Application of ZTR Index in the Assessment of Maturity of Stream Sediments in Akinmorin Area, Southwestern Nigeria

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Abstract- Ten sediment samples were collected from streams in Akinmorin, southwestern Nigeria, and analyzed in order to determine the types and abundance of heavy minerals present, assess their maturity and infer their provenance. Furthermore, a total of three representative rock samples were collected from the area for essential mineral analysis. Heavy minerals separation was carried out usingbromoform, while thin sections of the rocksamples were prepared andexamined under the petrographic microscope. Heavy minerals identified are Zircon, Tourmaline, Rutile, Sillimanite, Garnet, and Staurolite.The abundance of zircon in the sediments range from 296 to 9, Tourmaline range from115 to 5, Rutile range from 26 to 4, Garnet range from187 to 31, while Staurolite range from 53 to 0. The ZTR Index for the sediments range from 20.83 to 70.18.Modal analysis revealed minerals composition in banded gneiss as quartz (47.1%), plagioclase feldspar (29.4%), and biotite (23.5%); granite gneiss as quartz (27.4%), plagioclase feldspar (29.9%),biotite (25.6%), and hornblende (17.1%) while in biotite-garnet-gneiss; quartz (20.9%), plagioclase feldspar (25.1%), orthoclase feldspar (0.84%%),biotite (52.2%), and garnet (1.04%).The presence of Zircon, Tourmaline, Rutile, Sillimanite, Garnet and Stauroliteindicate mixed sources of acid igneous and medium to high grade metamorphic rocks for the stream sediments, while the range of ZTR index is an indication of a mineralogicallyimmature to sub-mature sediments, a short transport history and provenance. These results show that the stream sediments of Akinmorin area originated from the surrounding basement rocks.

Indexed Terms- Granitoids, Heavy minerals, Mineralogical maturity, Provenance, Stream sediments, ZTR Index.

I. INTRODUCTION

In host rocks, minerals are present either as rock forming minerals such as quartz, feldspar, amphibole, pyroxene and mica or as accessory minerals such as zircon, apatite and tourmaline. [1] Heavy minerals like tourmaline, staurolite, zeolite,zircon, rutile, garnet, and ilmeniteare commonminor components in most crystalline rocks and occur as secondary minerals in the environment of deposition such as stream sediments.Stream sediments are derived from igneous, sedimentary and metamorphic rocks, which serve as host to these heavy minerals that have been subsequently weathered, transported and deposited along stream channels within a regime of low flow velocity.

The concentration of heavy minerals in sand sized terrigenous sediments may fluctuate considerably due to some factors that may include provenance, sedimentary processes and post-depositional dissolution [2]. Sediments in streams are capable of preserving the physical, chemical and biological composition of the mineral constituents and hence, stream sediments are good indicators for assessing and evaluating qualities of total environment by their capability to reflect long term quality situation that are often independent of the current inputs [3] -[5]. Conventional heavy minerals such as ilmenite, magnetite, zircon, tourmaline, garnet and rutilecould be applied in provenance studies and is often used in the field of sedimentology [6].

Heterogeneous contribution to surface drainage load are mostly caused by population growth, urbanization, agricultural activities and development of new industrial zones[7] and uncontrolled direct dumping of domestic waste and discharge of domestic and industrial sewage water into the urban drainage systems are critical components of trace/heavy mineral contamination in underground water [8].

The studies of rocks and heavy mineral assemblage in the stream sediments within Akinmorin area were carried out in this research work with the objective of assessing sediment maturity and inferring provenance.

II. GEOLOGY OF AKINMORIN AND ENVIRONS

Akinmorin is entirely underlain by crystalline basement rocks and located within latitude 003^0 56'-004^0 00' and longitude 7^0 45'- 7^0 48' (Figure 1).

