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Structural Lineaments and Geochemical Characterizations of Migmatites in Garram Pankshin-Kanke, Plateau State

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Abstract
This study explores the structural lineaments and geochemical characteristics of migmatites within latitudes 9°10'00"N and 9°10’45"N and longitudes 9°30’00"E and 9°30‘35"E, and covered a portion mapped of WASE sheet 191-SW, on the scale of 1:100,000. A total of 15 samples collected, 12 representative samples were studied macroscopically and petrographically. Therefore, field mapping and morphological features, our findings reveal four (4) different lithologic units, vis: Metatexites, Ditexites and a diverse range of mineral assemblages, including microcline, silimanite, cordierite indicative of varying degrees of metamorphism and partial melting. The structural analysis highlights the fluids movement and significant lineament orientations that suggest history of tectonic stress regimes – two inversions trending NW-SE Liberian Orogeny, and NE-SW Pan-African Orogeny. The major elements composition shows that the rocks are characterized by high SiO2 in the range of 51.04 - 97.34 wt % with an average of 78.74wt%, JJ-8 and FeO_3 and Al_2O_3 enrichment are pronounced in the rock samples showing average of 17.76 wt% (JJ-11), 19.90wt% (JJ-4) and 19.91 wt% (JJ-4), 20.33 wt% (JJ-11) respectively. In addition, Na_2O remains consistently less than K_2O in most of the samples. The rocks are generally depleted in, MgO, and MnO. The diatexite migmatite rock in this study was found to be originated from sedimentary protoliths of various compositions. Fractional crystallization which encompasses the formation of plagioclase and biotite as indicated by the negative correlation between the values of SiO_2 versus CaO, MgO, Na_2O, Al_2O_3 and Fe_2O_3, are in congruent with the field and petrographic proof of plagioclase and biotite abundance.

Key Words: *Petrography, Lineaments, Metatexite, Diatexite, Granulite Facies, Morphology.*

1.1 INTRODUCTION

Migmatites can affect a variety of protoliths, and have been identified over the majority of geological time, and develop in different tectonic conditions (Ferre, G. & Caby, 2006). As seen in Figure 3 below, the study region is situated in the Northwestern portion of Plateau State and is contained within Latitudes N09^{0}16’45’’, N09^{0}10’00’’ and Longitudes E9^{0}30’00’’, E9^{0}55’00’’ on a scale of 1:25,000 part of sheet 149 NW. By accreting terranes between the converging West African Craton, the Congo Craton, and the East Saharan Block, the study area of Garram and its surroundings became a part of the Nigeria Basement Complex of Plateau State, which was a part of the Neoproterozoic Trans Saharan belt between 700 and 850 Ma (Ferre, & Caby, 2006).

With outcrops of high, moderate, and low-level exposures, the region is distinguished by its highland and undulating terrain. As seen in Figure 1 below, the majority of the outcrops range in height from 419 to 670 meters above sea level. The outcrops (structurally regulated) regulate the area's little stream and the drainage pattern is dendritic. Both sheet and gully erosion are present in the region (Figure 2).

