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PETROGRAPHIC AND PROVENANCE STUDIES OF HEAVY MINERALS IN SANDSTONES FROM IFELODUN, NIGERIA

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ABSTRACT

Petrographic and provenance studies of heavy minerals in Ifelodun sediment were carried out. Sediment samples from eight locations were obtained from the study area; sieved to allow only sand-size lithology. The result was achieved after subjecting this sieved lithology obtained to analyses using a binocular (transmitted and reflected light) microscope. Minerals were separated in a funnel using bromoform with a specific gravity of about 2.89 (gravity method). The heavy minerals present in lithologic sand units are mainly staurolite, tourmaline, zircon and other opaque minerals including cassiterite. The most dominant non-opaque mineral is staurolite with 27.5% of the total minerals counted in the area. Staurolite is very appreciable in locations AR1 with 60% presence (which is 80% of the non-opaque minerals), AR3, AR5, AR7 and OL15b (each with 30%). OL15b also recorded a better amount of tourmaline (20%); Zircon is better in OL6b with 20% of the heavy minerals available in this location. The source rock predicted is porphyroblastic schists.

Keywords: *Petrographic, Provenance, Source Rock, Minerals, Porphyroblast, Sediments*

INTRODUCTION

Mineral study provides provenance information for paleotectonic reconstruction if tied with petrographic remarks under the microscope (Dewey, 2005; Garzanti, 2019) and is extensively conducted by researchers due to their economic importance. Heavy mineral study is predominantly useful as product of sediment sources and sediment transport path. Its assemblages have been used to trace the source of the basinal sandstones (Hibbard, 2002; Mohemmed *et al.*, 2015). With heavy mineral and petrographic information, we can measure the extent of sedimentary recycling (that is, mineralogical and chemical compositions of sediments may reveal the special effects of the present-day weathering system and previous weathering and diagenetic variation history). The heavy mineral accumulation in deposits reveals their parent rocks and their origin (Raiswell and Anderson, 2005; Oladipo *et al.*, 2018). Factors that impact this accumulation are weathering, mechanical abrasion, physical categorization and diagenetic consideration in burial (Morton and Hallsworth, 1999; Oladipo *et al.*, 2018).

Morton *et al.* (2013) studied the provenance of Triassic sandstones from the Devon coast and indicated that the Devon coast succession has provenance characteristics which show the source from a combination of granitic and metasedimentary lithologies of ages of above 550 Ma. Tobia and Kafy (2016) researched on the heavy mineral assemblages in fluvial recent sediments revealing pyroxene, amphibole, epidote, serpentine, apatite, tourmaline, zircon, and opaque minerals. They stated that the existence of few zircon particles of euhedral shape reflects the limited effect of the acidic igneous source rocks.

These minerals have high-density constituents of siliciclastic deposits and involve those with specific gravities (s.g) > the two key framework constituents of sand, sandstones, quartz (with s.g of 2.65) as well as feldspar (s.g 2.54 to 2.76). They are high-density minerals with s.g $\geq$ 2.9 g/cm^3 (Muller, 1997; Oladipo *et al.*, 2018). Density classification is essential as these minerals hardly contain more than one percent of sandstones. Concentration is realized by the separation of the sandstone. Minerals are also parted using dense liquids like bromoform, tetrabromoethane (or nontoxic polytungstate) accordingly. Minerals having lower densities than heavy minerals such as the micas (biotite and muscovite), dolomite, aragonite, anhydrite, magnesite and quartz, are termed light minerals.

This research aims to conduct studies on petrographic and provenance of heavy mineral assemblages of the sediments. This will expose the minerals available and their corresponding source rocks in the area of study. Heavy minerals occur in all sediments and sedimentary rocks. Deposits are only made when there is a very massive enrichment of minerals. Mineable concentrations of reasonably heavy or hard minerals which have been stored as a result of physical processes are referred to as placer deposits. Most minerals (heavy) are opaque and darken the deposit as they gathered in enormous amounts, and are referred to as black or mineral sand.

THEORY

Heavy Minerals could be opaque or non-opaque minerals; opaque ones frequently 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 Tables 1 and 2. The ones available are primary accessory minerals, which indicates the provenance of igneous and metamorphic rocks (including granites, pegmatites, mica schists, gneisses), and the presence of hydrothermally generated minerals.

