



PETROGENESIS, MAJOR OXIDES AND TRACE ELEMENTS GEOCHEMISTRY OF MIGMATITE IN AJUBA, KWARA STATE, NIGERIA

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ABSTRACT

Petrogenesis, major oxides and trace elements geochemical study was carried out on migmatite in Ajuba. The study area is located on Latitudes 8° 05'N and 8°13'N and Longitudes 5°23'E and 5°30'E. Five rock samples were taken from the migmatite outcrops and used for petrographic and geochemical analyses. The geochemical analysis was done using X-ray Fluorescence Spectrometer technique. The dominant rock type is migmatite; gneiss and granite outcrops were also found in sparse distribution. Ptygmatic folds, which constitute the palaeosome, is the common structure observed on the migmatite rock. The petrographic analysis shows that the migmatite consists of quartz, biotite, plagioclase, hornblende and microcline. The major oxides analysis indicates SiO₂ as the dominant oxide with concentration range values (70.71 wt. % - 79.32 wt. %) and average of 74.80 wt. %. Al₂O₃ (14.98 wt. % - 16.44 wt. %, average: 15.70 wt. %) and Fe₂O₃ (9.10 wt. % - 15.41 wt. %, average: 12.39 wt. %), K₂O (6.67 wt. % - 8.86 wt. %, average: 7.50 wt. %) and CaO (0.49 Wt. % - 4.64 wt. %, average: 2.73 wt. %). P₂O₅, MnO and TiO₂ are less than 1.0 wt. %. The trace elements analysis indicates the concentration distributions: Rb (0.11-0.15 ppm, average 0.13 ppm), Co (0.04-0.17 ppm, average 0.10 ppm). Trace elements < 0.10 ppm are Zn, W, Ni, Cu, V and Pb. From the petrographic and geochemical assessment, the petrogenesis of the migmatite has silica-rich igneous parentage. Moreover, the plots of SiO₂-CaO and K₂O-SiO₂ placed the migmatite on the "upper boundary field of Franciscan Greywacke" protolith and Shoshonite series, respectively.

Keywords: *Leucosome, Major oxides, Melanosome, Migmatite, Neosome, Petrogenesis, Trace element*

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INTRODUCTION

Migmatite is a combination of metamorphic rock and igneous rock; it involves two or more different parts which are petrogenetically connected and to their protoliths (Sawyer, 2008). It is made when a gneiss, which is a metamorphic rock partially melts; and mixes with recrystallised igneous rock. They are also named diatexite. Types of migmatites include metatexites and diatexites. Metatexites have a lesser melt portion and preserved coherent pre-partial melting qualities in the palaeosome and residuum. Neosome exist dominantly in the diatexites and coherent pre-partial melting arrangements are absent (Pawley *et al.*, 2015). The different phases of the rock are due to the transformation of some fraction that happens in the metamorphic palaeosome (Mehnert, 1971), when an originator rock is affected by considerable number of pressures and temperatures. Metamorphic rocks are aggregate of solid mass which are altered at extreme pressures and temperatures, though could form crystal again but not made through melting. Igneous rocks are solid masses that are made by cooling from entirely molten silicate material.

Migmatites are found beneath deformed metamorphic rocks that characterize the base of eroded mountain chains, frequently within Precambrian cratonic blocks (Sawyer, 2008). It is the oldest member of the Precambrian Basement complex in Nigeria (Oyawoye, 1964; Rahaman 1976; Ayodele, 2015). Migmatites are seen frequently as tightly, incoherently folded veins (ptygmatic folds). These create separations of leucosome, light-colored granitic components exsolved within melanosome (which is a dark coloured amphibole- and biotite-rich portion). Mesosome may also exist and its colour is intermediate among that of leucosome and melanosome.

According to Lyell (1837), migmatite is the penultimate part of an order of lithologic alterations. He stated that when there is a deposition of unconsolidated deposit (protolith for upcoming metamorphic rocks) and there is a rise in temperature and pressure with depth, a protolith passes through a diagenetic order from porous sedimentary rock through hard rocks and phyllites to metamorphic schists; the differentiation of the original sedimentary constituent is still possible. More so, the schists are re-formed as gneiss that folia of the remaining minerals substitute with quartzo-feldspathic portions; partial melting is still observed with sets of leucosome merge to produce separate strata in the neosome, and is seen as detectable migmatite. Goransen (1938) clarifies that the subsequent leucosome strata in stromatic migmatites hold water (H₂O) and carbon (iv) oxide (CO₂) content in an irregular reaction series from the paleosome which makes the leucosome exceptionally mobile. Holmquist (1916) stated that metamorphic rocks are converted into granulite; the procedure is termed anataxis. Imasuen and Onyeobi (2014) have conducted petrographic analyses of the rock samples which shows migmatites consist of quartz, feldspar (plagioclase, microcline and orthoclase) and also biotite.