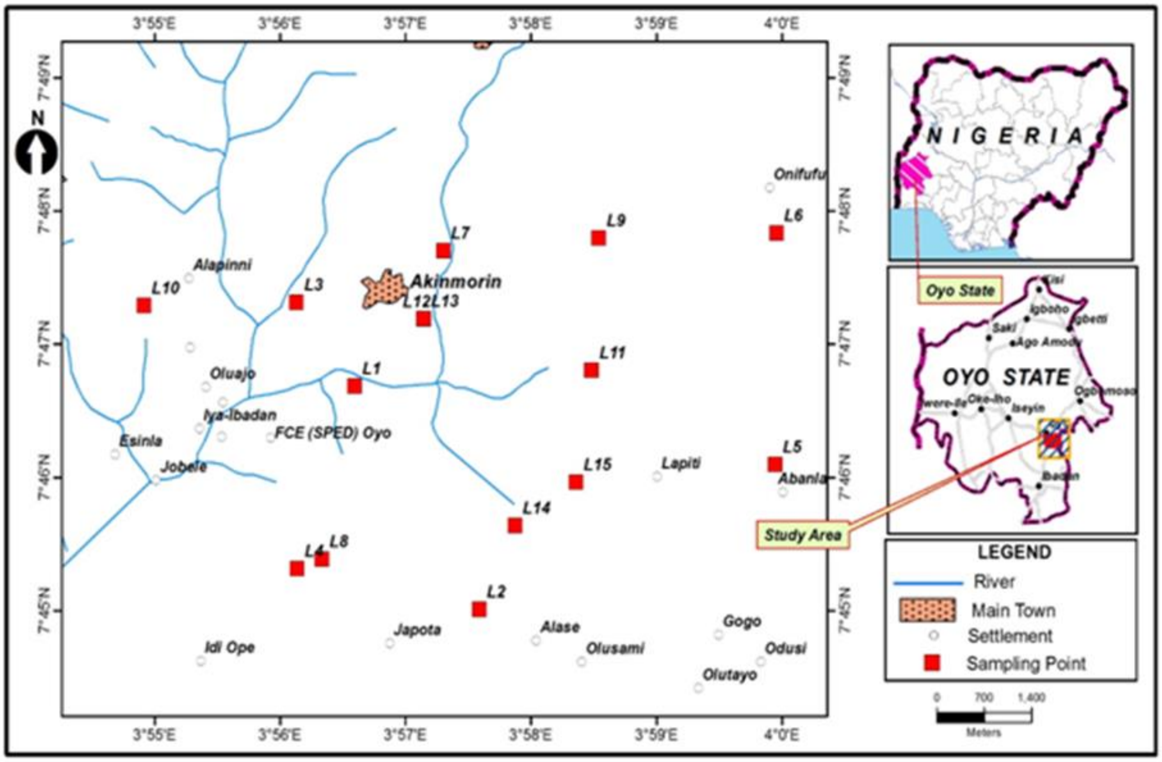

Figure 1: Drainage and sample location map of Akinmorin area

Akinmorin is located within the southwestern Precambrian Basement Complex terrain. The crystalline rocks of the Precambrian Basement Complex is a major litho-petrological components of the geology of Nigeria. The major group of the rocks of the basement complex wereclassified in order of their increasing age intoMigmatite-Gneiss complex, Schist belts comprising the Metasedimentary and Metavolcanic rocks, the Pan African Granitoids also known as the Older Granites, the Charnockitic, Gabbroic and Dioritic rocks and the Unmetamorphosed Dolerite rocks [9]. The Migmatite-Gneiss complex is the most widespread in the basement complex of the southwestern Nigeria[10] and the migmatite –gneiss complex is further subdivided into three components namely the Older Metasediments or Early Gneiss, Banded and grey gneisses or Mafic-Ultramafic Bands, Granite gneisses and Migmatite or the Granitic components [11].

The schists are metasedimentary and metavolcanic rocks that are largely sediment dominated and most the important lithologies in this group are pelites, semi-pelites and quartzite. The schist belts are known to be mineralized in gold, BIF, marble, manganese and hence the most studied rocks in the basement complex terrain [12].

The older granites are rocks of a wide range of composition like the tonalities, granites, granodiorites, syenites and pegmatites. Basically, the geology of the study area comprises the migmatite gneiss, quartzite, marble and schists (Figure 2).

