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Geological and Petrographic Evaluation of the Rocks in Zaranda Area, Sheet 149 NW Northeastern Nigeria

Umar Lawan Dalorima¹, Ahmed Isah Haruna², Hamman Ishaku Kamale^{3*}, Abubakar Sadiq Maigari², Timorthy Peter Bata², Abdulmajid Isa Jibrin², Adamu Mukhtar Hassan²

ABSTRACT

The Zaranda area (Sheet 149 NW, Bauchi) lies on the eastern flank of the Nigerian Younger Granite Province and exhibits a complex lithological assemblage comprising migmatite, granodiorite, pegmatite, biotite granite, and rhyolite. Field geological mapping and petrographic analysis of 75 representative samples reveal that stromatic metatexite, banded orthogneiss, diatexite and nebulite form the predominant basement rocks. Petrographically, the migmatites are characterized by quartz with undulous extinction, K-feldspar, plagioclase with albite twinning, and mafic minerals such as biotite, chlorite, orthopyroxene and sillimanite, indicative of medium to high-grade metamorphism. Banded orthogneiss is typified by alternating felsic and mafic mineral bands and mineralogically consists of clinopyroxene and sillimanite. The upgraded schist has abundant muscovite and biotite minerals, along with cordierite and pyroxene implying formation under high temperature metamorphic conditions. Pegmatites, occurring as dykes, sills and lodes, contain microcline, quartz, myrmekitic texture, and sericitization halos, with some hosting lithium-bearing spodumene and quartz veins suggestive of tantalum-tin mineralization. The biotite granite, forming ring dyke around Zaranda Hill, and cross-cutting rhyolite dykes reflect anorogenic magmatism linked to Mesozoic extensional tectonics. These geological and petrographic features collectively point to a polyphase tectono-magmatic evolution and highlight the rare-metal mineralization potential of the Zaranda Complex.

Keywords: Zaranda, Younger Granite, Migmatite, Pegmatite, Petrography, Rare-metal mineralization, Nigeria.

1. INTRODUCTION

The Zaranda area is located west of Bauchi in northeastern Nigeria and lies within the eastern flank of the Nigerian Younger Granite Province. Geographically, it falls within sheet 149 NW, bounded by latitudes 10° 15' N to 10° 30' N and longitudes 9°

30' E to 9° 45' E. the area is part of Toro Local Government of Bauchi State and is accessible via the Bauchi-Jos highway, with additional access provided by footpaths, lateritic roads, and cattle tracks (Fig. 1).

The Nigerian Younger Granite Province covers an estimated area of about 22,000 Km², from the southernmost Afu complex in Jos Plateau to the northernmost Shira complex in Bauchi State (Obaje, 2009). The province is characterized by high-level anorogenic magmatic intrusions which in most places are typified by crescent or ring-shaped outcrops of diverse lithologies. The area remains the most important sources of tin-tantalite-niobium and rare-metal mineralization (Batchelor and Bowden, 1985; Okonkwo, 2012). Kinnaird et al. (1985) reported that more than 50 Younger Granite Ring Complexes occur in Nigeria with varying dimensions from 2 to 25 km in diameter, while other Younger Granite massifs exceeds 1000 km² in areal extent.

The Zaranda Ring Complex represents a prominent structural and geomorphological feature in the study area (Fig. 2). It is one of the many Younger Granite complexes known for their classic ring structures, anorogenic characteristics, and associated economic mineralization (Kayode, 2017; Ahmed et al., 2021). The objective of this study is to characterize the lithological units, structural patterns and mineralogical assemblages of the Zaranda area, providing insight into the geological evolution and resource potential of the region.