Every rock is made due to different chemical, physical and biological conditions which lead to the creation of an extensive and distinct set of minerals and therefore result in submissions in various fields. Rocks are durable, soft, penetrable and impermeable; they are of several sizes and shapes. Migmatites have an attractive look, frequently being noticeable with irregular small areas of distinct shades fluctuating from nearly white to dark grey, and are extensively used as building stones, occasionally being refined for ornament. Migmatite in the construction industry comprises dimension stones and, road aggregate. It uses also include countertops, floor design, as facing stone, curbing, as artifacts, cemetery indicators, jewelry, tombstones, manufacturing of object stopping breeze from blowing

papers and bookends. This study aims to determine the petrogenesis of migmatite from petrographic and geochemical analyses.

LOCATION, CLIMATE AND GEOLOGY OF THE STUDY AREA

Ajuba is one of the villages in Osi, Kwara State of Nigeria at about 4000m west of Osi on Latitude 8° 05'N and 8°13'N and Longitude 5°23'E and 5°30'E. It covers an area of 9km² (Figure 1). One of the major villages in Osi is Ajuba settlement and it is situated within two rock suites, namely: Osi migmatite-gneiss complex to the west and Egbe schist belt to the east (Bamigboye & Adekeye, 2011).

The study area has dry and rainy seasons as the two alternating climatic conditions. The annual rainfall is between 1270 mm and 1524 mm, spread over the month of April to October. The maximum rainfall is usually experienced around June/July. The monthly temperature is maximum in March at about 30°C and minimum (lowest) in August at about 25°C (Olasehinde, 1999). Conversely, the dry season starts in November and ends in March.

The geology of Nigeria involves older and younger meta-sediments, Older and Younger Granites, and volcanic intrusives which are overlain by younger sedimentary basins of Illumedun, Chad, Dahomey, Benue, Bida, and Niger-Delta (Rahaman, 1976). The most dominant rocks include gneiss, granite, gabbro, migmatite, amphibolite and pegmatite. The granites are porphyritic and occur as boulders beside the river channel. Enormous outcrop of porphyritic granite is sited about 8 x 10² m south of the area. A typical feature of the Basement Complex tectonics is the widespread existence of fractures (Akinrinmade *et al.*, 2013). The varieties of surface essential features such as foliations, folds, faults, joints, fractures and fissures are noted. The presence of joints, faults and fractures in the subsurface are signs of a healthier and recommended aquifer (Olasehinde, 1999). It was observed that the rivers are constantly flooded by water at the peak of the rainy season; the flow rate drops to the average of about 2.7 ms⁻¹ in the dry season and maintains the average of about 7.4 ms⁻¹ during the wet season (Akinrinmade *et al.*, 2013).