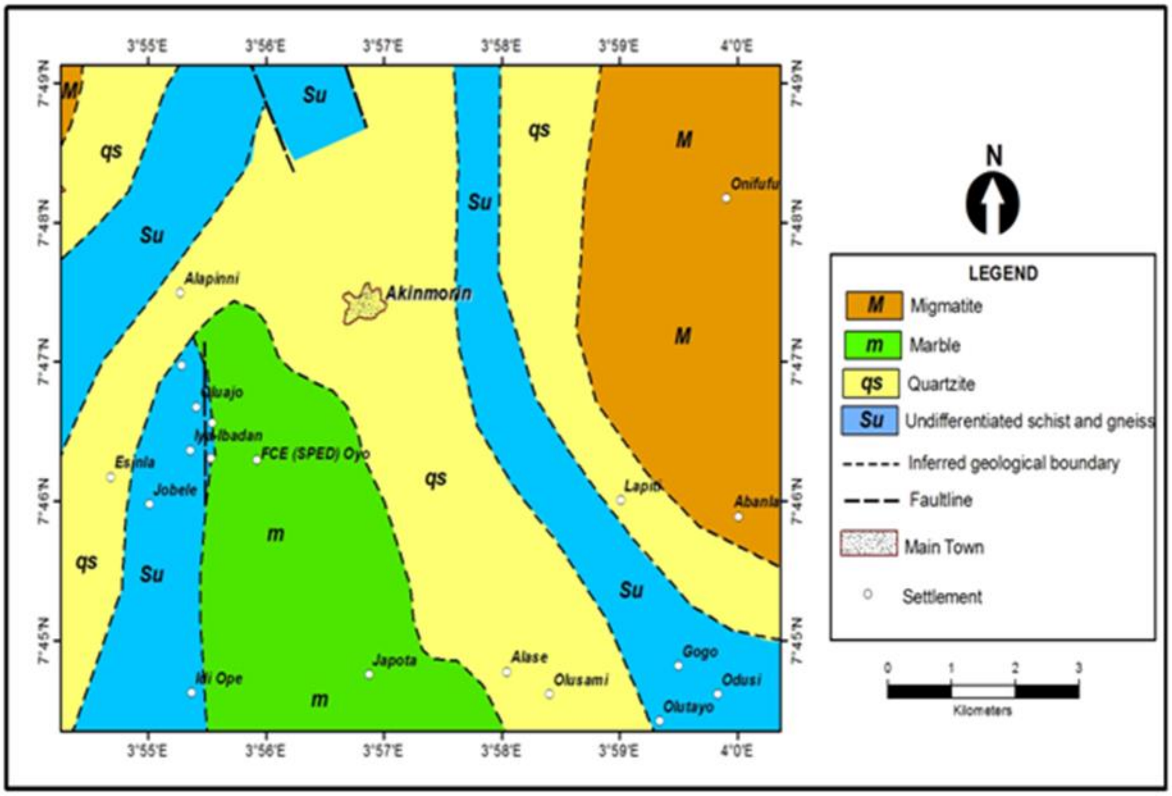

Figure 2: Geologic map of Akinmorin area

III. MATERIALS AND METHODS

- Field Work and Sample Collection

The field work involvedthe geological mapping of Akinmorin area, and the collection of rock samples and stream sediment samples along strategic points on the second and third order streams. The exercise was facilitated by the use of 1:50,000 scale topographic map, compass-clinometers and other needed field implements. The sample locations were identified with the Global Positioning System (GPS) and recorded in a field notebook.Representative stream sediment samples were collectedfrom ten locations, while three rock samples were taken to represent the lithological types present in the area (Table 1).

Table 1: Sample Locations

Sample No	GPS READING		Sample Media
	Latitude	Longitude	
1	N 07˚45' 51.9''	03˚56' 47.8''E	Granite Gneiss
2	N07˚46' 41.1''	003˚56' 35.7''E	Stream Sediment
3	N07˚46' 01.3''	03˚56' 05.0''E	Garnet schist
4	N07˚ 45'.56''	003˚57' 35.2''E	Stream Sediment
5	N07˚ 46'.56''	03˚56' 57.0''E	Banded Gneiss
6	N 07˚47'18.8''	003˚56' 07.8''E	Stream Sediment
7	N07˚45'18.9''	003˚56' 08.1''E	Stream Sediment
9	N07^0 46'05.8''	003^{0}59' 56.7''E	Stream Sediment
10	N07^{0}47'49.9''	003^{0}59' 57.4''E	Stream Sediment
11	N07^{0}47'42.0''	003^{0}57' 18.1''E	Stream Sediment
12	N07^{0}45'23.1''	003^{0}56' 20.0''E	Stream Sediment
13	N07^{0}47'47.8''	003^{0}58' 32.4''E	Stream Sediment

14	N07^{0}47'17.4''	003^{0}58' 54.9''E	Stream Sediment

heavy minerals were funneled out through the opening of the tap and collected on Whatman 250mm filter paper and thereafter allowed to dry,then mounted on slides and covered with Canada balsam. The slides are labeled according to sizes and heavy minerals studied using petrographic microscope.

- ZTR Index

Heavy mineral suites can be used as an index of sediment maturity using the ZTR (Zicron, Tourmaline, and Rutile) index. The ZTR index is calculated in mineral suites using the ZTR variable using the relationship:

ZTR Index = [(Z + T + R)/ Total non-opaque] * 100
Z = Zircon, T = Tourmaline, R = Rutile

The mineralogical maturity of the heavy mineral assemblages in sediments are quantitatively assessed by the ZTR Index after [13]. ZTR index less than 75 indicates a mineralogically immature to sub-mature sediments, while ZTR index greater than 75 indicate a mineralogically matured sediment. The percentage of three minerals i.e. zircon, tourmaline and rutile are calculated to 100%. The ZTR index can be used as a scale for estimating the degree of modification or maturity of the entire heavy mineral assemblage in the sediment [14].

- Thin Sectioning and Petrographic Studies

The rock samples were cut into smaller size of about 2mm using rock-cutting machine and one surface of the cut slice was polished using 400 grade carborudum.on glass plate. The polished slice was mounted on glass slide using araldite. Precautions were taken to ensure that any air bubble trapped between the glass slide and the sample were pushed out. The mounted sample on the slide is put under mounting jig for about 20minutes to allow effective glue of the sample on the slide. The size of the sample is then reduced to about 90microns on micro cutter machine. This sample is then lapped on glass plate using 90, 400, 600 and 800 grades of carborondum. After every successive grade during lapping, the sample must be observed under microscope to ensure that the desired sample thickness is obtained. The cover plate is carefully placed on Canada balsam that was earlier spread on the section and placed on hot plate for about 15minutes. Excess Canada balsam is cleaned using mentholated spirit and thereafter washed with detergent and allow to cool.