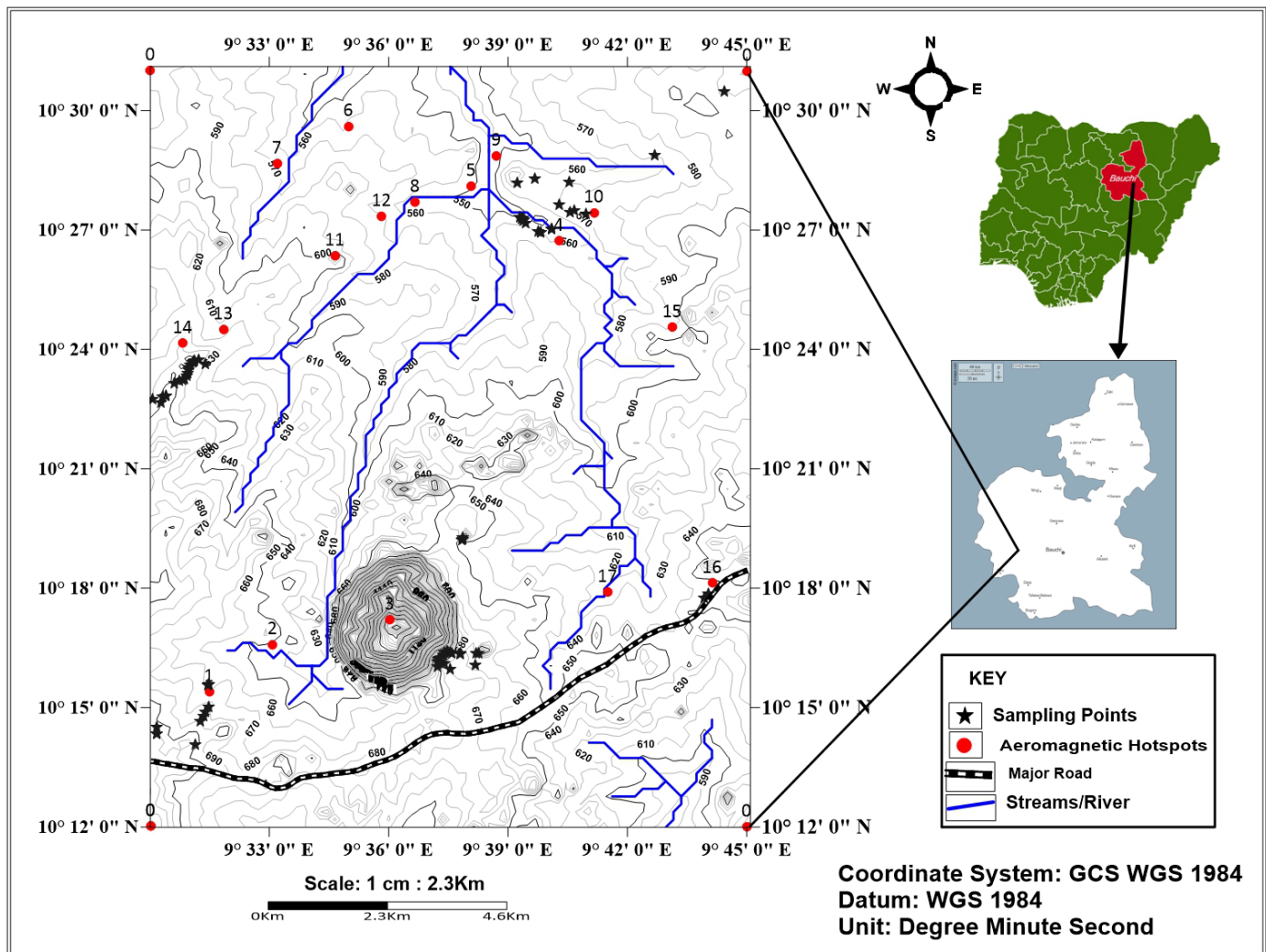


Figure 1. Topographic map of Zaranda area showing the study area and sampling point

Geological Setting

The Nigerian Younger Granite are a series of Mesozoic, epizonal, anorogenic intrusions emplaced predominantly in a north-south belt across central Nigeria (Fig. 3). These complexes developed along a tectonic axis that coincides with the rifting and separation of the African and South American plates during the opening of the south Atlantic Ocean (Badejoko, 1985; Badejoko, 1986). This tectonic

setting facilitated crustal extension and the formation of deep-seated fractures, providing conduits for magma emplacement (Ogunleye, 2006).

Petrologically, the Younger Granite complexes consist mainly of peralkaline and peraluminous granites, syenites, trachytes, and minor gabbros and dolerite. Rhyolites, ignimbrites, and tuffs are less commonly preserved (Pastor, 1984; Obaje, 2009). Imeokparia (1984) and Okonkwo (2012) noted that the ring complexes commonly exhibit multiphase ring-shaped intrusive events resulting from crustal anatexis and mantled-derived magmatism, evolving from early mafic to later felsic phases and emplaced within anorogenic (intraplate) tectonic settings.