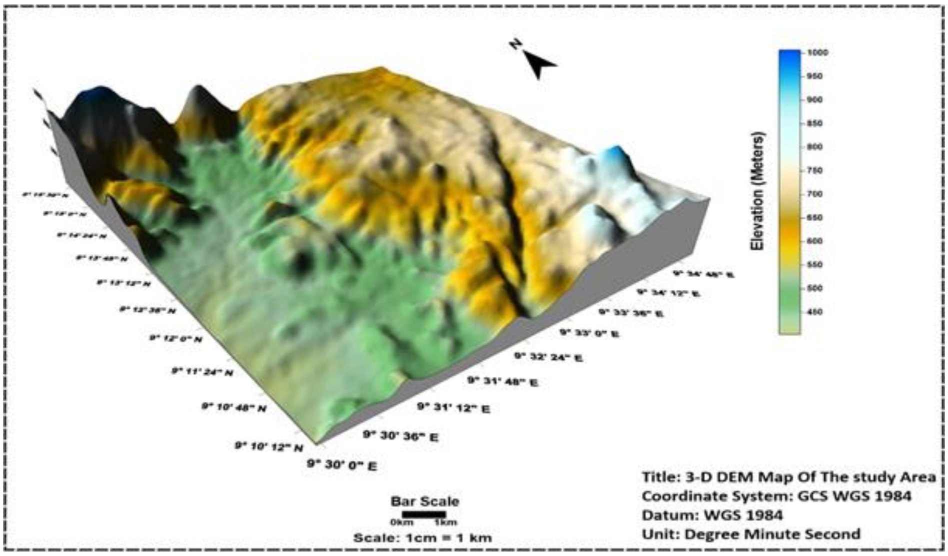

Figure 1: Map of the Study Area showing the Relief

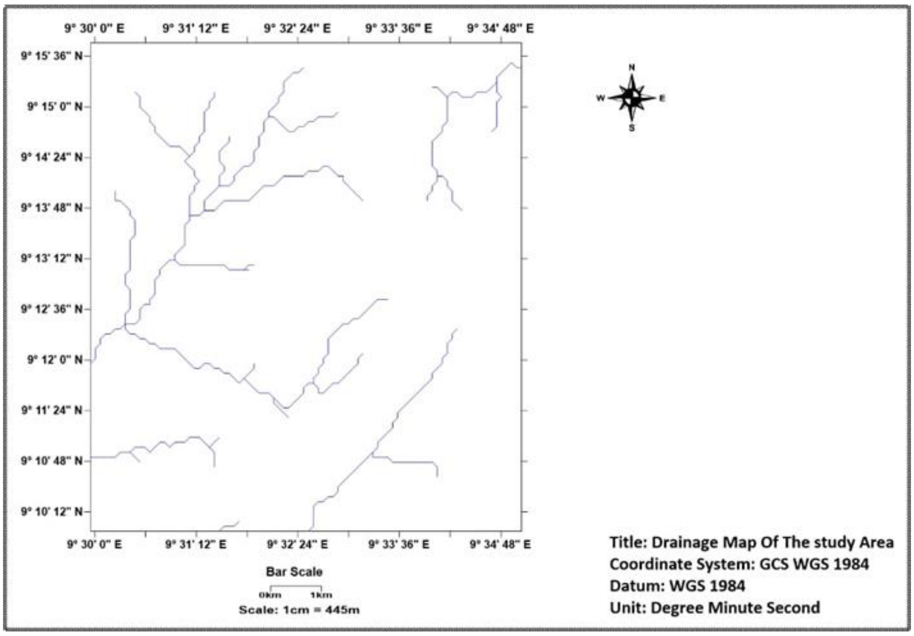

Figure 2: Map of the Study Area Showing the Dranage Pattern

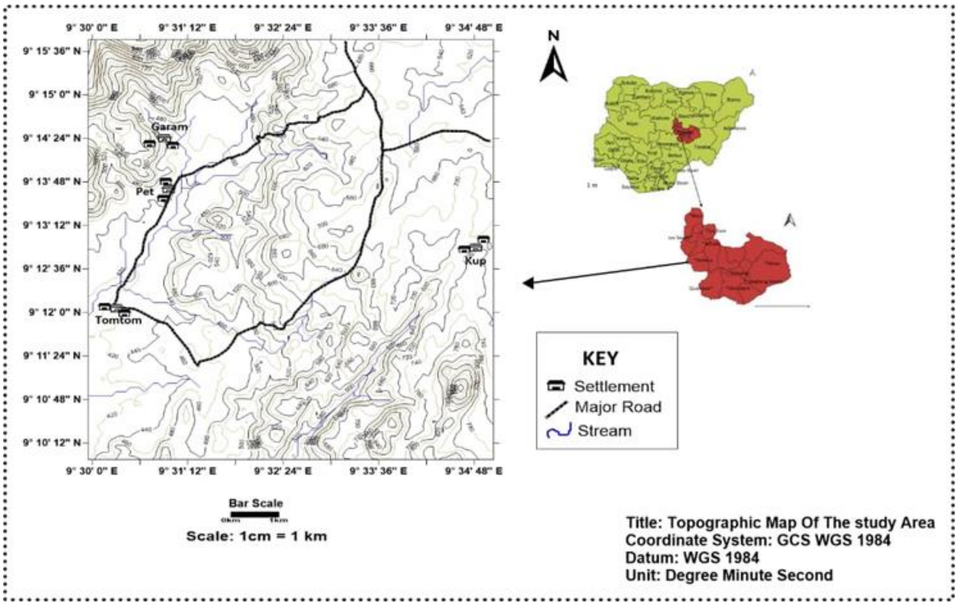

Figure 3: The Map of the Study Area Showing the Location and Accessible Road

1.2 GEOLOGIC SETTINGS

The study area falls within the region dominated by crystalline rocks including gneisses, migmatites, and Meta sediments of Precambrian age. The major rock unit of the area includes granite gneiss, migmatitic gneiss, and diorite. Others include granites and pegmatite. Migmatite Gneiss is the major rock unit and mostly intruded by Granitoids of the Older Granite suites (granodiorites, diorites) during the Pan African orogeny (600±150My). Available age data, Ekwueme, (2003) indicates that Nigerian Basement Complex is mainly of Proterozoic age and has been involved in at least two orogenic events. During the first event, the Eburnean orogeny (1950±250Ma) pre-existing ancient sediments and volcanics were subjected to wide spread migmatization and granitization. There was also local mobilisation and intrusion of granite. Rocks formed during this ancient granitic cycle are represented by Gneisses, Quartzites, schists, and amphibolites. These rocks constituted the bulk of the migmatite Gneiss Complex MGC. The second orogeny, known as the Pan African orogeny (600±150Ma) is characterized by local mobilisation, migmatization and intrusion of granites, known as the Older Granites (Figure 4).

The Jos Bauchi transects, situated at the east of the main terrane boundaries, and includes mostly gneisses and anatexite of Meta sedimentary origin. The depositional age of the sediments are poorly constrained. No basement - covered relationship has been identified. U-Pb zircon ages on syn-kinematic to late kinematic plutons from the Jos-Bauchi area suggest that the Pan African tectono-thermal events took place between 638-3 and 595-7 Ma (Dada, 1989; Ferre, & Caby, 2006) Another U-Pb monazite age from the studies yield an age of 618-10Ma (Dada et al, 1993).

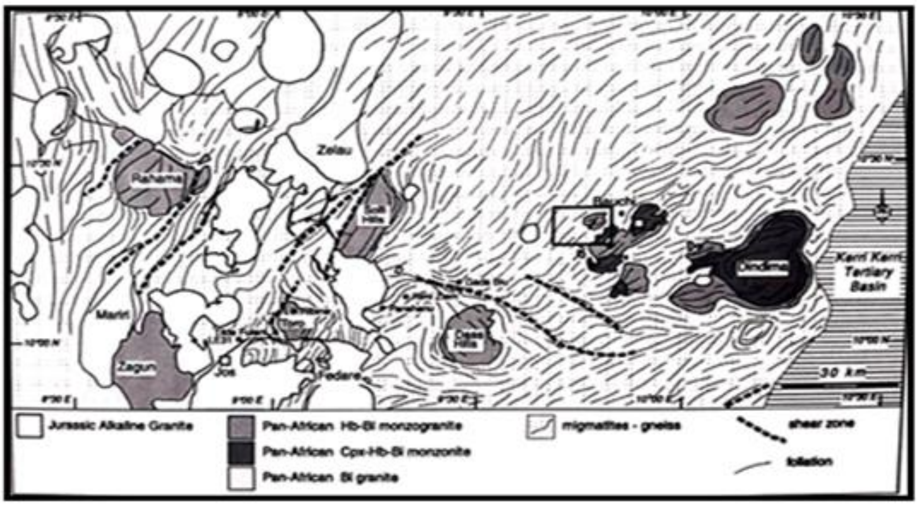

Figure 4: Geologic map of Jos-Bauchi area. Foliations compiled from field data, SLAR images and previous maps
Source: Wright, (1971)

2.1 MATERIAL AND METHODS

2.3 Fieldwork

The field work commenced with a reconnaissance survey of the study area to become familiar with the environment and to take notes of the outcrops, settlement, drainage pattern, accessibility, inhabitants, and land use. This was followed by a detailed field work which involves geological mapping and sample collection.

2.4 Geological Mapping

Topographic map of the study area was acquired and carefully examined, before a portion selected for the research purposes. The portion then was enlarged to the scale of 1:25,000, for easy visibility and maneuver at the field. During the course of mapping, elevation readings are recorded in the field notebook. The systematic methods of mapping along with profiles from one outcrop to another, taking note of the river channels that revealed subsurface lithologies, getting up the ridges and hills, sampling fresh rock units, carefully observation to structures such as dykes, veins, joints, at each location with the coordinates using GPS and labeled permanent marker. Megascopic descriptions of each rock sample (i.e., textures, color, and composition) in hand specimen observed using hand lens and field labeled were designated to rock samples accordingly, Figure 5.