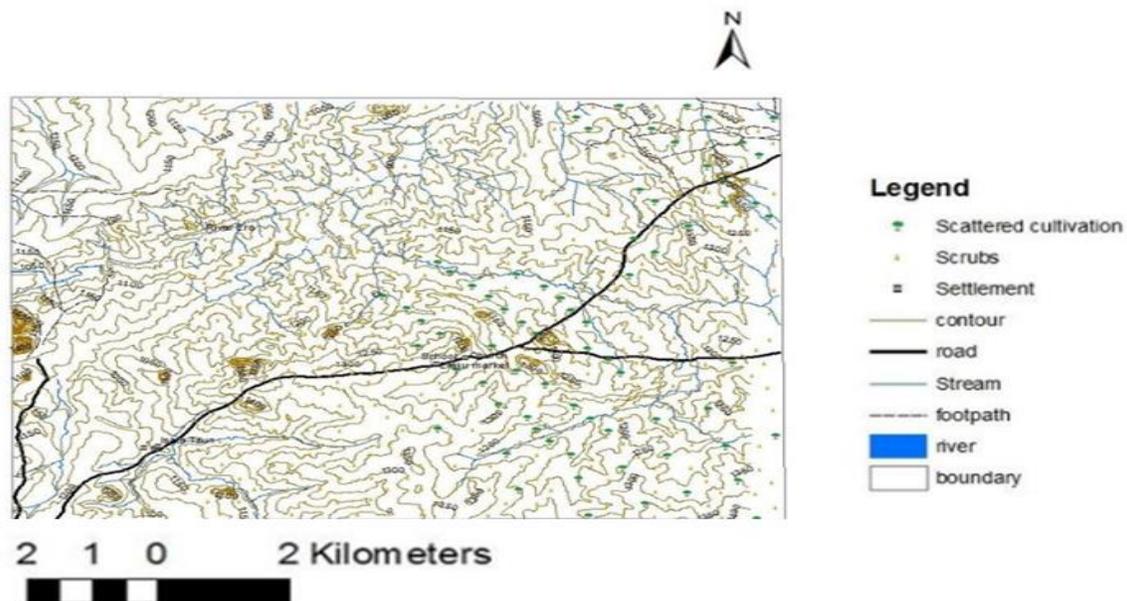


Figure 1: Topographic map of Osi

Source: Akinrinmade *et al.* (2013).

GENESIS OF MIGMATITE

A metamorphic rock is a rock that has been transformed inside the Earth into a new type of rock in terms of its body (metasomatic), mineralogical and geochemical (petrologic) content. The source rock from which a metamorphic rock came is called the protolith. Metamorphism can be triggered by burial, tectonic stress, heating by magma or modification by intruding fluids. Protolith of a migmatite may suffer partial melting to become neosome. The unaltered protolith in migmatite is called palaeosome and it usually has conspicuous features such as foliations, folds and layering. Some rocks in a palaeosome are resistant to partial melting or microstructural alteration and they are called resisters (for example, quartzites, calc-silicates, and metamafic rocks). Neosome has two sections, namely: melt and magma. The melt is a silicate liquid without crystals, while magma is a silicate liquid that comprises crystals. The crystals may have either crystallized from the melt (which is liquidus phases) or they are the solid product of the melt response (also called peritectic products). Magmas are non-Newtonian fluids. Newtonian fluids are fluids that have a linear comparative connection among differential stress and shear strain (that is, the viscosity of the fluid will not be changed irrespective of any external stresses). Non-Newtonian ones are categorized by a non-linear relationship between the shear stress and the shear strain. As a consequence, the viscosity will vary and become thinner or thicker once external stresses are applied. The neosome comprises the solid (which are residuum and melanosome) and the liquid (which is leucosome) components of the melt creating metamorphic response (Sawyer, 2008; Pawley *et al.*, 2013).

The leucosome results from segregated partial melt and it may comprise microstructures that show crystallisation from a melt or magma. Leucosomes may be in-situ (if a darker selvage of mafic minerals and other minerals like garnet or cordierite are present which in turn characterizes the solid products of the melt reaction) or segregated and migrated from their source. In-situ leucosome results from the crystallisation of an anatectic melt or part of a melt, which has segregated from the residuum but has stayed at the site where the melt was formed. In-source, leucosome results from anatectic melt, which has moved away from the place where it was formed but is still around the boundaries of its source layer. The outcome of crystallisation of a felsic portion that has migrated from its source area entirely into non-metamorphosed rocks is granite dyke, sill, and pluton. Partial melting or anatexis yields metatexite and diatexite with mineralogical and chemical arrangements (Afolabi *et al.*, 2019).

MATERIALS AND METHOD

The field materials used are topographic map, hammer, chisel, compass clinometers, sample bag, marker, safety gear, footwear, pencil, pen and notebook. The laboratory materials used are, petrographic microscope, rock cutting machine, X-ray Fluorescence spectrometer, jaw crusher, pulveriser, etc.

The fieldwork involved geological mapping on a scale of 1:12,500 resulting in the geological map (Figure 2). The laboratory work involved sample preparation, petrographic study and geochemical analysis.

The petrographic study was undertaken with the aid of petrographic microscope at the Microscopic Laboratory, Department of Geology and Mineral Sciences, University of Ilorin, Nigeria. Five rock samples were made into several thin sections and subsequently polished using carborundum powder to obtain slides with the required thickness and a

perfectly smooth surface. Fresh rock samples were collected for hand specimen examination. Preliminary observation and identification of each constituent mineral were carried out.