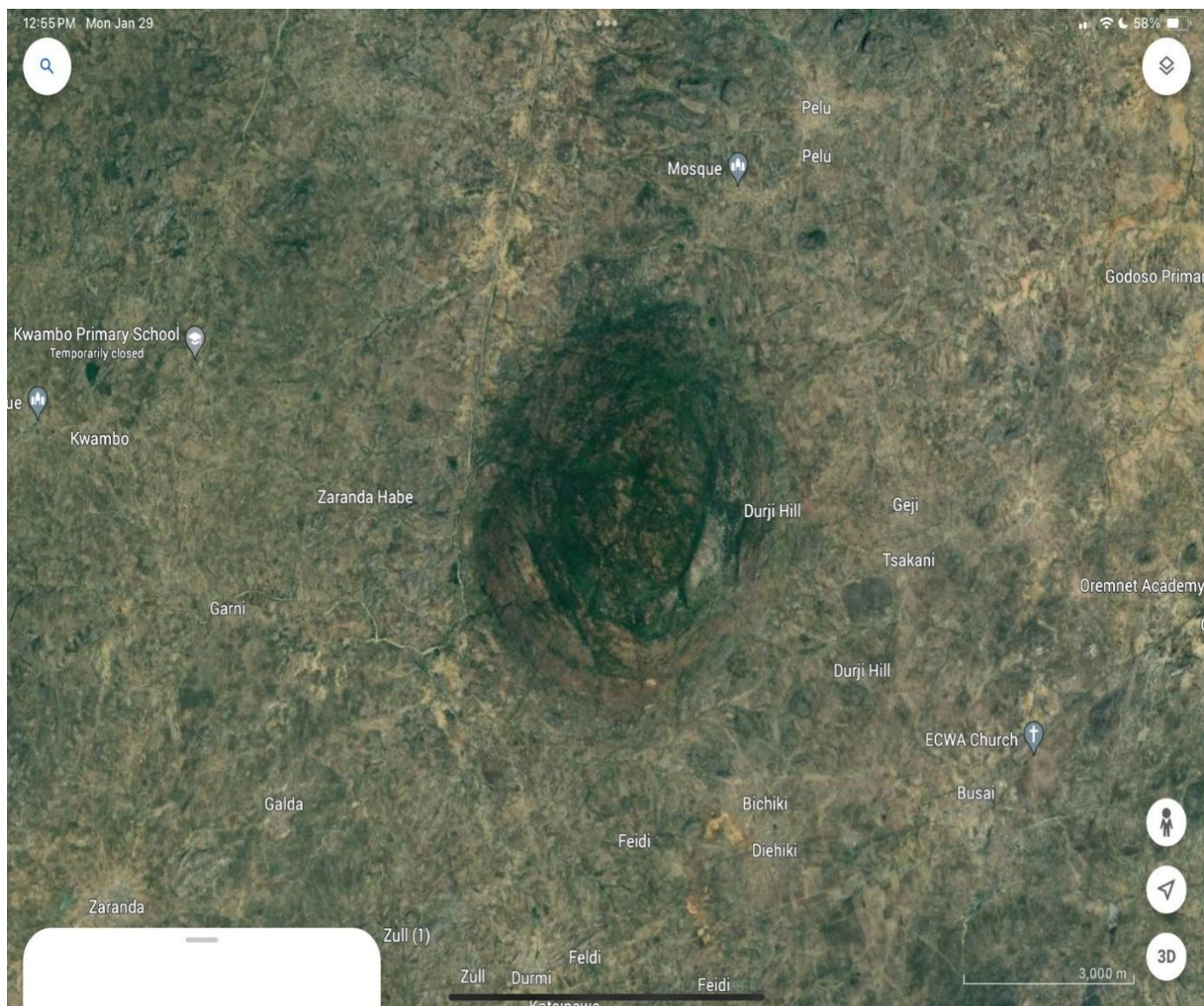


Figure 2. Satellite Image of the Zaranda Area (Google Earth, 2019)

2. MATERIALS AND METHODS

Overview

An extensive review of existing literature was first conducted to understand the regional geological context. This was followed by a reconnaissance survey of the Zaranda area to assess topographic and lithological features. Systematic geological field mapping and rock sampling were then carried out using standard field techniques. 75 samples were selected and subjected to thin-section preparation procedures and the prepared slides were investigated using polarizing microscope.