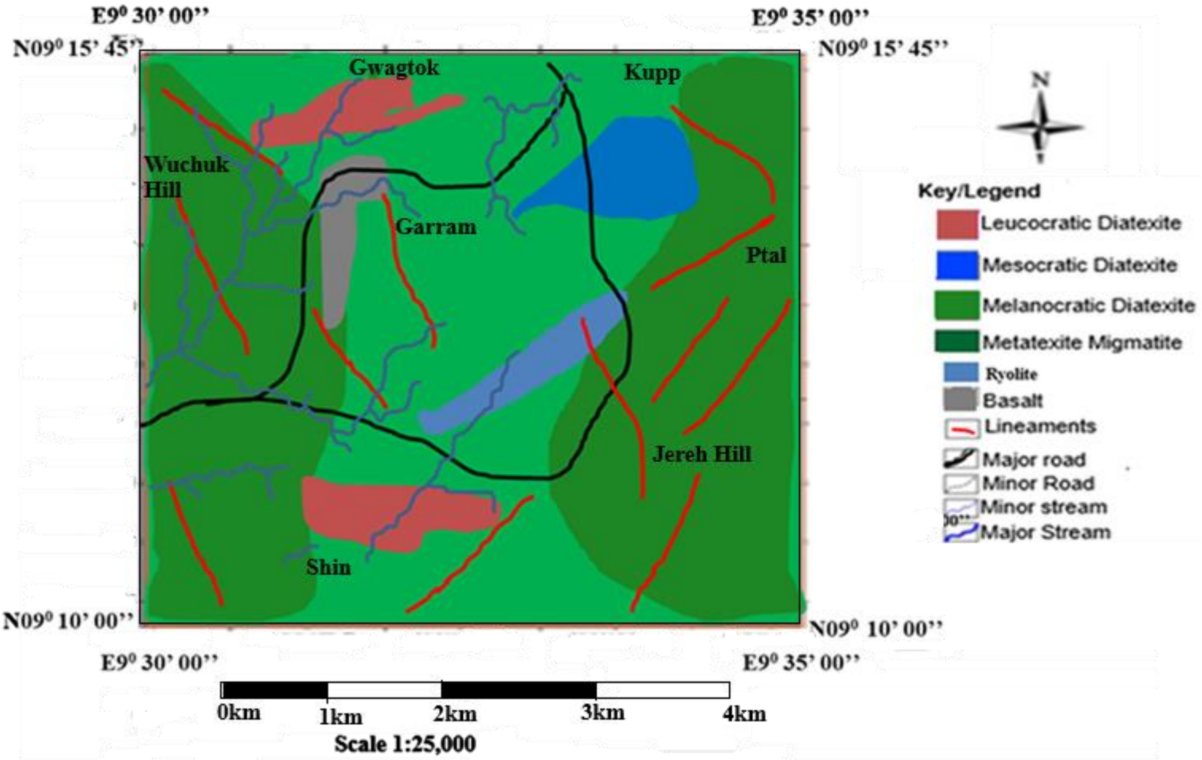

Figure 5: The Geologic Map of the Study Area

The geology of the area was stated according to the information obtained from the different rock types in the field, viz, Ryolite, Basalt, Metatexites, and Diatexites rocks (Leucocratic, Melanocratic, and Mesocratic) Figure 25. The rocks are different elevation and composition, their morphology and petrography revealed the orogenic episode that acted upon them, thought to be complicated environment.

2.4 Samples Collection

Samples of fresh rock units were taken at each location with assigned coordinate readings. The First-Order division and the Second-Order division morphological classification of were used as the principal guidance. This technique was repeated for the throughout the sampling locations in the study area covering about twenty three different points. A total of thirty five different lithologic samples were collected, sorted and grouped into eight on the basis of morphology, from which suitable representative samples selected from the general population, and eleven in total were designated for both petrography thin-section and whole rock geochemistry.

2.5 Laboratory Work

2.6 Petrography Thin-Section

Petrographic assessment involves the description of rock samples in thin-section under the Optical Microscope in the laboratory, with the aid of petrographic microscope, rock properties are view both in Plane Polarized Light (PPL), and Cross Polarized Light (XPL). The optical properties observed under PPL are color, pleochroism, relief, cleavage, shape, alteration, while the properties observed under XPL analysis are birefringence, interference color, extinction angle, and exsolution.

2.7 Geochemistry

The Geochemical analysis using Electron Diffuse X-ray Florescence (EDXRF) technique; commonly called XRF, was carried out at Nigerian Geological Survey Agency (NGSA), Kaduna State.

The Working Principle of X-ray Spectrometer (XRF, X-Ray Fluorescence) is a non-destructive technique that uses X-rays to excite the atoms in a sample, causing them to emit characteristic X-rays that are measured to determine the elemental composition. The sample is irradiated with a primary X-ray beam, which ejects inner-shell electrons, leading to the emission of characteristic X-rays. It has several advantages: Fast and non-destructive analysis, Multi-element analysis capability, High precision and accuracy, Low detection limits (ppm-ppb range), Portable and handheld devices available for field analysis.

3.1 RESULTS AND DISCUSSIONS

Structural Lineaments in the study area

The study area lies within the Nigerian Basement Complex, a region characterized by migmatite-gneiss rocks formed during Precambrian tectonic events. The structural lineaments and their significant in such settings, synthesized from the research, Figures 6, 7.

1. Formation identified

Structural lineaments are linear or curvilinear geological features (e.g., faults, fractures, foliations) that reflect tectonic stress histories. In the study area, these structures often result from Pan-African orogenic events (~600–500 Ma), which caused intense deformation, metamorphism, and partial melting.

2. Foliation and Joints: Migmatites in southwestern Nigeria exhibit N-S to NNE-SSW trending foliations (NNE98SSW; Elevation 414m), indicative of compressional stresses during crustal shortening.

3. Fault Systems: The study area revealed NE-SW and E-W trending fractures aligned with migmatite boundaries (JJ-1A, JJ-1B; Trending direction, N20E; Elevation, 431m), inferred as channels for heat leaching during metamorphism.

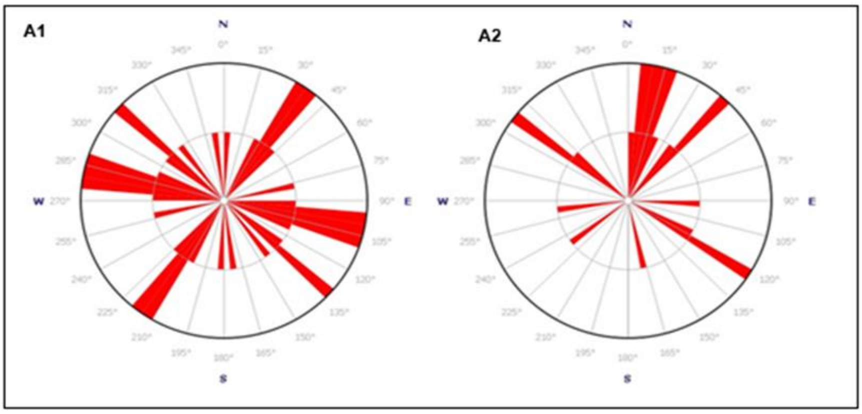

Figure 6: The Structural Rose Diagram mapped in the study area; A1=The Structural Strike, A2=The structural Trend

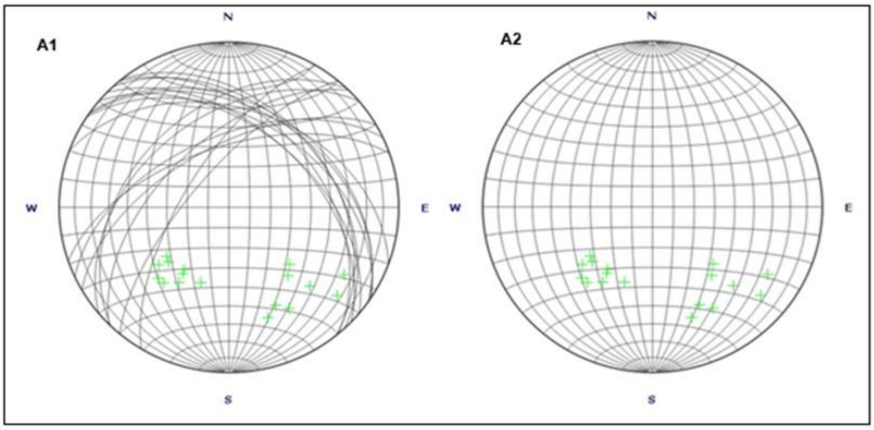

Figure 7: The Stereographic Presentation of Structural Features in the study area; A1=S-pole diagram and A2=Beta Diagram

3.2 Physical and Petrographic Properties & Geomorphology of Rhyolite, Basalt, Massive Quartzite, Metatexite Migmatites and Diatexite Migmatites

In the study area, the Massive Quartzite, the Ryolite and the Basalt are formed in the later orogenic episodes. Migmatites, which form under high-grade metamorphic conditions and partial melting (anataxis), can be classified into Metatexites and dominant Diatexites (leucocratic, melanocratic, and mesocratic), (Table 1) based on their mineral composition and color index. These terms describe the relative proportions of light-colored (felsic) and dark-colored (mafic) minerals in the migmatites rock.