IV. RESULTS AND DISCUSSION

- Petrography
- Granite Gneiss

  Granite Gneiss is a high grade metamorphic rock derived from pre-existing igneous or sedimentary rock and is usually medium to coarse grained. Granite gneiss was encountered in two locations within the study area. Microscopic examination and modal analysis reveals the mineral composition as quartz (27.4%), plagioclase feldspar (29.9%), biotite (25.6%), and hornblende (17.1%) (Figure 3, Table 2).

- Biotite Garnet Schist

  Garnet under the microscope characteristically show a distinctive range of colors from pale pinkish or reddish almandine, spessarite, pyrope or andradite to yellowish or brownish almandine, spessarite, pyrope or andradite. The diagnostic mineral in garnet is the titanium-rich dark brown or black color schorlomite. The biotite-garnetiferrous schist from the study area displays a poikiloblastic structure with modal analysis of the mineral constituents as Quartz (20.9%), Plagioclase Feldspar (25.1%), Orthoclase Feldspar (0.84%), Biotite (52.2%), and Garnet (1.04%).(Figure 4, Table 2).

- Banded Gneiss

  Banding is characteristic of gneissic rocks that is developed under high temperature and pressure conditions. Banded gneiss is derived from the layering arrangement of dark and light mineral constituents. The darker bands have relatively more mafic or ferromagnesian minerals while the lighter bands have more felsicminerals consisting of lighter elements like silicon, oxygen, aluminum, sodium, and potassium. Banding is the result of the subjection of the protolith to extreme shearing force, stretching out the original rocks into sheets. Banding could also be the result of metamorphic differentiation, which separates different materials into different layers through chemical reactions. The photomicrograph of Banded Gneiss (Figure 5, Table 2)from the study area shows the modal mineral constituents as Plagioclase feldspar (29.4%), Quartz (47.1%) and Biotite (23.5%) under petrographic microscope (×40).

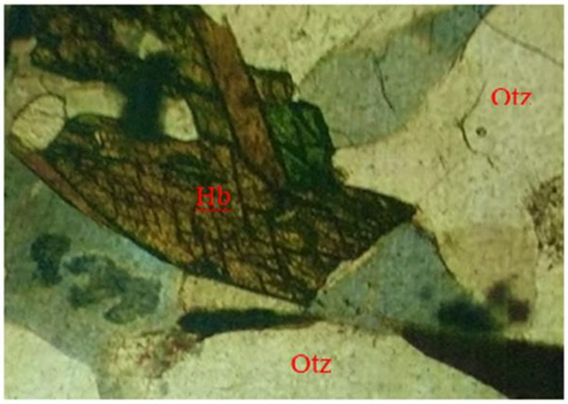

Figure 3: Photomicrograph of Granite Gneiss Showing Quartz (Qtz), and Hornblende (Hb).

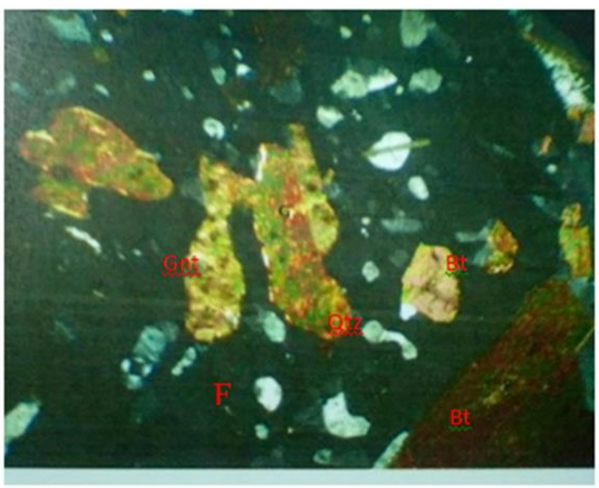

Figure 4: Photomicrograph of biotite garnet schist showing garnet (Gnt), quartz (Qtz), biotite (Bt) and feldspar (F)