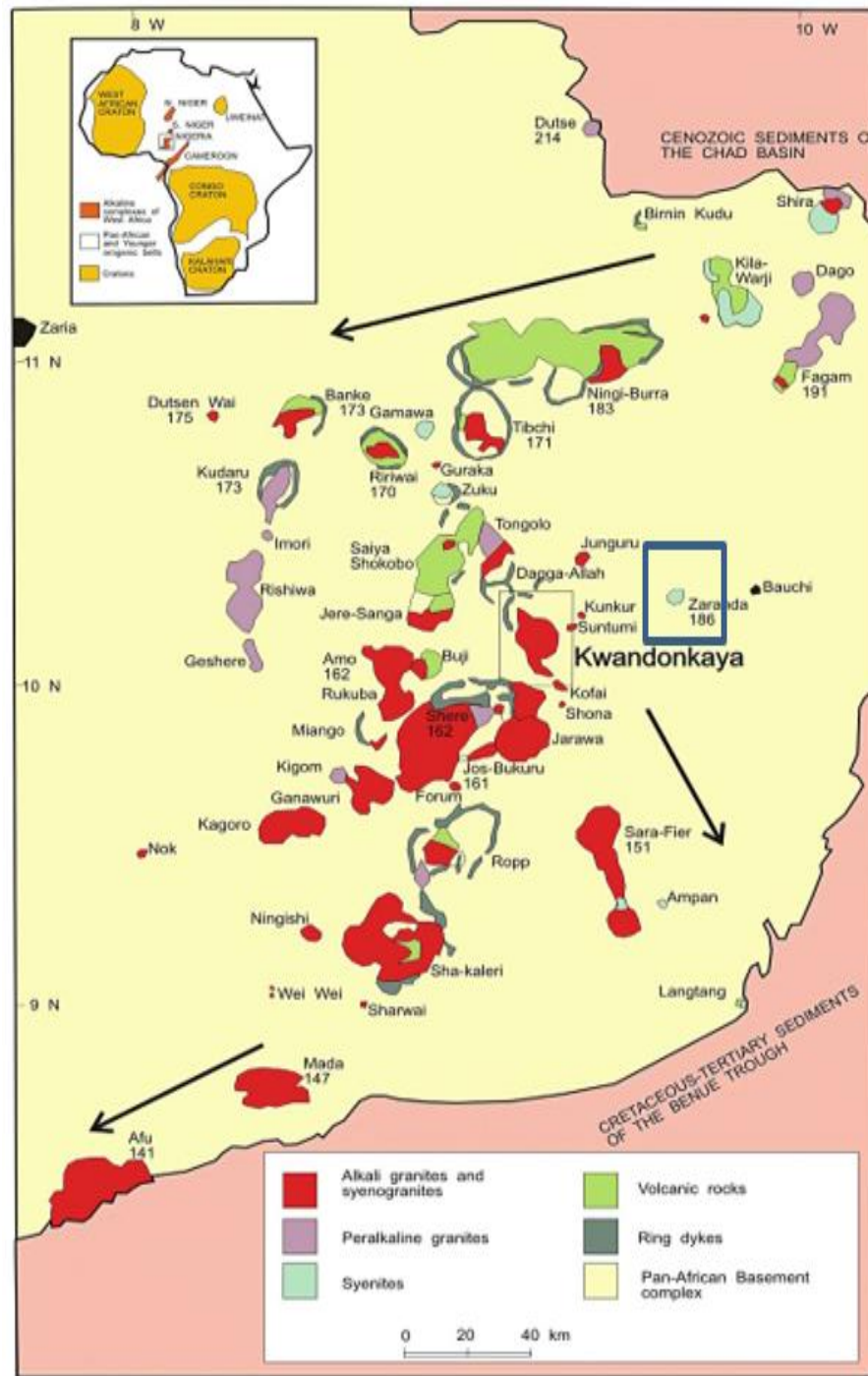


Figure 3. General geological setting of the Younger Granites showing the Study area (Ogunleye et al., 2006)

Materials and Methods

Mapping Instruments: Base map (Sheet 149 NW), Garmin Global Positioning System (GPS), hardcover notebook, pen, pencil, eraser, silver compass-clinometer, hand lens, digital camera, hard rock hammer, sample bags, and drone for aerial imagery. Laboratory Equipment: Thin section preparatory tools (cutting and grinding machines, Canada balsam, glass slides, polarizing microscope, fused glass bead preparation apparatus, razor blade, hot plate, abrasive powder, glass lap).