Five samples of migmatite were noted and collected for geochemical analysis. About 1kg of each sample was broken into pieces with a hammer and crushed into smaller pieces with a jaw crusher. The samples were thereafter pulverised in a disc mill for about two minutes and shipped for major oxides and trace elements analyses at Jiangsu Skyray Instrument Company Limited, Ibadan, Nigeria using X-ray Fluorescence Spectrometer technique. Mineral identification was carried out at the Microscopic Laboratory, Department of Geology and Mineral Sciences, University of Ilorin, Nigeria.

RESULTS AND DISCUSSION

RESULTS

The result of field studies reveals that the rocks in the study area are majorly migmatite, gneiss and granites [with migmatite about 60% of the total visible rocks] (Figure 2). Figure 3 presents the field photograph of migmatite with ptygmatic folds in Ajuba town. The photomicrograph of possible migmatite minerals is contained in Figure 4. The amounts of major oxides and trace elements detected are presented in Tables 1 and 2 [with their average results in Table 3]. The most abundant major oxides and trace elements are presented in Figures 5 and 8, respectively. Figure 9 presents the major oxides for sample locations.

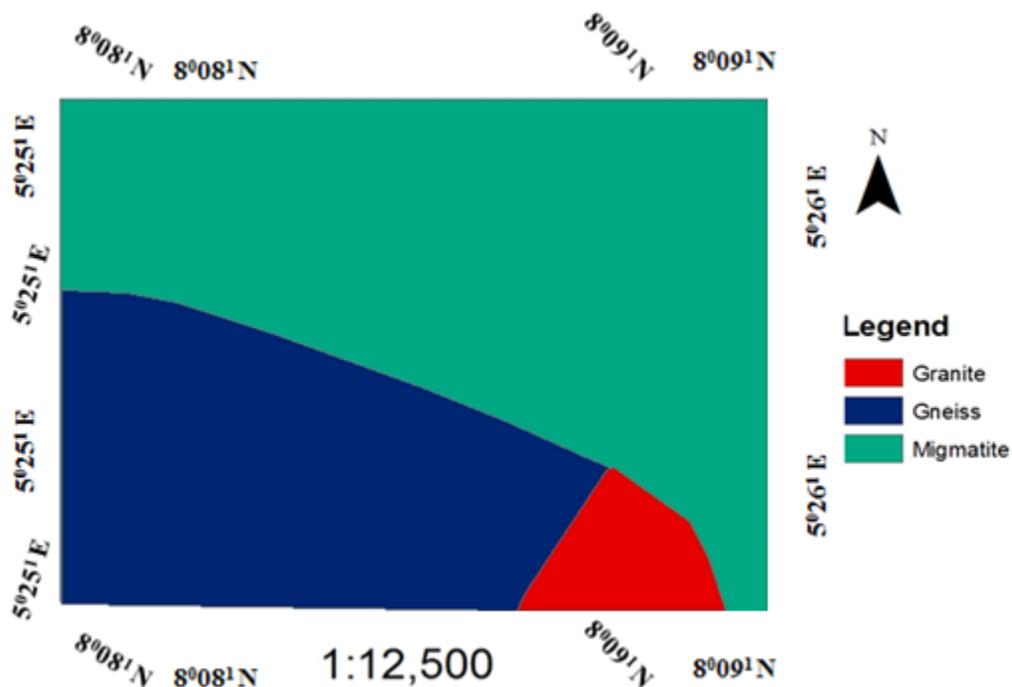


Figure 2: Rock Map of the Area



Figure 3: Field photograph of migmatite with ptygmatic folds in Ajuba town.