Table 1: Heavy minerals and their source rocks

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

Source: Feo-Codecido (1956)

Table 2: Major source rocks of the heavy mineral species

S/n	Heavy minerals	Source rocks
1	Biotite, tourmaline, apatite, zircon, rutile, amphibole and iron, titanium oxides, and occasionally garnet.	Granite
2	Biotite, garnet, sillimanite, apatite and zircon	Micaschists, gneisses and migmatites
3	Amphibole (abundant), apatite (accessory)	Amphibolites and amphibolitic schists
4	Garnet, staurolite and biotite(abundant), zircon, sillimanite, tourmaline, apatite, magnetite (accessories)	Porphyroblastic schists
5	Staurolite, andalusite, garnet and kyanite sometimes seen.	Schist-greywacke complex
6	Biotite, andalusite (chiastolite) in hornfels. Andalusite (chiastolite) and garnet in schists. Apatite, tourmaline, sillimanite, amphibole, pyrite, ilmenite and zircon are also seen.	Schists, greywacke quartzites, hornfels and metasediments

Source: Cascalho and Fradique (2007)

The ZTR index is a method of determining how weathered (both chemically and mechanically) sediment might be (Prothero and Schwab, 1996); it focuses 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. The index is commonly high in beach or littoral zone depositional environment due to the long transport distances from the source and the high energy of the environment.

$$\text{ZTR Index} = \frac{Zircon + Tourmaline + Rutile\ (100\%)}{\sum non-opaque\ minerals} \quad (1)$$

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

GEOLOGY AND LOCATION

The study area falls within the Precambrian basement of south western Nigeria (Yahaya et al., 2014). The lowest altitude is about 206 meters; the highest is about 314 meters. River channels and streams flow from South-west to the North-east direction. The field mapping of the area was done during the dry season. The area gets very sunny during the day, with relatively high temperatures and low humidity. Some of the river channels were already dried up. The average temperature of the area was about 30^{0}C, but is about 25^{0}C during the rainy season. The vegetation is typical of tropical and guinea savannah. Short grasses, scattered tall trees are seen. During the rainy season, the vegetation is usually thick but will dry up during the dry season. Some settlements in this area are Ago, Budo- Loke, Owode, Araromi, Magbon, Ajilete, Ekudaji, Ajoko, Ojutaiye and Agunjin. Fulani herdsmen settlement in the bushy environment is also noticed. The main livelihood of the people in this area is farming. They plant mostly cereal crops like guinea corn, maize and also involved in coal production, mining metallic minerals such as Gold. The major river accessible to the people is the river Ogun.

Ifelodun is in Kwara State, Nigeria (Figure 1); found within latitudes 8^{0}45^{1}N and 8^{0}5^{1}N; longitudes 4^{0}46^{1}E and 5^{0}6^{1}E. The dry season mostly witnessed about November to March annually; the rainy season is frequently experienced between April and October (Kayode et al., 2016). Within the North-eastern part is a noticeable relief which is an elongation of granite ridge from Share to Yikpata. The Eastern side has quartzite ridges which are of the lower elevation of about 128m.

The study area is underlain by the Precambrian Basement Complex of Southwestern Nigeria. The basement complex is one of the main litho-petrological constituents that make up the geology of Nigeria. It forms a portion of the Pan-African mobile belt and lies among the West African and Congo Cratons and south of the Tuareg Shield (Ayodele, 2015; Dada, 2006). It is interfered by the Mesozoic calc-alkaline ring complexes and superimposed by Cretaceous and newer sediments. Orogenesis includes Liberian (Archaean), Eburnean orogeny (Early Proterozoic), Kibaran orogeny (Mid Proterozoic) and Pan African Orogeny. The rocks are Migmatite-gneiss complex (it is the oldest and the most common rock type in the Nigerian basement complex. It comprises of two main of biotite gneiss and banded gneiss), Schist belts (occur in a 400000m wide zone. It may contain assemblages of mafic igneous rocks, pelitic schists and phyllites, banded iron formation and coarse-grained clastics and carbonate rocks). Older granites (occur within the schists and the older migmatite-gneiss complexes. They range extensively in age and configuration. They characterize a varied and lengthy magmatic cycle linked with the Pan-African orogeny).

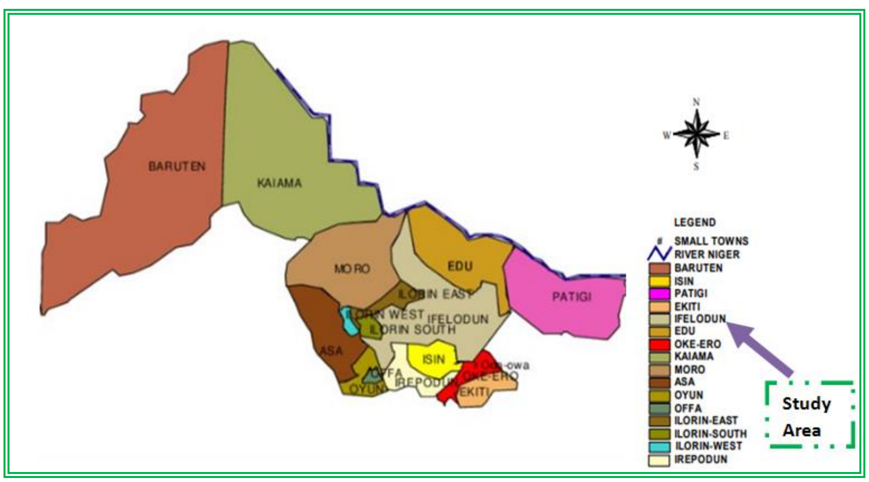


Figure 1: Map of Kwara State indicating Ifelodun

***Source**:* Kwara State Ministry of Lands and Housing (2010); Olabode and Ajibade (2010).

MATERIALS AND METHODS

MATERIALS

The materials used are hammer, chisel, German Standard Sieve, 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, computer with a spreadsheet program, field note, topographical map, binocular microscope, retort stand, watch glass, separating funnel, the position of light fraction, heavy liquid, funnel support, rubber tube, the position of heavy residue, pinch clip, filter funnel with support, and collecting bottle are materials used to set up the equipment for heavy mineral analysis.