Reconnaissance Survey

A reconnaissance survey was undertaken to identify key lithological components and to define accessibility as well as selection of the best mapping technique. The google map image and the base map were employed in guiding the selection of traverse lines and sampling points.

Field Geological Mapping

Field mapping of the Zaranda area was conducted on a scale of 1: 50,000, covering approximately 255 Km². A total of 231 rock samples were collected from systematically selected outcrops. Sample locations were referenced using Garmin GPS device. Each sample was described in terms of texture, mineralogy, color and structural characteristics. Major geological structures, including fold, faults, joints and foliations, were recorded and photographed. Particular attention was given to structural relationships among the rock units.

Thin Section Analysis

Seventy-five representative samples were selected for petrographic analysis and prepared as thin sections in the Department of Applied Geology, Abubakar Tafawa Balewa University, Bauchi. These samples included migmatites (n=14), granodiorite (n=3), Pegmatites and associated host rocks (n=15), Pegmatite (n=14), 'Hot spot' lithologies (n=4), Biotite Granite (n=3), and Rhyolite (n=9). Petrographic studies were conducted under plane polarized light (PPL) and cross-polarized light (XPL), with photomicrographs documented for representative mineral textures.

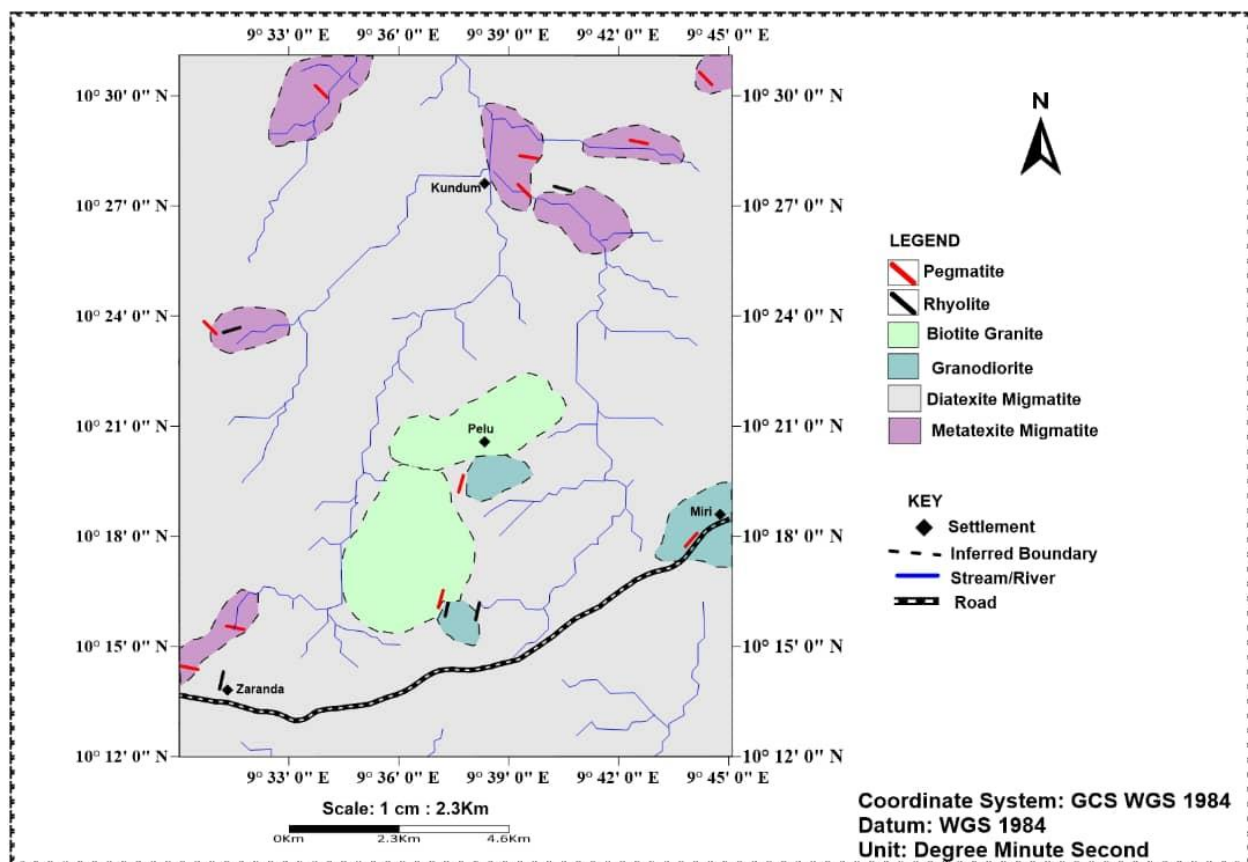


Figure 4. Geological map of the Zaranda area.