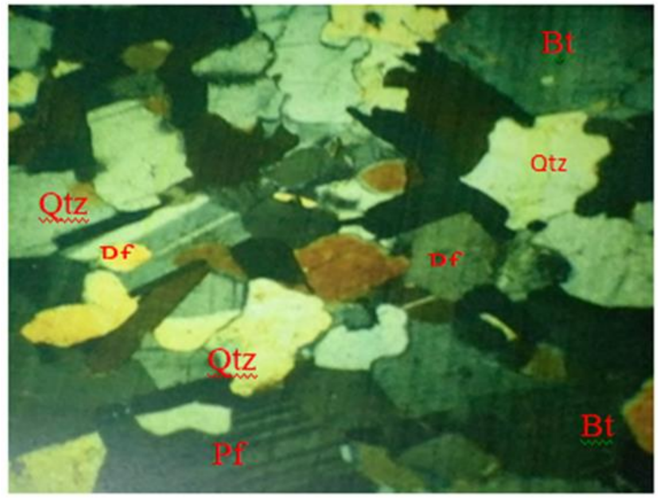

Figure 5: Photomicrograph of banded gneiss under crossed nicols showing Plagioclase Feldspar (Pf), Quartz (Qtz) and Biotite (Bt) (×40)

Table 2: Modal Analysis of Representative Rock Samples

Rock Types/Minerals	Banded Gneiss	Granite Gneiss	Biotite Garnet Schist
Biotite	23.5	25.6	52.2
Quartz	47.1	27.4	20.9
Hornblende		17.1	
Plagioclase Feldspar	28.2	29.0	24.1
Orthoclase Feldspar			0.84
Garnet			1.04
Total	98.8	99.1	99.08

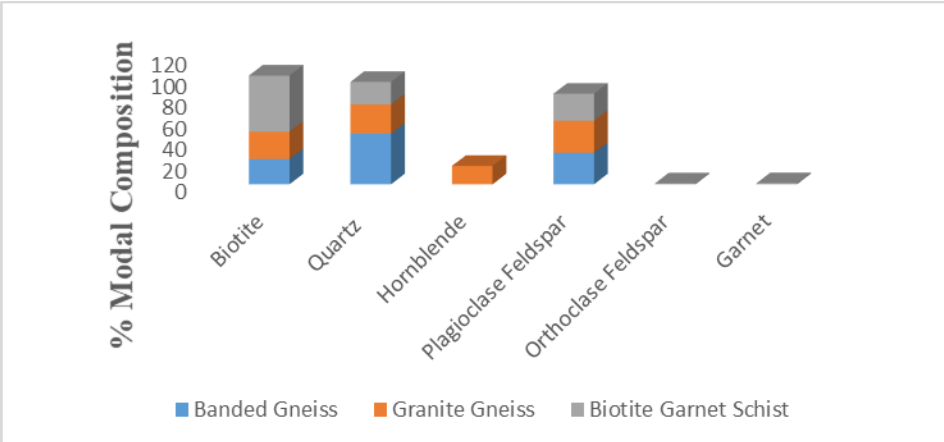

Figure 6: Modal composition (%) of Minerals of Representative Rock Samples

- Heavy Minerals Analyses
- Tourmaline

Tourmaline is one of the most dominant mineral of the non-opaque heavy minerals identified in the sediments. Tourmaline show characteristic prismatic, elongated and sub-roundedgrains. The grains are strongly pleochroic. The mineral is light brown, yellowish brown and greenish in color (Figure 7). A resistant heavy mineral with specific gravity of 3-3.25 showing striations. Tourmaline is next in abundance (Figure 8) to zircon. It is a common detrital heavy mineral in sedimentary rocks.

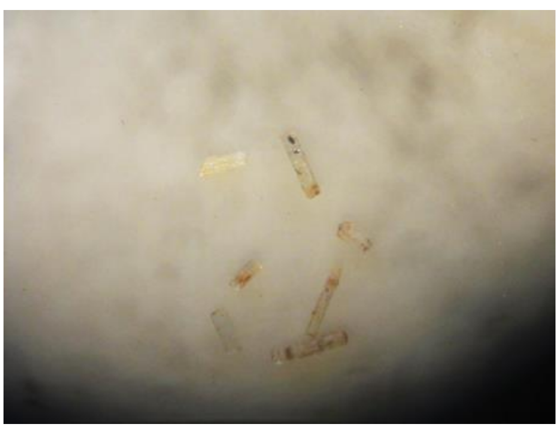

Figure 7: Tourmaline mineral in the stream sediments of Akinmorin area under crossed nicol (x40)

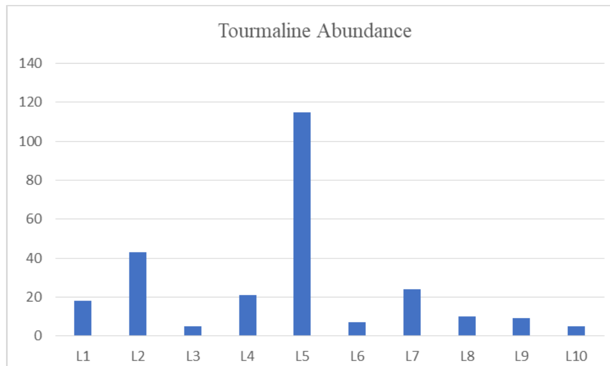

Figure 8: Relative Abundance of Tourmaline in the stream sediments of Akinmorin area

- Zircon

Zircon, the most abundant (70.66%) non-opaque minerals in the sediments, occur as prismatic euhedral to subhedral grains with well-developed crystalline faces depicting evidence of mechanical abrasion during transport. Zircon is one of the most stable heavy mineral that survives after a lot of reworking and lacks good cleavage. They are colorless having high relief and contains inclusions of other minerals with a specific gravity of 4.7 (Figure 9, 10).