METHOD

Rock samples were obtained from eight different locations (within latitudes $8^0 45^1$N and $8^0 5^1$N; longitudes $4^0 46^1$E and $5^0 6^1$E) in Ifelodun, Kwara State. They were analyzed using binocular microscope. Each sample was disaggregated [sieved to allow only sand-size particles as defined by Wentworth (1922)]. Minerals were parted in funnel using bromoform with specific gravity of about 2.89. They were sorted from other minerals of lower density by gravity method. Light density fractions float while high density ones sink after allowing for about seven hours. The particles of the heavy mineral were kept on the microscope slide for identification and then counted.

RESULT AND DISCUSSION

RESULTS

The outcomes of petrographic studies which show photomicrographs of heavy minerals from different samples are presented in Figures 2 to 9. These minerals were counted and represented in a chart (Figure 10) as they exist in sample locations. The fraction of the total heavy minerals available in the whole area of study is noted (Figure 11).

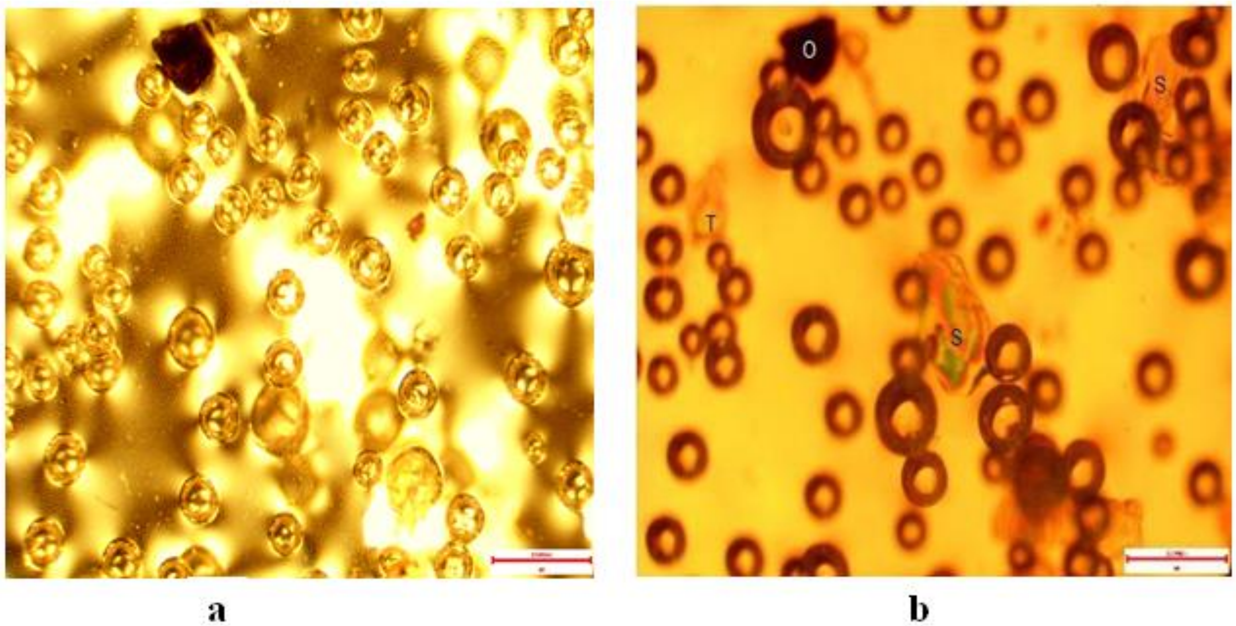


Figure 2: Photomicrograph of heavy minerals from sample AR1 under (a) Cross Polarized Light (XPL) (b) Plane Polarised Light (PPL); O= Opaque, S= Staurolite, T= Tourmaline.