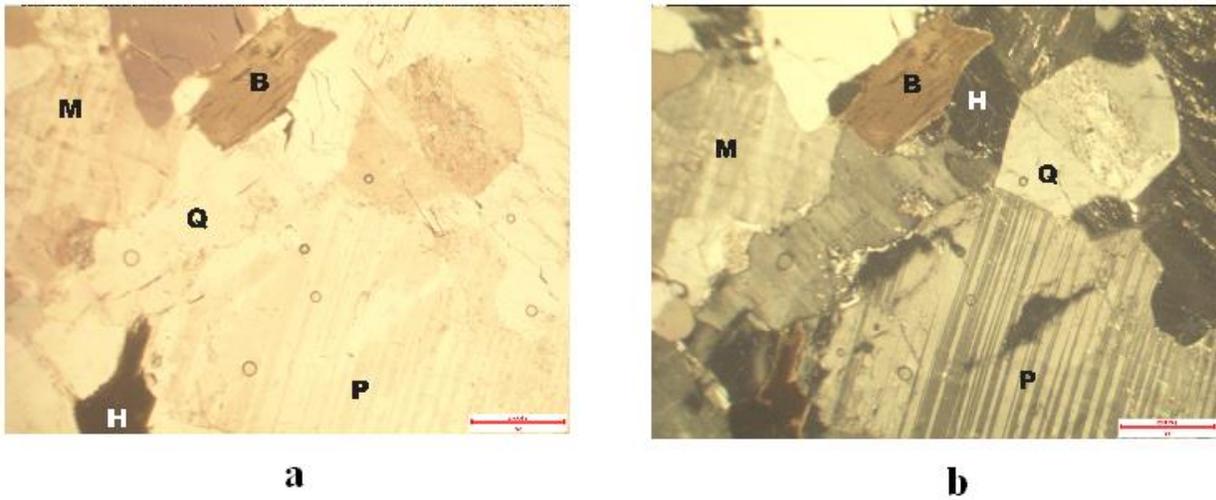


Figure 4: Photomicrograph of migmatite under (a) plane polarised light (b) crossed polarised light; Q =Quartz, B = Biotite, P = Plagioclase, H =Hornblende, M = Microcline.

Table 1: Amounts of available major oxides

Locations	Major oxides							
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	CaO	P ₂ O ₅	MnO	TiO ₂
AJ1A	73.660	15.708	15.414	6.666	4.643	0.505	0.144	0.190
AJ1B	79.316	15.347	14.708	7.026	2.514	0.464	0.121	0.257
AJ8	78.990	16.439	9.094	7.657	1.944	0.470	0.077	0.111
AJ9	71.296	14.984	11.147	8.860	0.488	0.463	1.291	0.201
AJ10	70.713	15.976	11.585	7.268	4.063	0.490	0.109	0.128
Total	373.975	78.454	61.948	37.477	13.652	2.392	1.742	0.887
AVE	74.795	15.6908	12.3896	7.4954	2.7304	0.4784	0.3484	0.1774

Table 2: The trace elements analysis results

Trace Elements	Locations				
	AJ1A	AJ1B	AJ8	AJ9	AJ10
Rb	0.1125	0.1219	0.1434	0.1529	0.1329
Co	0.1003	0.1716	0.0376	0.0614	0.1413
Zn	0.0942	0.0880	0.0797	0.0766	0.0838
W	0.0853	0.0514	0.0439	0.0651	0.0645
Ni	0.0407	0.0377	0.0459	0.0418	0.0391
Cu	0.0313	0.0292	0.0336	0.0280	0.0325
Au	0.0000	0.0000	0.0000	0.0000	0.0934
V	0.0214	0.0176	0.0136	0.0189	0.0149
Cr	0.0124	0.0099	0.0074	0.0056	0.0087
Pb	0.0035	0.0120	0.0000	0.0078	0.0019
TOTAL	0.8225	0.8682	0.7232	0.8143	0.9020

Table 3: Average amount of major oxides (in percentage) and trace elements

Major oxides	Average major oxides	Trace elements	Average amount of trace elements
SiO ₂	74.7950	Rb	0.13272
Al ₂ O ₃	15.6908	Co	0.10244
Fe ₂ O ₃	12.3896	Zn	0.08446
K ₂ O	7.4954	W	0.06204
CaO	2.7304	Ni	0.04104
P ₂ O ₅	0.4784	Cu	0.03092
MnO	0.3484	Au	0.01868
TiO ₂	0.1774	V	0.01728
		Cr	0.0088
		Pb	0.00504