3. RESULTS

Field Geology and Petrography

The Zaranda area comprises predominantly migmatitic rocks that serves as the basement complex and host lithology (Fig.4). Igneous rocks in the area include coarse-medium-grained granodiorite (Older Granite Suite), fine-to medium-grained biotite granite (Younger

Granite Suite), pegmatites, quartz veins and rhyolitic volcanic rocks. Laterite capping is also observed. The lithological distribution is approximately: migmatite (~75%), granodiorite (~7%), biotite granite (~5%), pegmatite (~10%), and quartz veins and rhyolite (~2%).

Migmatite Complex

Migmatites dominate the study area and include stromatic metatexite, banded orthogneiss metatexite, diatexite migmatite and nebulitic migmatite.

Stromatic Metatexite: it occurs as low-lying, melanocratic, foliated and deformed rocks which in places appear ptygmatically folded with visible crenulation cleavage. Mineralogically, quartz, feldspars, biotite and hornblende are observable on hand specimen but quartz and feldspar are the dominant minerals while biotite and hornblende occur in minor amount. The abundance of silica and presence of interior hollows in the stromatic metatexite indicated that in-situ assimilation has taken place and that was potentially responsible as hydrothermal fluids migratory pathways (Plate 1).

outcrops, often folded and mesocratic in appearance. The rock displays ptygmatic folds and crenulation cleavage. Quartz and feldspar dominate, with minor biotite and hornblende. High silica content and internal hollows suggest in-situ assimilation and potential for fluid migration (Plate 1). In thin section stromatic metatexite is characterized by the presence of quartz (Qtz), K-feldspar (Kfs), plagioclase (Pl), biotite (Bt), chlorite (Chl), orthopyroxene (Opx), and cordierite (Crd). The quartz is colorless with low relief and large subhedral crystal that are strained and displays undulatory extinction, due to deformation accompanying metamorphic recrystallization. K-feldspar appear as colorless subhedral to anhedral crystals which forms under low-to moderate-grade metamorphism. Plagioclase is recognized as colorless grains with low relief and diagnostic albite twinning. Biotite is identified by its brown color, vibrant interference colors and unidirectional cleavage. Chlorite is recognizable by its colorless to pale green occurrence with low relief and unidirectional cleavage, flaky habit that forms rims around biotite, suggesting retrograde reaction texture during metamorphism. Orthopyroxene appears green to pale brown crystals with characteristic cleavage indicating high temperature metamorphism. Cordierite is typified by colorless to pale blue crystals which forms under low-to medium grade metamorphism.