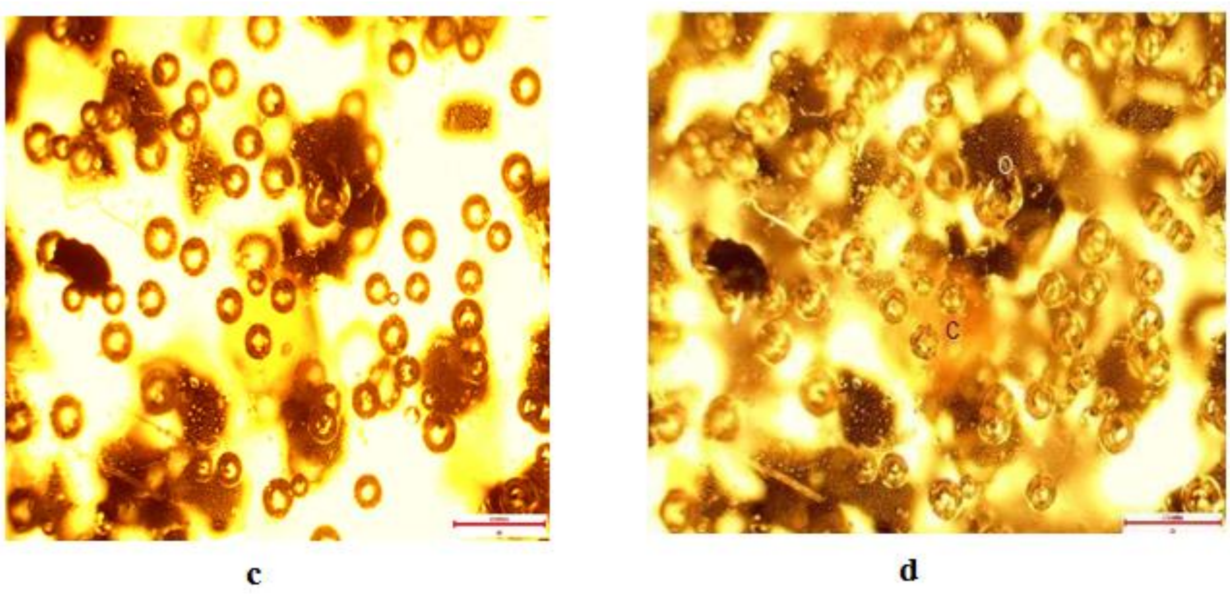
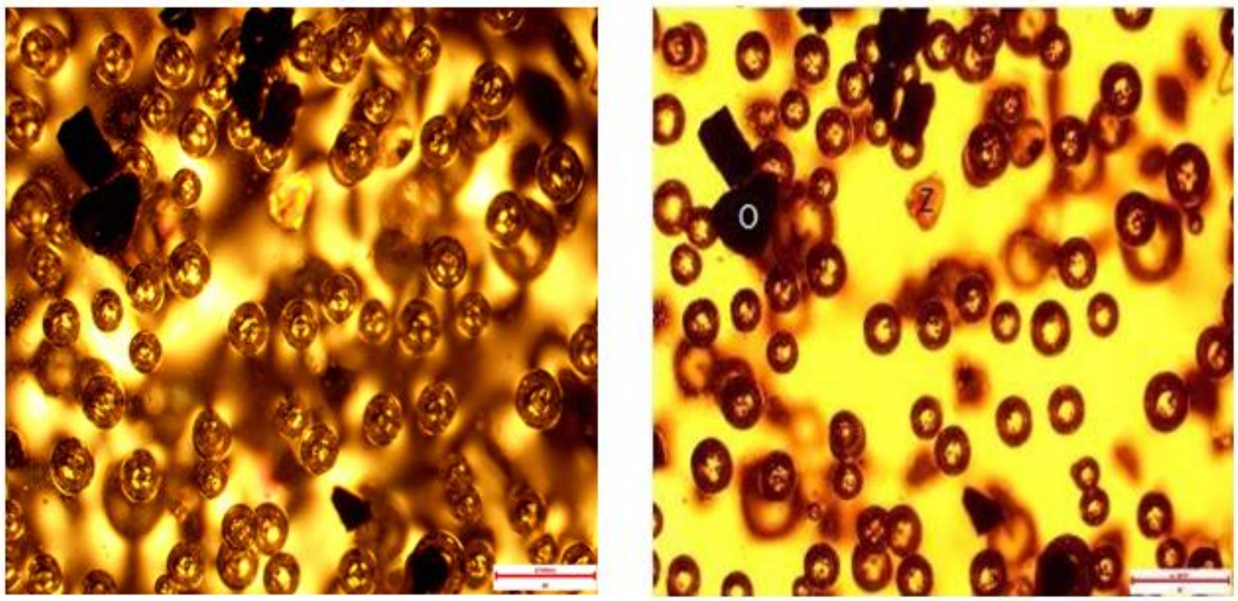


Figure 3: Photomicrograph of heavy minerals from sample AR3 under (c) Cross Polarized Light (XPL) (d) Plane Polarized Light (PPL); C= Cassiterite, O= Opaque mineral.



e f

Figure 4: Photomicrograph of heavy minerals from sample AR5 under (e) Cross Polarized Light (XPL) (f) Plane Polarized Light (PPL); O= Opaque mineral, Z= Zircon.