Figure 9: Zircon mineral in the stream sediments of Akinmorin area under crossed nicol (x40)

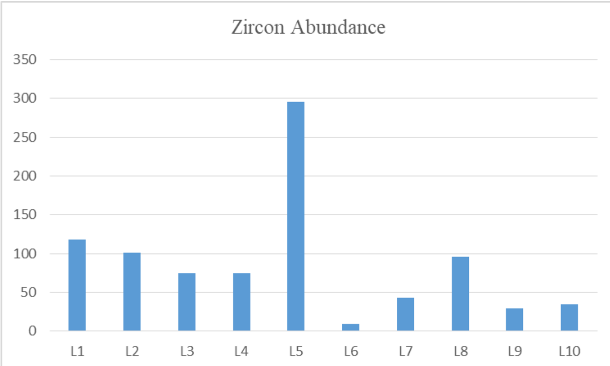

Figure 10: Relative Abundance of Zircon in the stream sediments of Akinmorin area

- Rutile

The colour of rutile in the stream sediments is reddish brown with high relief. It has a specific gravity of 4.2-5.6 (Figure 11). It common occur as accessory mineral in high temperature and high pressure metamorphic and igneous rocks. Rutile is a non-silicate mineral that occurs also as accessory constituents of granites, diorites, the gneisses and amphibolite [15]. *Rutile* is composed primarily of titanium dioxide (TiO_2), and the most common natural form of TiO_2. Rutile has economic value in the manufacturing of titanium oxide pigments, refractory ceramics, and production of titanium metal. Rutile is commonly among the most stable detrital minerals in sedimentary systems and is fairly abundant (8.62%) in the stream sediments of Akinmorin area (Figure 12).

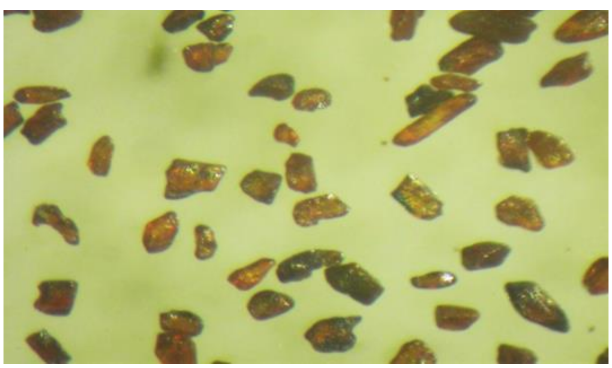

Figure 11: Rutile in the stream sediments of Akinmorin area under crossed nicol (x40)

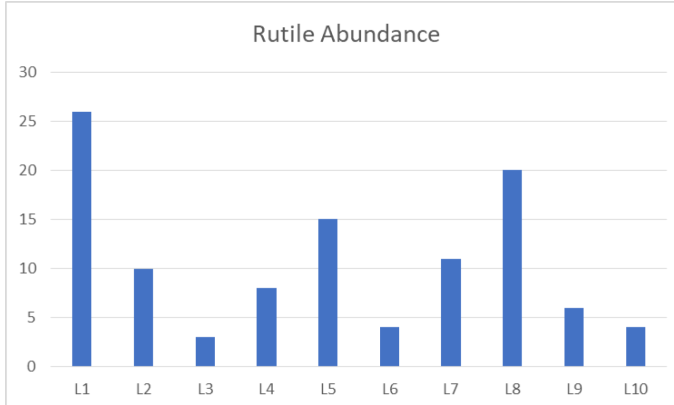

Figure 12: Relative Abundance of Rutile in stream sediments of Akinmorin area

- Garnet

This is a colorless or pale pinkish heavy mineral with slightly sharp edges, with specific gravity of 3.6- 4.2. It occurred as sub angular crystal (Figure 13) in the sampled sediments. Garnet is relatively abundant in the sampled sediments.