In thin section petrography from the study area, quartz, mica, and feldspar exhibit distinct properties under plane-polarized light (**PPL**) and cross-polarized light (**XPL**), which help in their identification. Moreso, the petrographic properties and their inferred Geological significance mineral assemblage described—microcline, Ca-plagioclase, K-plagioclase, biotite, garnet, cordierite, orthopyroxene, hornblende, and olivine—indicates a high-grade metamorphic environment typical of migmatites (Plates 1,2,3,4,5,6).

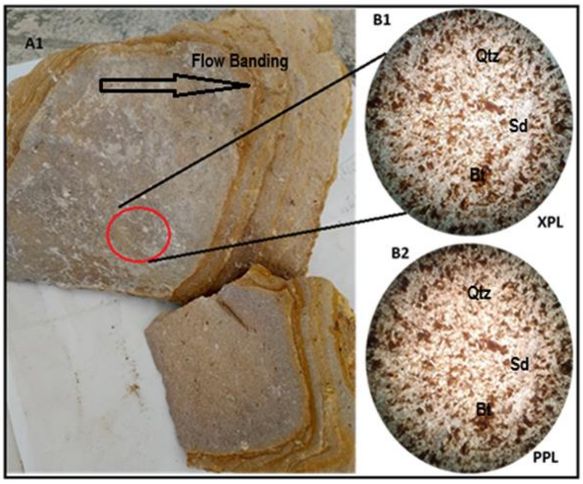

Plate 1: (A1) Hand Sample of Ryolite Rock of the Study Area, (B1) Photomicrograph under Cross Polarized-Light, XPL, (B2) Photomicrograph under Plane Polarized-Light, PPL. Qtz=Quartz, Bt=Biotite, Sd=Sanidine

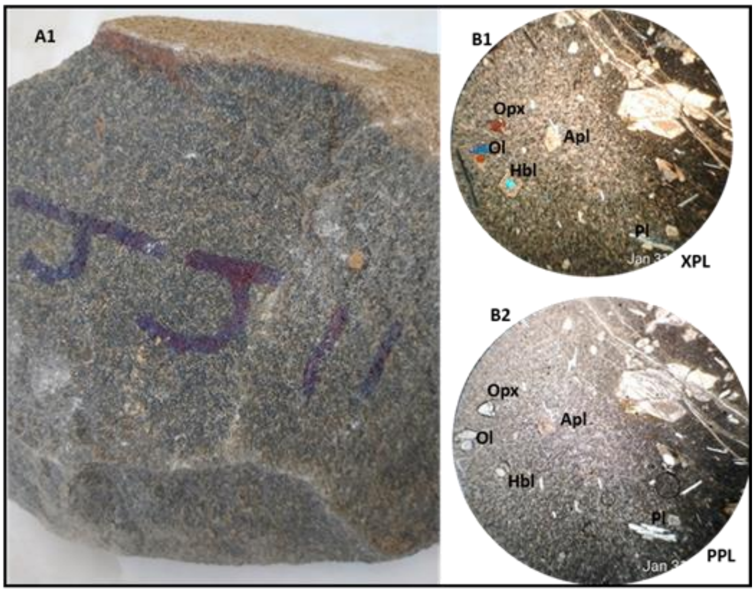

Plate 2: (A1) Hand Sample of Basaltic Rock of the Study Area, (B1) Photomicrograph under Cross Polarized-Light, XPL, (B2) Photomicrograph under Plane Polarized-Light, PPL. Pl=Plagioclase, Ol=Olivine, Hbl=Honblende, Opx=Orthopyroxene.

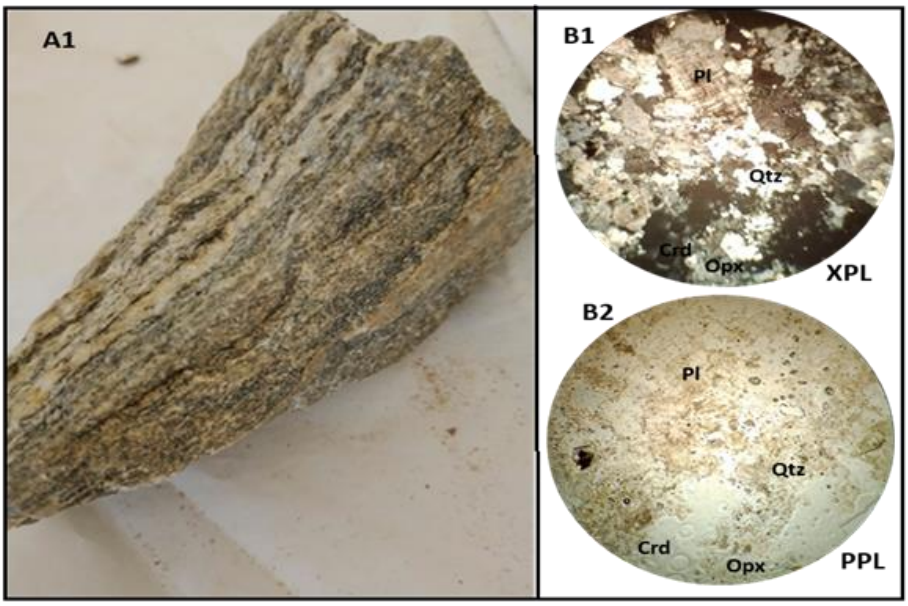

Plate 3: (A1) Hand Sample of Metatexite Migmatite Rock of the Study Area, (B1) Photomicrograph under Cross Polarized-Light, XPL, (B2) Photomicrograph under Plane Polarized-Light, PPL. Pl=Plagioclase, Opx=Orthopyroxene, Qtz=Quartz.

Table 1: Comparison of Leucocratic, Melanocratic, and Mesocratic Diatexites

Property	**Leucocratic Diatexite**	**Melanocratic Diatexite**	**Mesocratic Diatexite**
Color Index	<25% mafic minerals	>50% mafic minerals	30-50% mafic minerals
Appearance	Light-colored, granitic	Dark-colored, mafic-rich	Intermediate, balanced appearance
Felsic Minerals	Abundant (quartz, feldspar)	Minimal	Moderate
Mafic Minerals	Sparse (biotite)	Dominant (biotite, hornblende, garnet)	Intermediate (biotite, garnet)
Texture	Granoblastic, abundant leucosome	Residuum-dominated	Heterogeneous, mixed texture
Melt Content	High	Low	Moderate
Protolith	Felsic rocks (granites, tonalites)	Mafic rocks (amphibolites, gneisses)	Intermediate rocks
Metamorphic Grade	High-grade (partial melting prominent)	High-grade (mafic residue retained)	Intermediate to high-grade