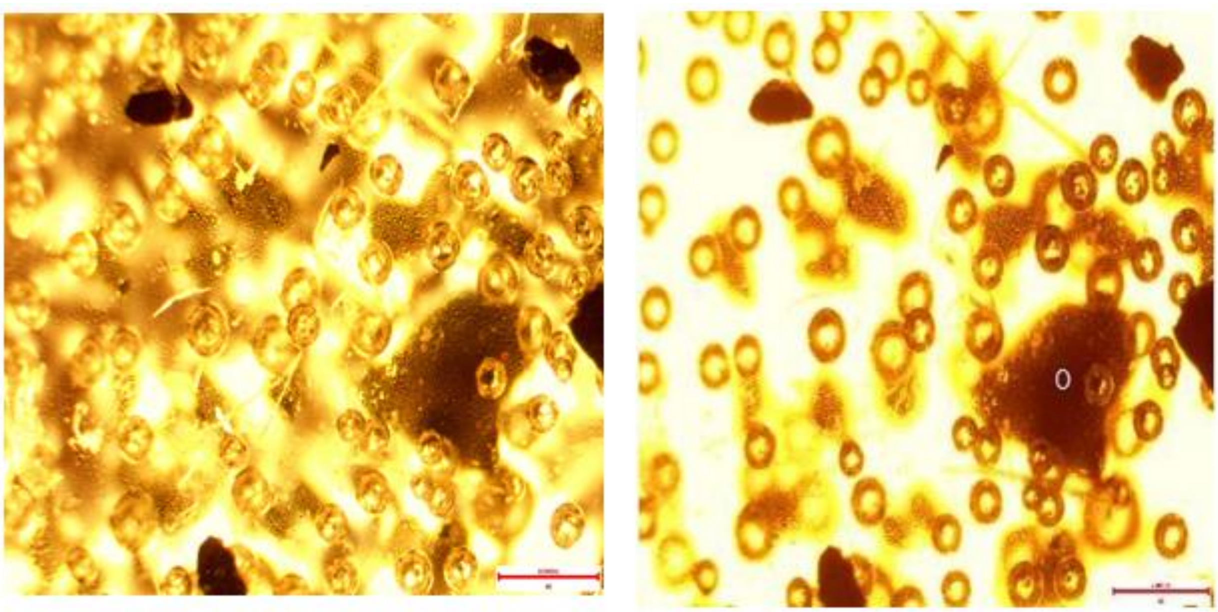


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Figure 5: Photomicrograph of heavy minerals from sample AR7 under (g) Cross Polarized Light (XPL) (h) Plane Polarized Light (PPL); O= Opaque mineral.