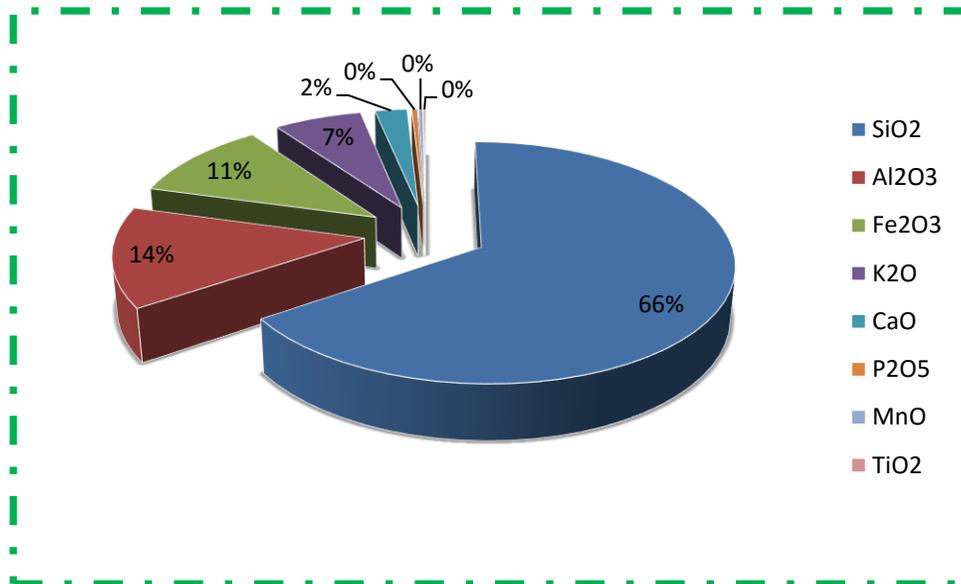


Figure 5: The pictorial representation of major oxide

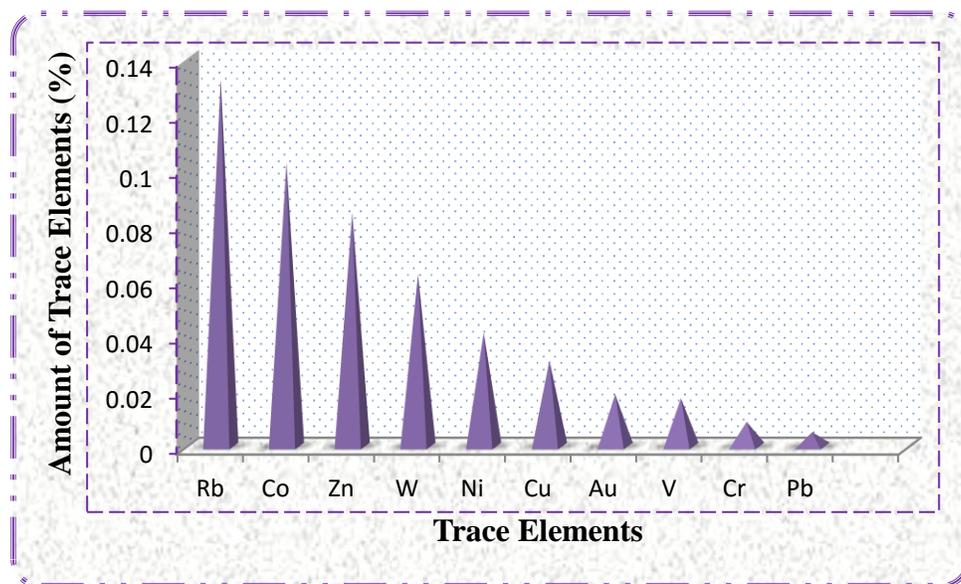


Figure 6: Trace elements in order of decreasing amount

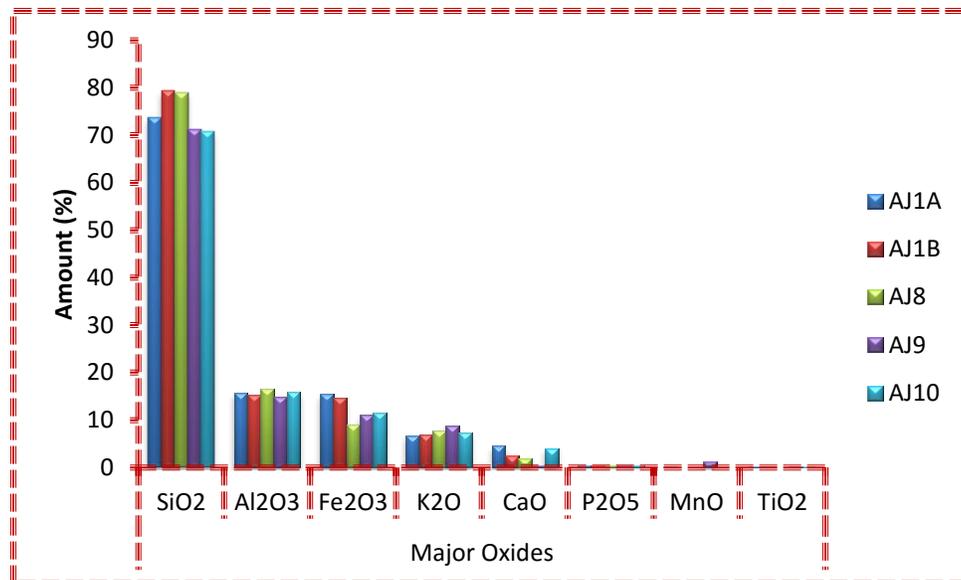


Figure 7: Histogram of concentration of major oxides with respect to their sample locations

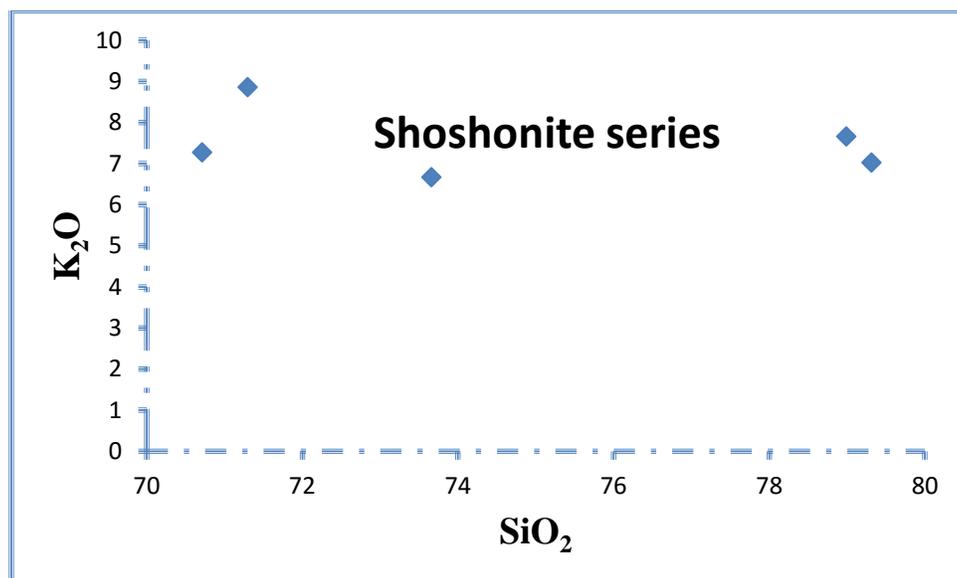


Figure 8: K₂O-SiO₂ plot for series classification

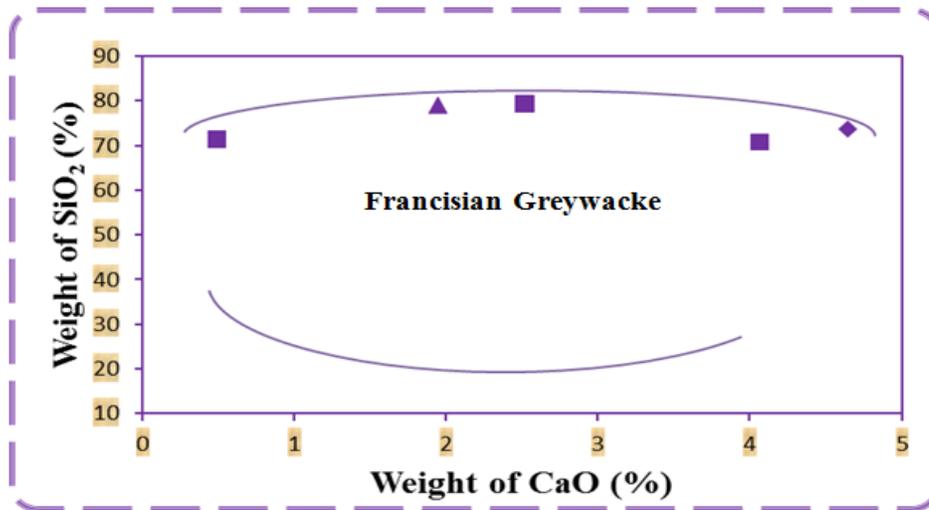


Figure 9: SiO₂-CaO plot (field of Franciscan Greywacke after Brown *et al.*, 1979)

DISCUSSION

The migmatite outcrops in the study area are medium-grained in texture and they occur in the southwestern and southeastern parts of the study area. Field evidence indicates that they were partially migmatized by the intrusion of acidic magma resulting in distinct felsic and mafic bands. Migmatite is very useful as dimension stones and aggregates in road, bridges and dam's construction. This outcrop covers about 60% of the study area (Figure 2). Most of the outcrops are very visible along the river channels as weathered material. The common structure observed in this rock is ptygmatic folds which constitute the palaeosome (Figure 3).