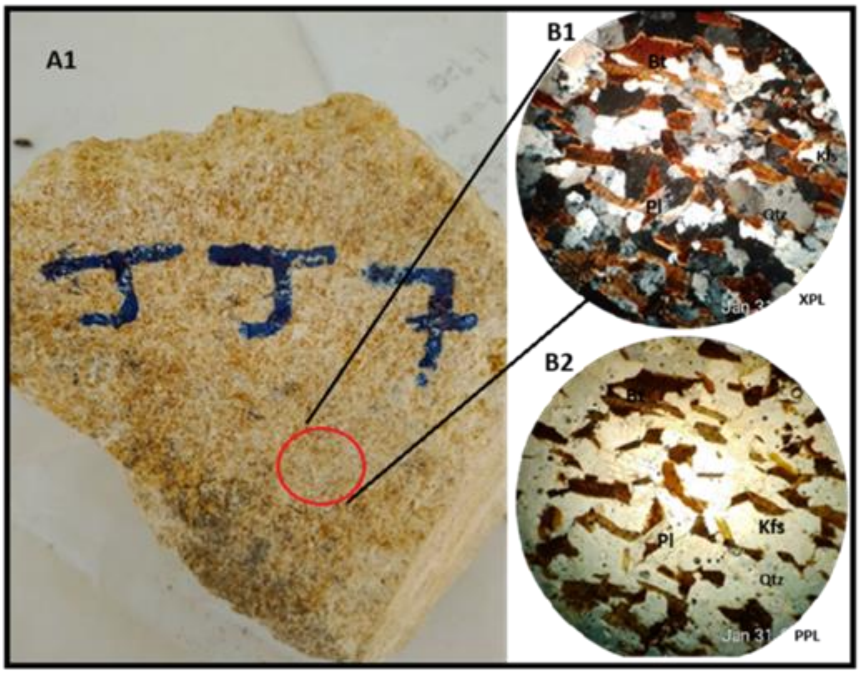

Plate 4: (A1) Hand Sample of Leucocratic Diatexites Rock of the Study Area, (B1) Photomicrograph under Cross Polarized-Light, XPL, (B2) Photomicrograph under Plane Polarized-Light, PPL. Pl=Plagioclase, Qtz=Quartz, Kfs=K-feldspar, Bt=Biotite.

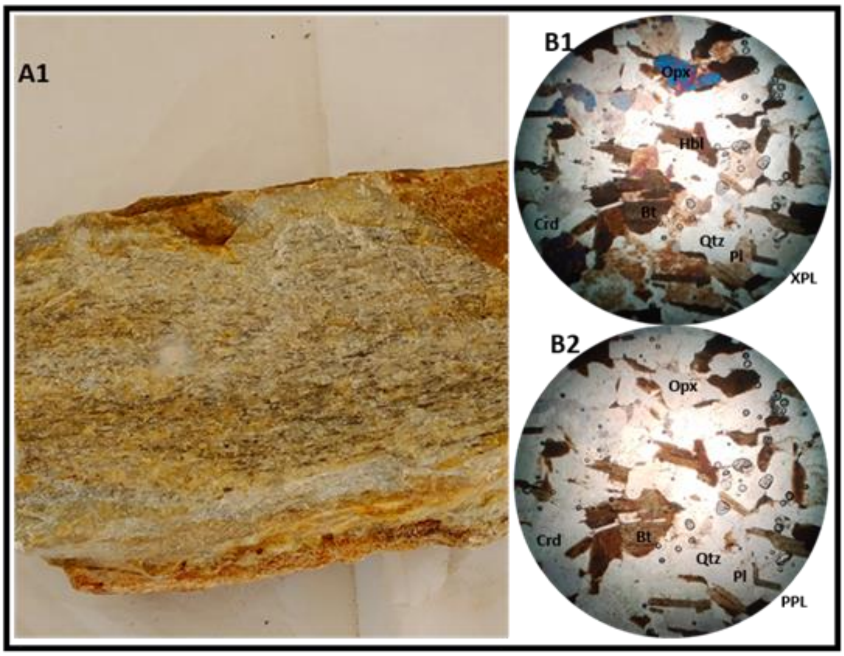

Plate 5: (A1) Hand Sample of Melanocratic Diatexites Rock of the Study Area, (B1) Photomicrograph under Cross Polarized-Light, XPL, (B2) Photomicrograph under Plane Polarized-Light, PPL. Pl=Plagioclase, Ol=Olivine, Hbl=Honblende, Opx=Orthopyroxene.

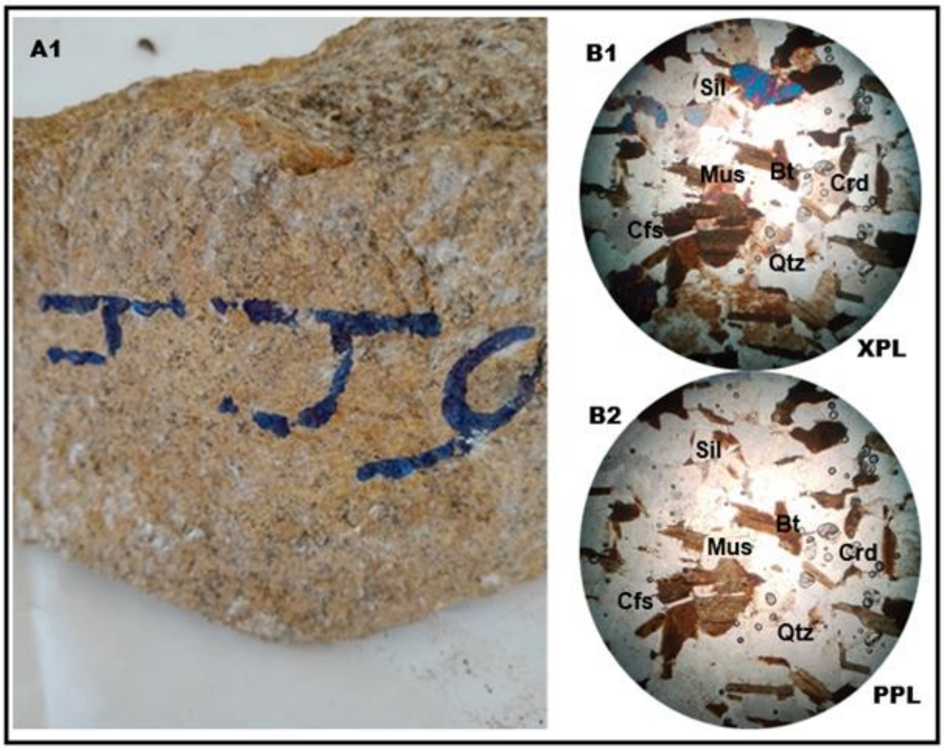

Plate 6: (A1) Hand Sample of Mesocratic Diatexites Rock of the Study Area, (B1) Photomicrograph under Cross Polarized-Light, XPL, (B2) Photomicrograph under Plane Polarized-Light, PPL. Pl=Plagioclase, Crd=Cordierite, Mus=Muscovite, Sil=Silimanite.