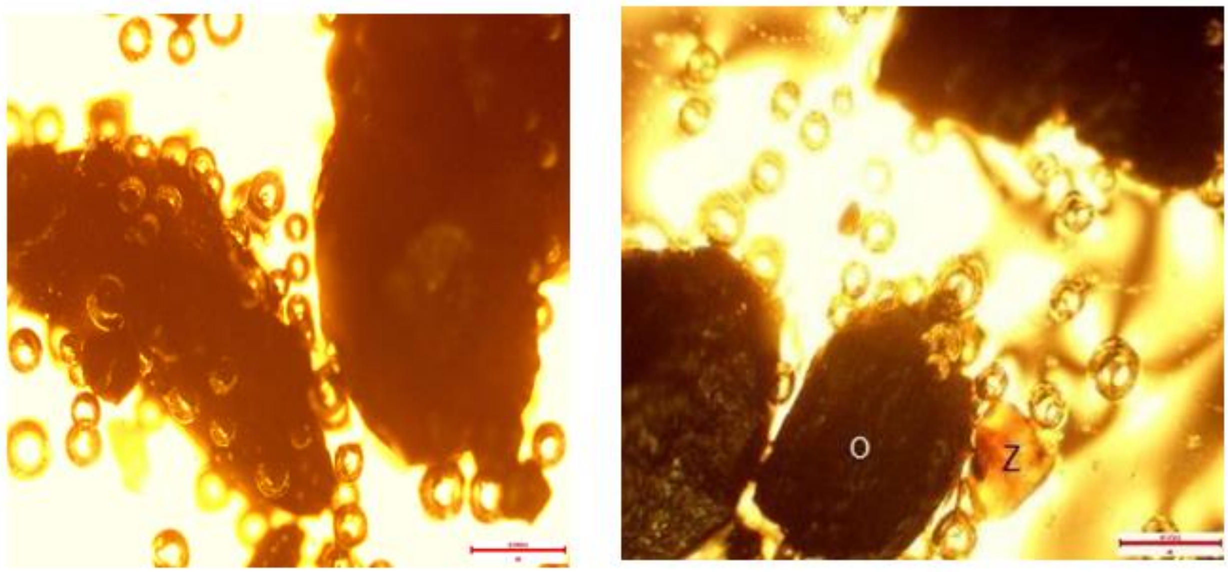

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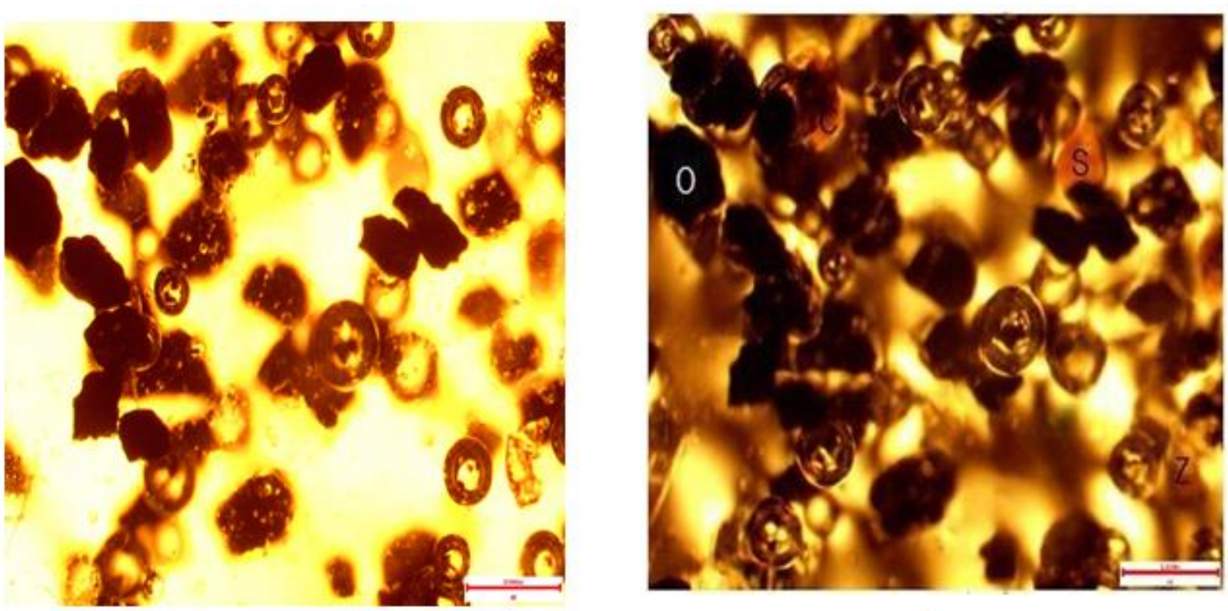
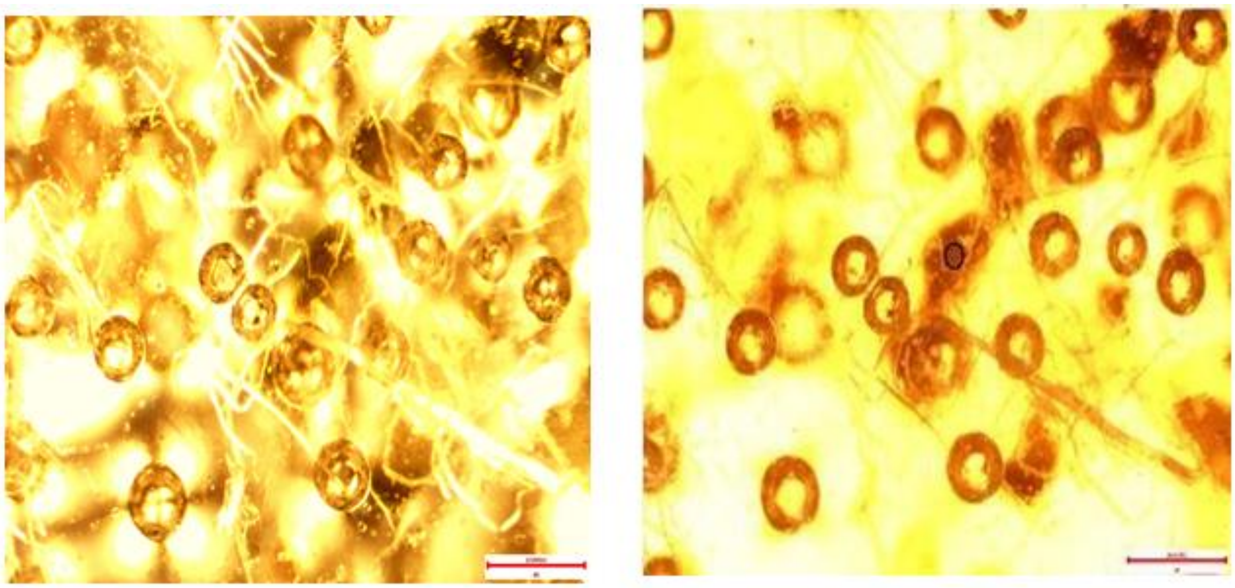
Figure 6: Photomicrograph of heavy minerals from sample AR16 under (i) Cross Polarized Light (XPL) (j) Plane Polarized Light (PPL); O= Opaque mineral, Z= Zircon.