In hand specimen, migmatites investigated are of alternating ensembles of light and dark coloured minerals (leucosome and melanosome minerals). The dark coloured are biotite and hornblende, while the light coloured are quartz and feldspar (Figure 4). Thin section studies revealed that the melanosome consists of hornblende and biotite, while the leucosome consists of plagioclase, quartz and microcline. The partial melting was possible due to temperature and pressure greater than 650⁰C and 34Mpa, respectively.

Tables 1 and 2 accounts for the percentage weight of major oxides and the type of trace element detected, respectively. The average of major oxides was computed as seen in Table 3 to give an account of the mean percentage of these oxides in Ajuba. It also includes those of trace elements. Major oxides geochemical analysis indicates silicon (iv) oxide (SiO₂) as the dominant major oxide in the area with a concentration range values (70.71 wt. % - 79.32 wt. %) and an average of 74.80 wt. %. Al₂O₃ (14.98 wt. % - 16.44 wt. %, average: 15.70 wt. %) and Fe₂O₃ (9.10 wt. % - 15.41 wt. %, average: 12.39 wt. %), K₂O (6.67 wt. % - 8.86 wt. %, average: 7.50 wt. %) and CaO (0.49 Wt. % - 4.64 wt. %, average: 2.73 wt. %). P₂O₅, MnO and TiO₂ are less than 1.0 wt. %. The trace elements geochemical analysis indicates the following concentration distributions: Rb (0.11-0.15 ppm, average 0.13 ppm), Co (0.04-0.17 ppm, average 0.10 ppm). Trace elements with less than 0.10 ppm in the area are Zn, W, Ni, Cu, V and Pb. From the petrographic and geochemical assessment, the petrogenesis of the migmatite has been inferred to have silica-rich igneous parentage. Moreover, the plots of SiO₂-CaO (Figure 9) and K₂O-SiO₂ placed the migmatite on the "upper

boundary field of Franciscan Greywacke” protolith and Shoshonite series, respectively. K_2O - SiO_2 plot in Figure 8 was used in line with Peccerilo & Taylor (1976), Brako *et al.* (2020) & Morrison (1980)] to classify the migmatite of the study area into shoshonite series. Besides, shoshonite series, other possible classification using the K_2O - SiO_2 plot for migmatite of the study area are tholeiite, cal-alkaline, high-K calc-alkaline series. K_2O - SiO_2 plot (Figure 8). corroborated that the migmatite rock is mostly of igneous intrusion (which is a group of saturated in silica, low iron enrichment, low TiO_2 as in the case of this research [it is the least amount], high but variable Al_2O_3 approximated to 16 wt. %).

CONCLUSION

Migmatite is the major rock type within the mapped area: Ajuba with 60% abundance when compared to other rocks noted during the survey. The common structure observed in this rock is pygmatic folds which make up the palaeosome. Migmatite outcrops investigated are made up of alternating bands of light and dark coloured minerals (leucosome and melanosome minerals). Silicon (iv) oxide (SiO_2) is the most abundant oxide in the area with an average of 74.80 wt. %) and concentration range values of 70.71 wt. % - 79.32 wt. %. Rb is the most abundant trace element in the study area with concentration range value (0.11-0.15 ppm) and an average value of 0.13 ppm. It is followed by Co (0.04-0.17 ppm, average 0.10 ppm). Trace elements with less than 0.10 ppm in the area are Zn, W, Ni, Cu, V and Pb. The petrographic and geochemical results established the petrogenesis of the migmatite to be of silica-rich igneous parentage. K_2O - SiO_2 plot indicates that the migmatite rock is mostly of igneous intrusion and classified the mapped region into shoshonite series. Lastly, the plot of SiO_2 -CaO defined the area covered be located “at the upper boundary of the field of Franciscan Greywacke”.

CONFLICT-OF-INTEREST DISCLOSURE

No conflict of Interest.

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