3.3 GEOCHEMICAL COMPOSITIONS

The major elements composition shows that the rocks are characterized by high SiO2 in the range of 51.04 - 97.34 wt % with an average of 78.74wt%, JJ-8 and FeO_3 and Al_2O_3 enrichment are pronounced in the rock samples showing average of 17.76 wt% (JJ-11), 19.90wt% (JJ-4) and 19.91 wt% (JJ-4), 20.33 wt% (JJ-11) respectively. In addition, Na_2O remains consistently less than K_2O in most of the samples. The rocks are generally depleted in, MgO, and MnO. The diatexite migmatite rock in this study was found to be originated from sedimentary protoliths of various compositions. Fractional crystallization which encompasses the formation of plagioclase and biotite as indicated by the negative correlation between the values of SiO_2 versus CaO, MgO, Na_2O, Al_2O_3 and Fe_2O_3, are in congruent with the field and petrographic proof of plagioclase and biotite abundance. The melting of the protolith occurred under hydrous conditions as indicated by the presence of hydrous minerals like biotite. Future research should focus on the relationship between these structural features and potential mineral resources, Figure 8.

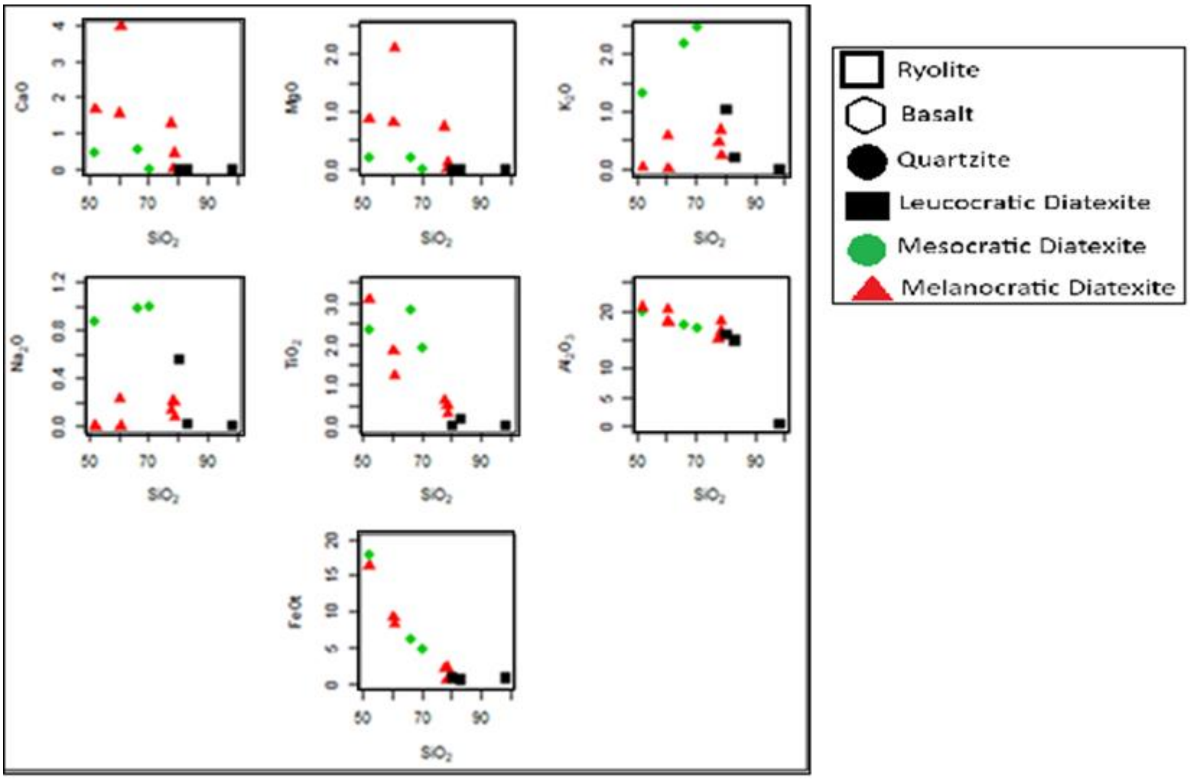

Figure 8: Variation Diagram of the Major Elements against Silica

3.4 Tectonic History of the Study Area: Garram Migmatites

In the study area, Garram migmatites, Harker diagrams revealed in Figures 9 and 10:

Metatexite: Low SiO_2 (60-66%), high MgO (2.1%) and FeO (10.13%), indicating a residual, unmelted protolith.

Diatexites: High SiO_2 (70–79%) and depleted MgO/CaO, consistent with melt-dominated layers formed via partial melting.

Tectonic Discrimination: Plots of Na_2O vs. K_2O aligned with S-type granite signatures, pointing to a metasedimentary origin (Figure 9, 10).

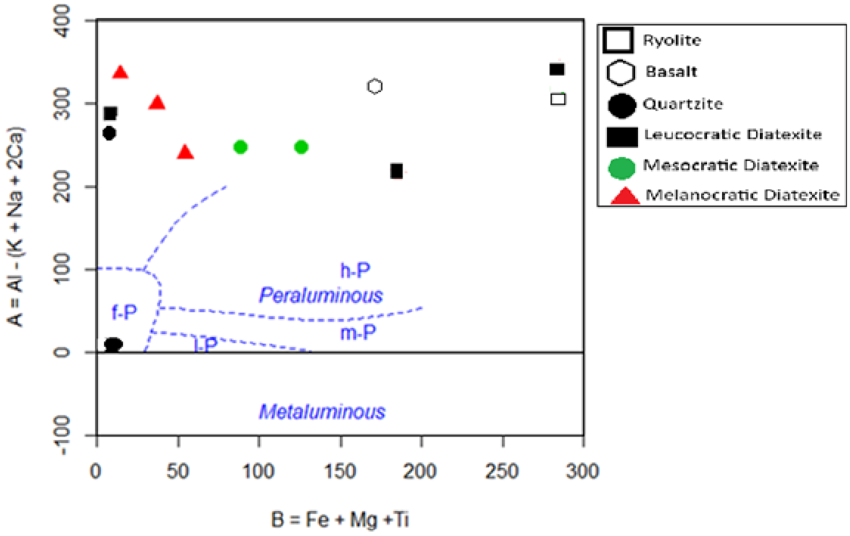

Figure 9: B-A diagram proposed by Debon and Le Fort (1983) modified by Villaseca et al, (1998) with fields for various paraluminous rock types. Abbreviations: l-P = low paraluminous; m-P = moderate paraluminous; h-P = high paraluminous; f-P = felsic paraluminous.

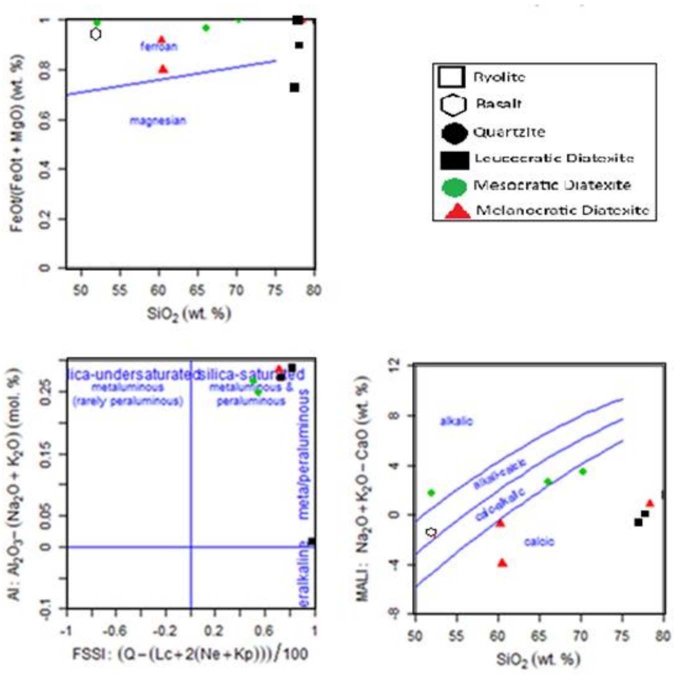

Figure 10: Classification Scheme of Granite Tectonic Discrimination

3.5 Provenance Reconstructions; the Emplacement and Evolution of Migmatites

Various models were used to determine the ancestry of rocks in the study area. Ternary diagram of Al_2O_3/(FeOt + MgO) - 3CaO - 5(K2O/Na_2O) on which the composition of rocks in the study area is plotted to know the source of the rock. The Diatexites shows the signature of meta-sediments the one Metatexites and Diatexites indicates the signature of Tonalitic source (Figure 11).