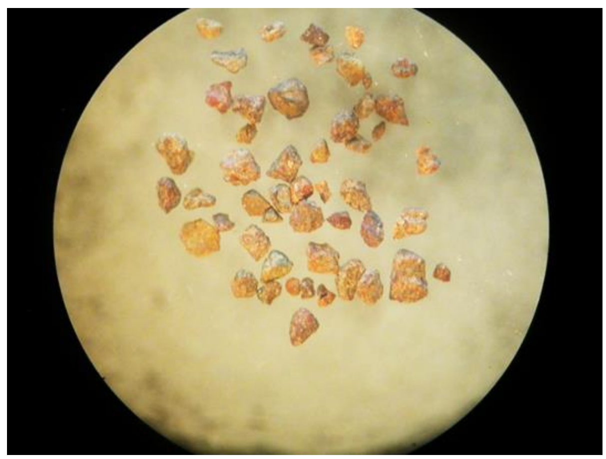

Figure 13: Garnet in the stream sediments of Akinmorin area under crossed nicol (x40)

- Staurolite

This is pale or brownish yellow which is weakly pleochroic and has a specific gravity of 3.74-3.85. Staurolite often has many quartz inclusions and its crystals are usually prismatic and elongated. The relief is high and has a straight extinction (Figure 14). It occurs with almandine garnet, micas, kyanite; as well as albite, biotite, and sillimanite in gneiss and schist of regional metamorphic rocks

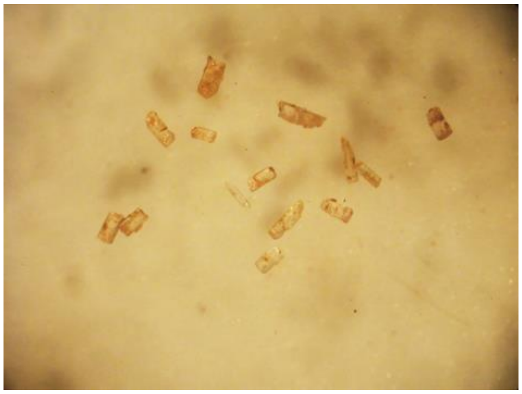

Figure 14: Staurolite in the stream sediments of Akinmorin area under crossed nicol (x40)

- Illmenite

Illmenite is a titanium-iron oxide mineral with formula $FeTiO_3$. Its specific gravity range from 4.70 to 4.79 with metallic luster (Figure 15).

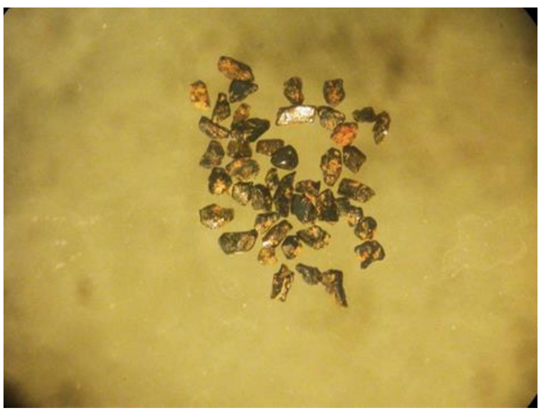

Figure 15: Illmenite in the stream sediments of Akinmorin area under crossed nicol (x40)

- ZTR Index

Heavy mineral suites may be used as an index of maturity using the ZTR index. The letters in ZTR stand for three common minerals found in highly-weathered sediments: zircon, tourmaline, and rutile. The ZTR index minerals are commonly present and abundant in beach, stream and river sediments because of their high specific gravity and resistance to chemical and physical weathering. The ZTR index can also be used as a scale for the estimation of the degree of modification or maturity of the entire heavy mineral assemblage [14].

The relative abundances of Zircon, Tourmaline and Rutile in the stream sediments of Akinmorin area is shown in Figure 16. Zircon is a common heavy mineral, derived from granitic, volcanic, and metamorphic recycled sources. Rutile is an ultrastable, widespread accessory metamorphic mineral mostly found in high grade metamorphic rocks, particularly in schist, and gneisses [14]. Tourmalines are widespread in all types of detrital sediments and are ultrastable both mechanically and chemically. Tourmaline has proven particularly useful as a provenance mineral due to its presence in many rock types, chemical responsiveness to environment of formation, complex and variable chemical and mechanical weathering, and stability through digenesis and metamorphism. Tourmalines hardness and chemical stability make it extremely durable in sedimentary cycle. The relatively higher concentrations of tourmaline, rutile and zircon in the heavy mineral assemblage of Akinmorin stream sediments indicate a mixed source of both igneous and metamorphic origins [14].

The opaque mineral species exceeded the non-opaque minerals (Table 3, Figure 17) in the sediments. The relatively higher abundance of heavy opaque minerals suggests an oxic (oxygen-rich) environments of deposition [16]. The heavy mineral garnets indicate a high grade metamorphic source while tourmaline, rutile and zircon indicate both igneous and metamorphic origins [17]. Furthermore, Staurolite, Rutile and Garnet are more abundant in the sediments relative to Epidote and Sillimanite, which is indicative of dynamo thermal metamorphic rock source [14].

The ZTR index (Figure 18) ranges from 20.0 to 70.18 indicating a mineralogically immature to sub-mature sediments [13].