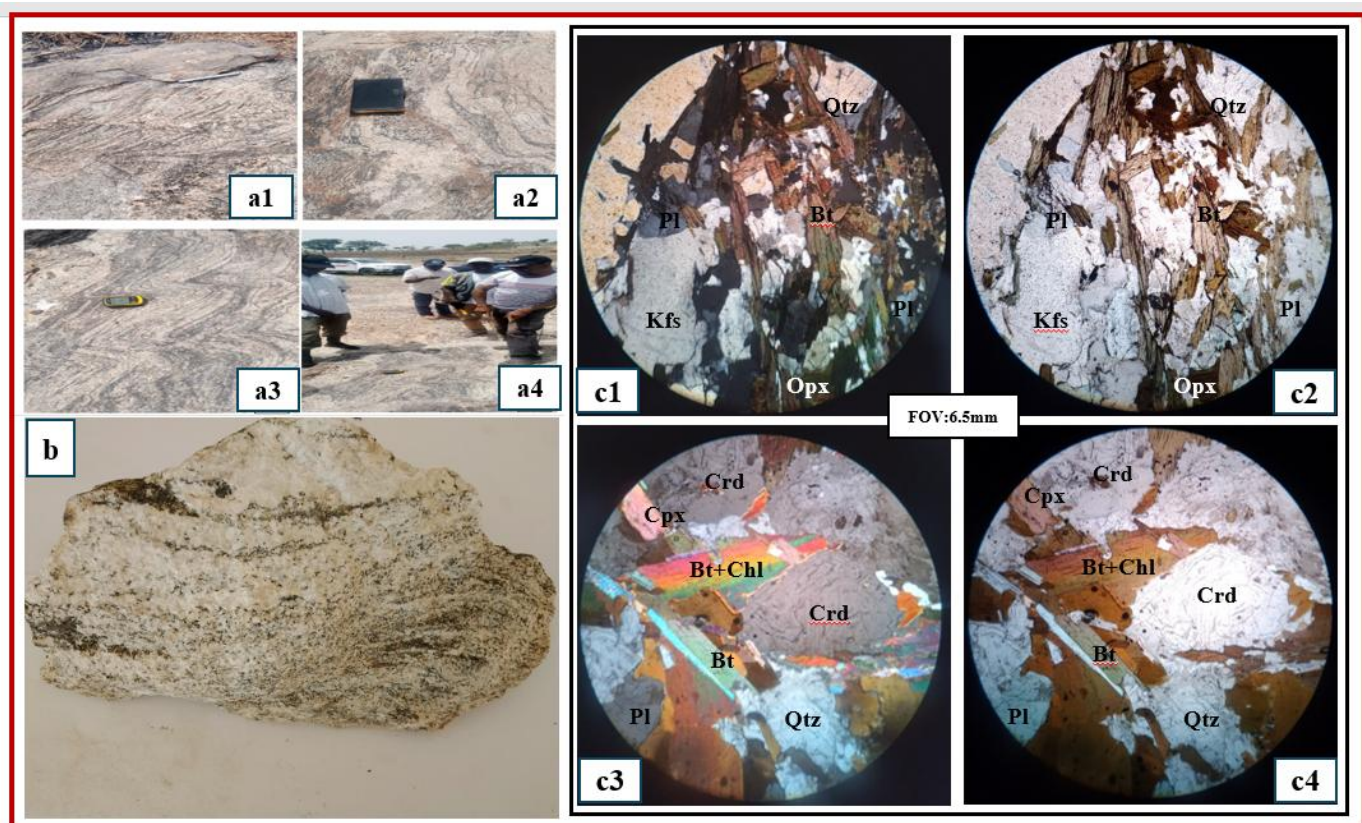


Plate 1. Field photograph of stromatic metatexite (a1) crenulation cleavage (a2) folded and foliated melanosome (a3) ptygmatic folding (a4) low-lying outcrop of stromatic migmatite. Photomicrograph of stromatic metatexite (c1, c3 = Xpl; c2, c3= ppl).

Banded Orthogneiss: This fine- to medium-grained, mesocratic rock displays alternating mafic and felsic bands, showing in-situ segregation. It forms pressure domes in areas of exhumation and is occasionally brecciated. In thin section, the banded orthogneiss composed of quartz (Qtz), biotite (Bt), plagioclase (Pl), clinopyroxene (Cpx) and sillimanite (Sl) (Plate 2). Quartz crystals are recognizable as colorless, low relief, strained with some cracks and undulatory extinction. Biotite appears brown, flaky with perfect cleavage in one direction and foliated, it is visibly pleochroic. Plagioclase is identified by its colorless to light gray appearance, perfect bidirectional cleavages and characteristic polysynthetic twinning. Clinopyroxene appears pale green to brown with high relief, strong birefringence, prismatic habit, and pleochroic, having two directional cleavages and undergo oblique extinction. Sillimanite is colorless, with low relief, slender prismatic habit, non-pleochroic, displaying higher order interference colors and undergo straight extinction.