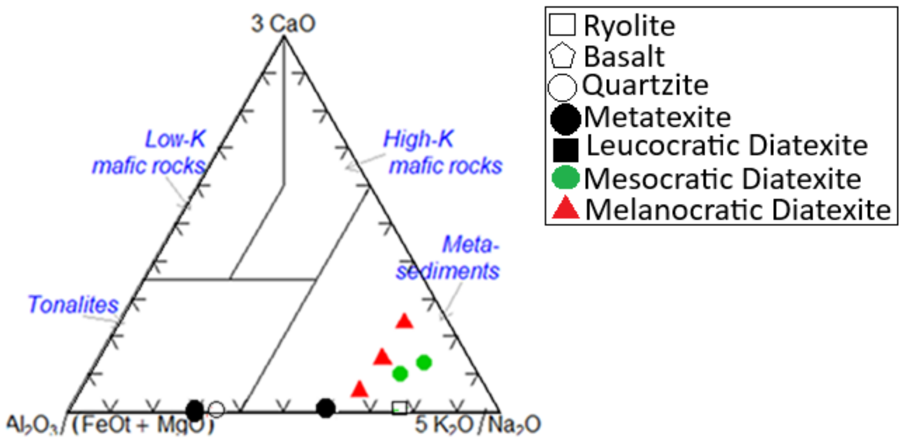

Figure 11: Ternary diagram plotted for $Al_2O_3/(FeOt + MgO)$ - 3CaO - 5(K2O/Na_2O)

3.6 Tectonic discrimination

The tectonic discrimination of migmatite rocks in the study area, primarily inferred through geochemical, mineralogical, and structural analyses linked to the Pan-African orogeny and regional metamorphic events;

1. Geochemical Signatures and Tectonic Classification

Major Element Trends: Migmatites in the region exhibit 'negative correlations' between SiO_2 and MgO, CaO, TiO_2, and FeO, alongside 'positive correlations' with Na_2O and K_2O. These trends align with fractional crystallization processes and magma differentiation, typical of 'syn-collisional and volcanic arc settings'.

Alumina Saturation Index (ASI): The migmatites range from 'mildly metaluminous to strongly peraluminous', indicating S-type granitic affinities derived from metasedimentary protoliths. This peraluminous nature is linked to crustal melting during collisional tectonics.

Harker and Tectonic Discrimination Diagrams:

Plots such as the Frost diagram classify migmatites into both 'ferroan and magnesian fields', reflecting variable crustal sources and metamorphic conditions.

Modified Alkali-Lime Index (MALI) trends suggest a transition from 'calc-alkalic to alkali-calcic series', indicative of polygenetic magmatism involving partial melting and fractional crystallization.

4. Tectonic Environment Discrimination

Syn-Collisional Signatures: Geochemical data (e.g., high Rb, low Nb-Ti) and tectonic diagrams (e.g., Rb vs. Y+Nb) classify the migmatites as 'Volcanic Arc Granites', formed during continental crustal thickening, [5] (Figure 12, 13).

Post-Orogenic Overprints: High temperature trace element enrichment (e.g., LILEs like Ba in K-feldspar and Mica, Sr) and alkali-calcic trends in diatexites suggest a post-orogenic magmatism, possibly linked to delamination or asthenospheric upwelling, R1-R2, (Figure 12, 13).

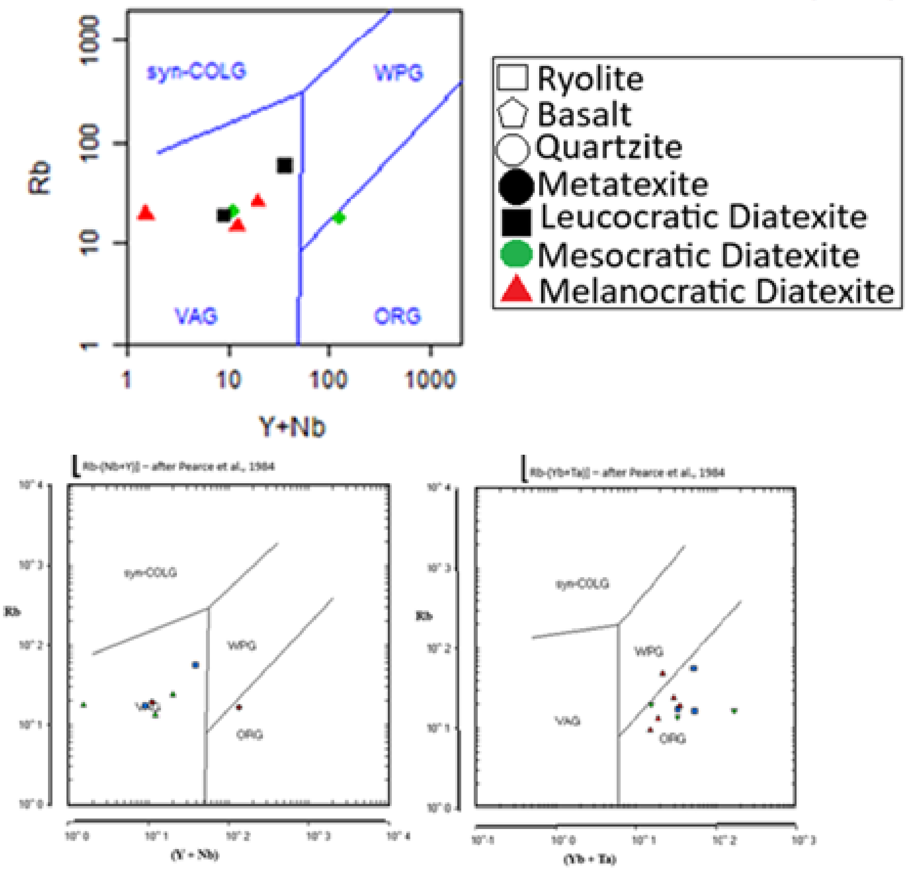

Figure 12: Discrimmnation Diagram for Geotectonic Environment by [5]
Abbreviation: lORG – Ocean Ridge Granites; VAG – Volcanic Arc Granites: WPG – Within Plate Granites; syn-COLG – syn-Collisional Granites