Table 3: Heavy Mineral Abundance in the Stream Sediments of Akinmorin area

Sample No	Zircon	Tourmaline	Rutile	Epidote	Garnet	Staurolite	Ilmenite	Opaque	ZTR	Non Opaque	ZTR Index (%)
L1	118	18	26	0	32	-	129	253	162	323	50.15
L2	101	43	10	5	78	7	32	493	154	276	55.79
L3	75	5	3	2	64	-	-	284	83	149	55.70
L4	75	21	8	3	68	-	3	347	104	178	58.42
L5	296	115	15	14	100	53	14	441	426	607	70.18
L6	9	7	4	-	55	-	2	140	20	96	20.83
L7	43	24	11		46	13	26	392	78	163	47.85
L8	96	10	20	16	187	12		309	126	341	36.95
L9	29	9	6	4	31	-	7	80	44	86	51.16
L10	35	5	4	2	39	-	1	121	44	85	51.76
Total	877	357	107	46	700	85	214	2860	1241	2304	

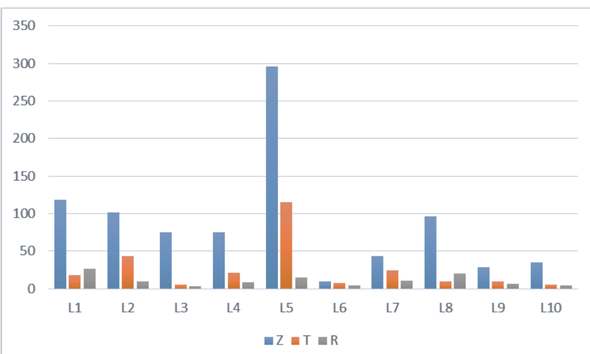

Figure 16: Concentration of Zircon, Tourmaline and Rutile in the stream sediments of Akinmorin area

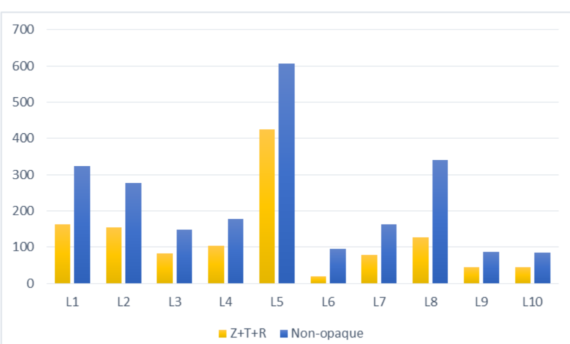

Figure 17: Proportion of Non-opaque Minerals to ZTR in the stream sediments

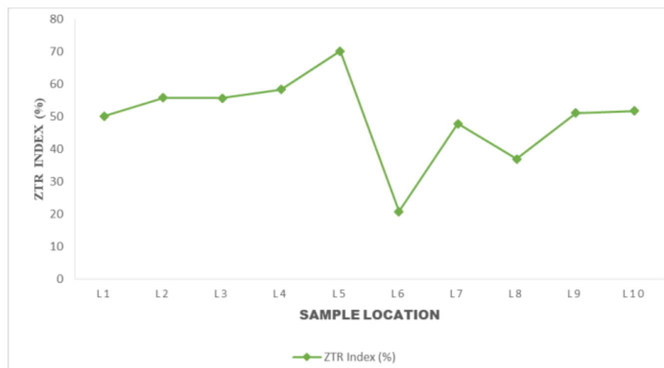

Figure 18: ZTR Index for the stream sediments of Akinmorin area

CONCLUSION

Petrographic and stream sediments studies of heavy mineral assemblage in Akinmorin area were carried out. Modal analysis reveals the mineral composition of the granite gneiss as quartz (27.4%), plagioclase feldspar (29.9%), biotite (25.6%), and hornblende (17.1%); the mineral composition of the biotite-garnetiferrous schist is Quartz (20.9%), Plagioclase Feldspar (25.1%), Orthoclase Feldspar (0.84%), Biotite (52.2%), and Garnet (1.04%); while banded gneiss is composed of Plagioclase feldspar (29.4%), Quartz (47.1%) and Biotite (23.5%).

Analysis of the heavy mineral assemblages in the stream sediments indicate the presence of opaque and non-opaque heavy mineral. The non-opaque heavy minerals include Zircon, Tourmaline, Rutile, Garnet, and Staurolite.The order of abundance of the non-opaque heavy is Zircon>Garnet>Tourmaline>Rutile>Staurolite. TheZTR index for the stream sediments range from 20.0 to 73.08 showing that the streams sediments are mineralogicallyimmature to sub-mature indicating a short transportation history and provenance. From the heavy mineral analysis the presence of minerals such as zircon, tourmaline and rutile, which are mainly igneous and metamorphic minerals coupled with dominant element of Stauroliteshowed that the sediments were derived basically from a mixture of acid igneous and medium to high grade metamorphic rocks.Consequently, most of the stream sediments in Akinmorin area were derived from the rocks of the basement complex surrounding the area.

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