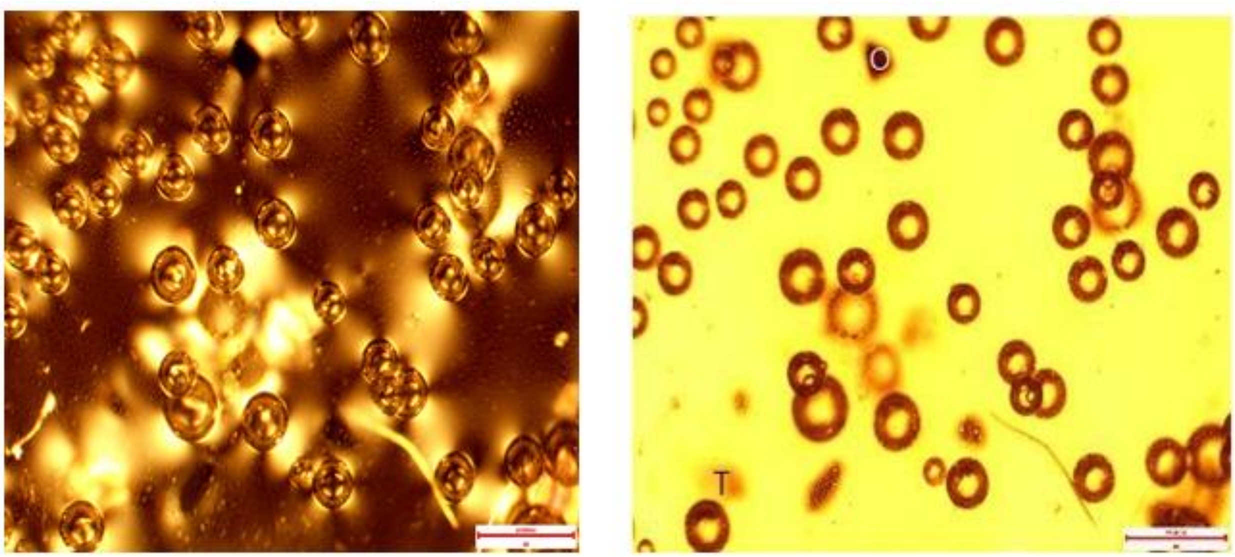
k l

Figure 7: Photomicrograph of heavy minerals from sample AGS18 under (k) Cross Polarized Light (XPL) (l) Plane Polarized Light (PPL); C= Cassiterite, O= Opaque mineral, S= Staurolite Z= Zircon.



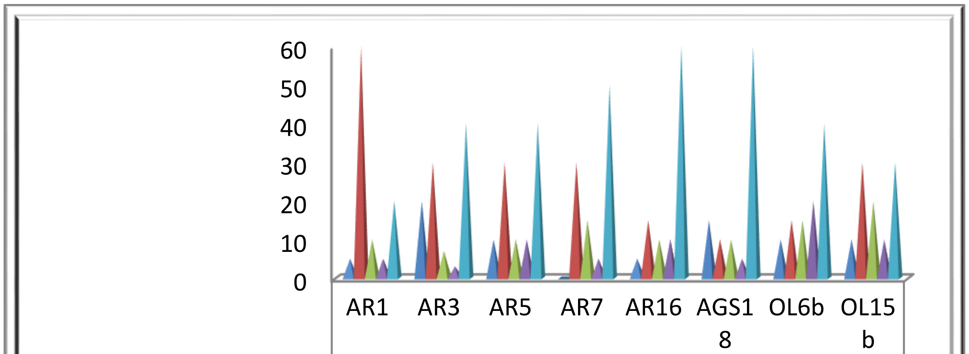
m n

Figure 8: Photomicrograph of heavy minerals from sampleOL6b under (m) Cross Polarized Light (XPL) (n) Plane Polarised Light (PPL); O= Opaque mineral.



o p

Figure 9: Photomicrograph of heavy minerals from sample OL15b under (o) Cross Polarized Light (XPL) (p) Plane Polarized Light (PPL); O= Opaque mineral, T= Tourmaline.



	AR1	AR3	AR5	AR7	AR16	AGS18	OL6b	OL15b
Cassiterite (%)	5	20	10	0	5	15	10	10
Staurolite (%)	60	30	30	30	15	10	15	30
Tourmaline (%)	10	7	10	15	10	10	15	20
Zircon (%)	5	3	10	5	10	5	20	10
Opaque minerals (%)	20	40	40	50	60	60	40	30