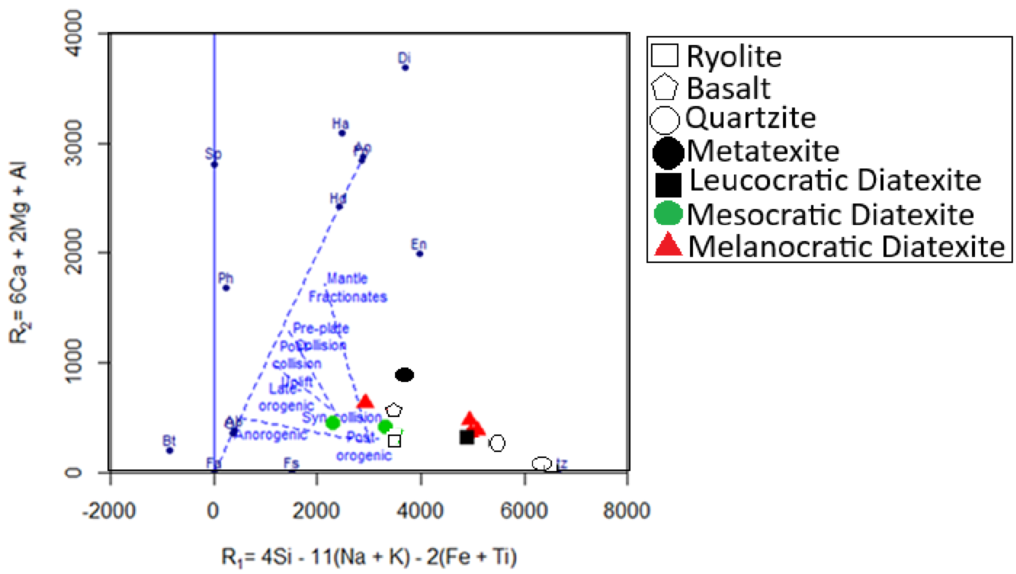

Figure 13: Discrimination Diagram which distinguished between granites from fractional mantle, pre-orogenic granites, post-orogenic uplift granites, late-orogenic granites, anorogenic granites, syn-collisional granites.

3.7 Geochemical Processes

a. Fractionation: The separation of elements during magmatic differentiation, i.e., a steep Light Rare Earth Element (LREE, e.g., La, Ce) to Heavy Rare Earth Element (HREE, e.g., Yb, Lu) slope indicates strong fractionation, typical of melts derived from garnet-rich sources where HREE are retained and a basalt with enriched La/Yb but depleted Yb indicates partial melting in the presence of residual garnet (Figure 14). Interpretation suggests a source in the deep mantle where garnet is stable.

b. Partial Melting: This determined the degree of melting and source characteristics. Higher enrichment of incompatible elements (e.g., Th, U, and Ba in Samples JJ-1A, JJ-1B, and JJ-6) in melts indicates a low degree of partial melting (Figure 14). Interpretation shows multi-element (spider) diagrams can differentiate between low-degree (enrichment in LREE) melting.

c. Crystallization: Fractional crystallization of minerals from a melt. A negative Eu (Samples JJ-6, JJ-11) anomaly in granitic rocks reflects plagioclase removal during crystallization since Eu substitutes into plagioclase. The interpretation indicates extensive fractional crystallization in the magmatic system (Figure 14).

2. Source Composition and Crustal Contributions; Crustal-derived sources based on trace element patterns, the enrichment in large-ion lithophile elements (LILE) like Rb, K, and Sr, with the depletion in high-field strength elements (HFSE) like Nb, Ta, and Ti. The interpretation suggests recycling of crustal material or assimilation of crustal components into magmas.

3. Tectonic Settings; Different tectonic settings generate distinct multi-element (spider) diagram patterns. Subduction zones shows enrichment of fluid-mobile elements (LILEs) high Ba, Rb, and Sr with negative Nb-Ta and Ti anomalies (Figure 14) and depletion of HFSEs. The interpretation Indicates metasomatism of the mantle wedge by fluids released from the subducting slab.

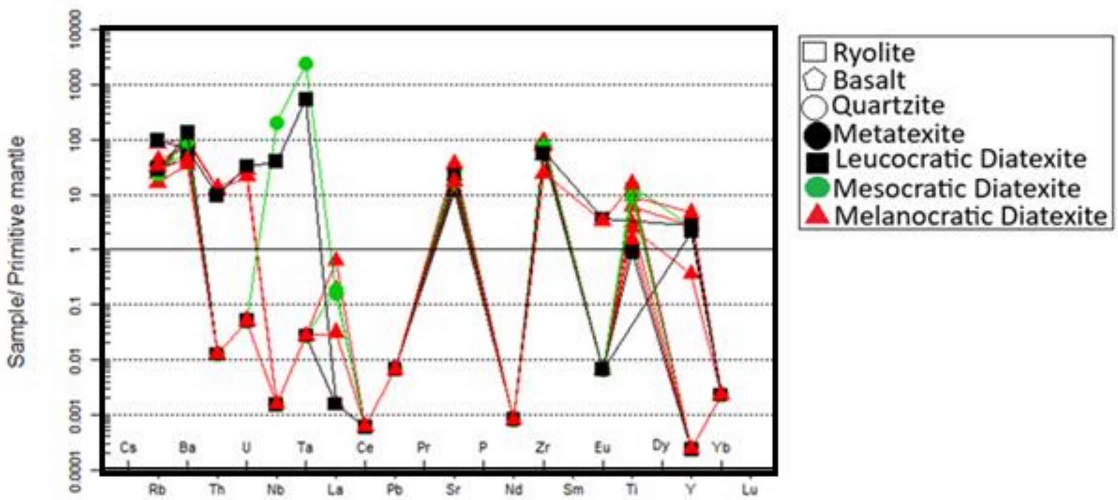

Figure 14: Chondrite-Normalised incompatible element pattern for different rock units

3.8 Critical Minerals and Resources

➢ **Rare Metals (Sn, Nb, Ta):** Migmatite-hosted pegmatites contain **cassiterite (SnO_2)** and **columbite-tantalite (Nb-Ta)**, critical for electronics and green technologies. Hydrothermal albitization may concentrate Sn in leucosomes, as seen in the related province Wamba pegmatites of northcentral Nigeria.

- **Lithium (Li) Potential: Spodumene** and **lepidolite** in zoned pegmatites suggest Li enrichment, though direct evidence in the study area requires further exploration.
- **Industrial Minerals: Quartz** and **feldspar** from leucosomes are used in ceramics, glass, and construction. **Muscovite** serves as an insulator in electrical industries.

Gemstones: Beryl (and **tourmaline)** occurs in pegmatitic zones, though their commercial viability in this area remains underexplored.

4.1 CONCLUSIONS

The results deduced the tectonic setting to be orogenic continental arc, continental collision and transitional post orogenic uplifts, with meta aluminous to peraluminous composition S-type granites. This give rise to migmatites & leucogranites, and associate minerals of biotites, muscovites, hornblende, garnet, cordiarites, associated with basalt and rhyolite volcanism.

The rock evolutions continental collisional granite formed by partial melting of recycled crustal material. The continental arc granite formed by partial melting or mantle-derived mafic underplate plus crustal contribution i.e., subduction energy; transfer of fluids and dissolved species from slab to wedge, melting wedge, transfer of heat upward. The post-orogenic granite was formed from the partial melting of lower crust plus mantle and mid-crust contribution by crustal heat plus mantle heat (rising asthenosphere plus magma).

The study area depicted a complex metamorphic terrain characterized by amphibolite to granulite facies of high grade metamorphism.

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CONFLICT OF INTEREST

There is no conflict of interest in this research work in what so ever way

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