands and sandstones of eastern Moray". *Trans. Geol. Soc. Edinb.* Vol 7; pp 148 – 172, 1896.
- [11] V.C. Illing, "The oilfields of Trinidad". *Proc. Geol. Ass.* Vol 27; pp115, 1916.
- [12] P.G.H. Boswell, "On the mineralogy of sedimentary rocks". London. Thomas Morby, 1933.
- [13] D.J. Doeglas, "Interpretation of results of mechanical analysis". *Journal of Sedimentary Petrology* 16, pp 19 – 40, 1946.
- [14] M.A. Mange and W.H. Maurer, "Heavy mineral in colour". Chapman and Hall, London, UK, 145p, 1992.
- [15] C. O. Hutton, "Studies of heavy detrital minerals". *Bulletin of the Geological Society of America*. Vol 61; pp 635 – 710, 1950.
- [16] G. Feo-codecido, "Heavy Mineral Techniques and their Application to Venezuelan Stratigraphy". *American Association Petroleum Geologists Bulletin* 40(5), pp 984 – 1000, 1955.
- [17] J.F. Hubbert, "A Zircon-Tourmaline-Rutile maturity index and the interdependence of the composition of heavy mineral assemblages with the gross composition and texture of sandstones". *Journal of Sedimentary Petrology* 32, pp 440 – 450, 1962.
- [18] P. Gazzi and G.G. Zuffa, *Le arenarie paleogene dell' Apennino emiliano*. *Miner. Petrogr. Acta*. Vol 16; 97 – 137, 1970.
- [19] R.A.A. Thomas, "An integrated grain size and heavy mineral analysis of the Paleocene strata of the London basin". *Developments in Sedimentology* 58, pp 307 – 322, 2007.
- [20] S.W. Petters, P.M.P. Zaborski, N.U. Essien, D. Nwokocha and D.O. Inyang. "Geological Excursion guidebook to the Cretaceous of the Calabar Flank, SE Nigeria". NMGS 46<sup>th</sup> Annual Conference, Calabar 2010. pp 28, 2010.
- [21] D.C. Turner, "Upper Proterozoic Schist belts in the Nigerian sector of the Pan – African province of West Africa". *Precambrian Research* Vol. 21; pp 55 – 79, 1983.
- [22] H.A. Jones and R.D. Hockey, "The geology of part of Southwestern Nigeria". *Nigeria Geological Survey Bulletin* No.31. 87p, 1964.
- [23] I.B. Odeyemi, "Preliminary report on the field Relationships of Basement Complex Rocks and Igara, mid western Nigeria". In: Kogbe, C. A. (Ed) *Geology of Nigeria*. Elizabethan Publishing Company Lagos, pp 58-63, 1976.
- [24] M.A. Rahaman, "A review of the Basement Geology of Southwestern Nigeria". In: Kogbe, C. A. (Ed) *Geology of Nigeria*. Elizabethan Publishing Company Lagos. pp 41 – 56, 1976.
- [25] M.A. Rahaman, "Recent Advances in the study of the Basement Complex of Nigeria". In: *Precambrian Geology of Nigeria*. Oluyide, P. O., W. C. Mbonu, A. E. Ogezi, I. G. Egbuniwe, A. C. Ajibade and A. C. Umeji (Eds). Geological Survey of Nigeria, Kaduna, Nigeria, pp: 11 – 43, 1988.
- [26] E.E. Okon, "Geology of Iwere-Ile and its environs". Field School Report submitted to the Department of Geology, University of Ibadan. Unpublished Report. 68p, 2010
- [27] R.M. Bateman and A.J. Catt "Provenance and paleoenvironmental interpretation of surficial deposits with special reference to post-depositional modification of the heavy mineral assemblages". *Developments in Sedimentology* 58; pp 151 – 188, 2007.
- [28] J.S. Galehouse "Point counting": In Carver, R. E. (Ed.), *Procedures in Sedimentology*, Wiley, New York, pp 385 – 407, 1971.
- [29] G.M. Friedman, "Dynamic Processes and Statistical Parameters Compared For Size Frequency Distribution of Beach and River Sands". *Journal of Sedimentary Petrology* 37, pp 327-354. 1967.
- [30] B.K. Sahu. "Depositional Mechanism from the Size Analysis of Clastic Sediments". In: Kogbe, C. A. (Ed) *Geology of Nigeria*. Elizabethan Publishing Company Lagos, 34(1) pp 73 – 83; 1964.
- [31] R.J. Cheel, "Introduction to Clastic Sedimentology". Prentice Hall Inc., 134p, 2005.