Figure 10: The variation of minerals strength in their corresponding locations

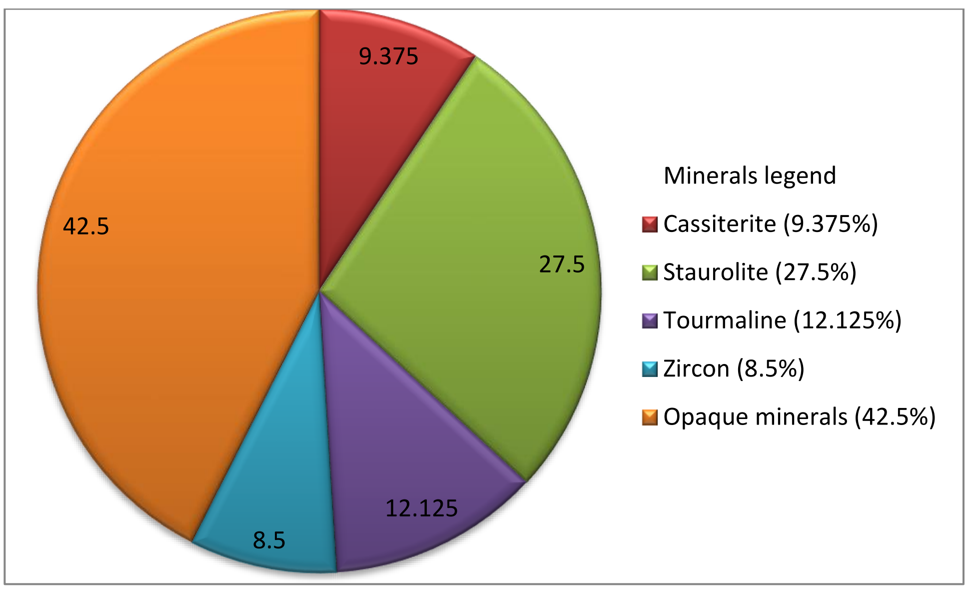


Figure 11**: The pie chart of total heavy minerals presence in the study area**

DISCUSSION

Location AR1 has cassiterite and other opaque, staurolite, tourmaline and zircon minerals are present. Cassiterite is generally an opaque mineral but it is presented in the result independently from other opaque mineral because of it high amount in other locations of study. In this location, the most abundant mineral is staurolite with 60% of the total minerals. This suggests its source rock as porphyroblastic schists since minerals like zircon and tourmaline are also available although they are in small quantity.

AR3 comprises the same minerals in AR1. Apart from opaque mineral, the heavy non-opaque mineral with the highest appreciable amount is staurolite with 30%. Cassiterite also shows much presence. The source rock could be porphyroblastic schists having also the presence of zircon and tourmaline in lesser amount.

AR5 also presents staurolite as the outstanding prominent non-opaque mineral available. Zircon, tourmaline and cassiterite show one-third amount of staurolite present. Therefore, the source rock is porphyroblastic schists.

Samples were also collected from AR7. The sediments contain huge amount of opaque minerals but staurolite again peaks with 30% among non-opaque minerals. Tourmaline has a better amount though cannot be compared to staurolite value. Zircon is present but with very low amount. Possible source rock of sediment is porphyroblastic schists. No cassiterite mineral was recorded or noted here.

In AR16, the quantity of staurolite is low but it is the highest non-opaque mineral in this area. Opaque dominates with 60% of the heavy minerals. Zircon and tourmaline have the same value (10% each). The rock this sediment is sourced from is porphyroblastic schists.

AGS18 presents cassiterite mineral which is generally opaque mineral as the one with maximum value (15%); the presence of staurolite is better as tourmaline. Zircon presence is very low. Cassiterite is tin oxide (SnO_2) mineral; translucent in thin crystals. An Alluvial or placer deposit containing the resistant weathered grain is the environment it is sourced and it is minor constituent of igneous rock. More so, with the presence of staurolite, zircon and tourmaline, we say porphyroblastic schist is the source rock.

Zircon minerals dominate area OL6b with 20% of heavy mineral available. The source rock is porphyroblastic schist since staurolite and tourmaline are also seen.

Staurolite is the most abundant mineral with 30% of the total minerals in location OL15b.The presence of tourmaline is appreciable (20%); the amount of zircon is better (10%) and the source rock is porphyroblastic schists.

A porphyroblast is a bulky mineral gemstone in a metamorphic rock; matures among the finer grained medium and may be partially or entirely irregular in form. The connection of porphyroblast development to distortion is assessed by matching the form orientation of traces of mineral presences in the porphyroblast to the matrix fabric (Bell and Johnson, 1989). Metamorphic minerals are recorded in a sequence called the crystalloblastic series. Generally, this series make the source of a particular rock to be known.

However, petrographic investigation prevents us from losing valuable evidence conveyed by rock fragments and thus, enables us to assess heavy mineral presence more precisely. With this knowledge, provenance interpretations can be based on firm ground. The results obtained show that the sediment is sourced from porphyroblastic schists of metamorphic rock. This is noted with reference to Tables 1 and 2 used for interpretation. Petrographic studies made possible the results of Figures 10 and 11 from Figures 2 to 9 and support the deduction of the source rock of sediments. The pie chart (Figure 11) defines the area to have more staurolite (27.5%) among non-opaque minerals and 51.875% of opaque minerals (with addition of cassiterite minerals).

CONCLUSION

Petrographic investigations enable us have valuable evidence conveyed by rock fragments to give account of heavy mineral concentration more precisely and their corresponding source rocks in the area of study. The most dominant non-opaque mineral is staurolite in almost all the locations in the area. About 52% of opaque minerals were counted which dominated all the locations. Zircon was recorded as the mineral with least occurrence. The amount of tourmaline and zircon are only better in locations OL15b and OL6b respectively. The source rock dominating the area is porphyroblastic schists of metamorphic rock with emphasis on non-opaque heavy minerals.

CONFLICT-OF-INTEREST DISCLOSURE

No conflict of Interest.

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