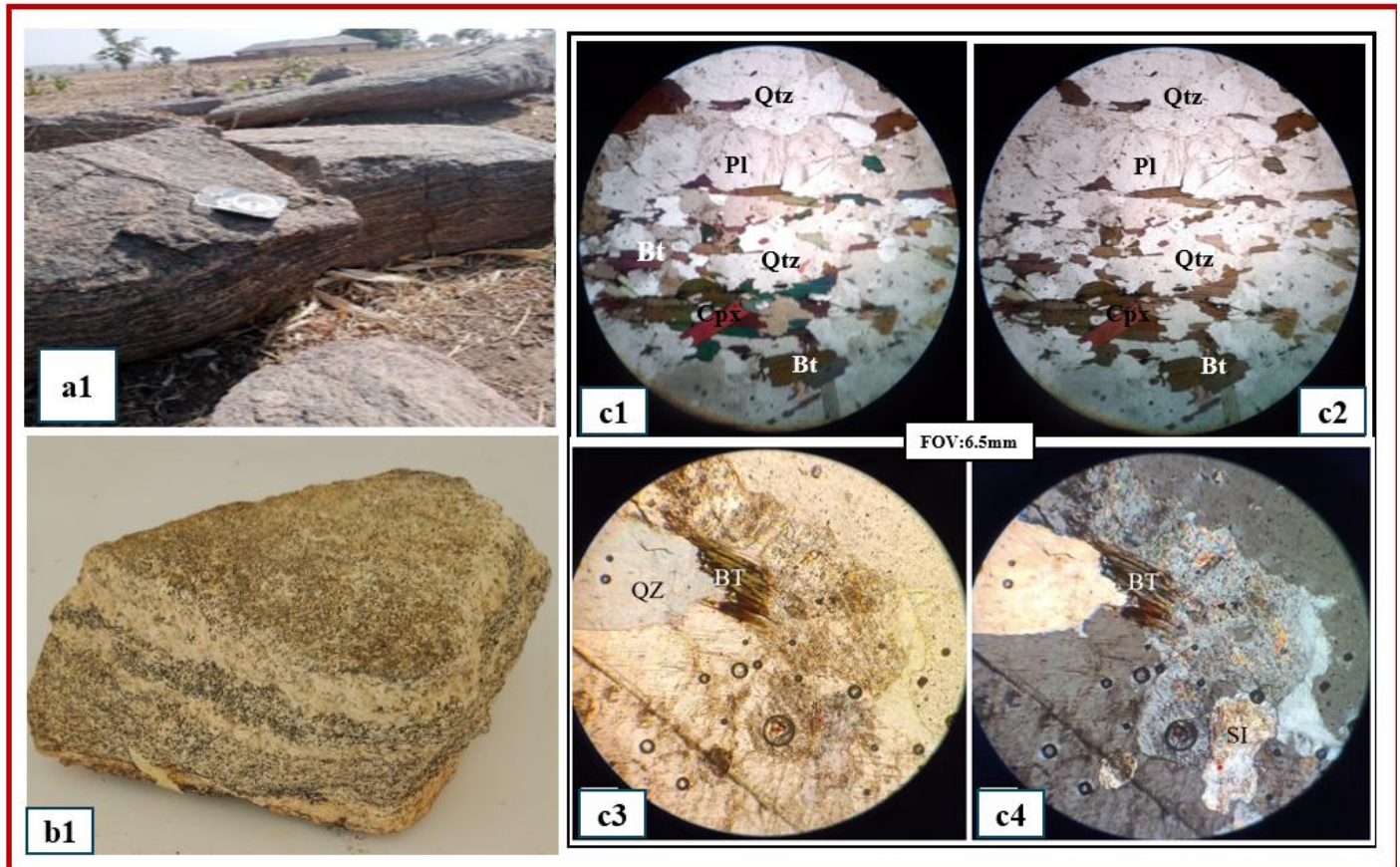


Plate 2. Field photograph of banded orthogneiss (a1) foliated low-lying banded orthogneiss (b1) hand specimen sample, (c1, c2, c3, c4) photomicrographs of banded orthogneiss.

Diatexite: Exhibits a mixed fabric with signs of partial melting and intense deformation. Leucosome and mesosome are mixed, and garnet, quartz, and biotite are abundant. Doming from isostatic adjustment is evident, and pegmatite intrusions are common.

Nebulite: occurring in limited exposures, these coarse leucocratic rocks contain feldspar porphyroblasts and quartz. The presence of intersecting pegmatite veins suggests their role as fluid pathways. Thin section investigation of Nebulite reveal the presence of quartz (Qtz), K-feldspar (Kfs), plagioclase (Pl), biotite (Bt), pyroxene (Pyx) and sillimanite (Sil). Quartz appears colorless, with low relief and weak birefringence, characterized by deformational crack and display undulous extinction. K-feldspar is recognized by colorless outline, with low relief, bidirectional cleavages, sericitization signatures were visible. Plagioclase is typified by colorless outlook, low relief, weak birefringence, perfect cleavages in two directions and characteristic albite. Biotite appears brown and flaky crystals with perfect cleavage in one direction and vibrant interference colors. Pyroxene is recognizable as pale brown crystal having cleavages indicating high temperature metamorphism. Sillimanite is colorless with high relief and needle-like habit which undergo straight extinction, indicating high temperature metamorphism (Plate 3).

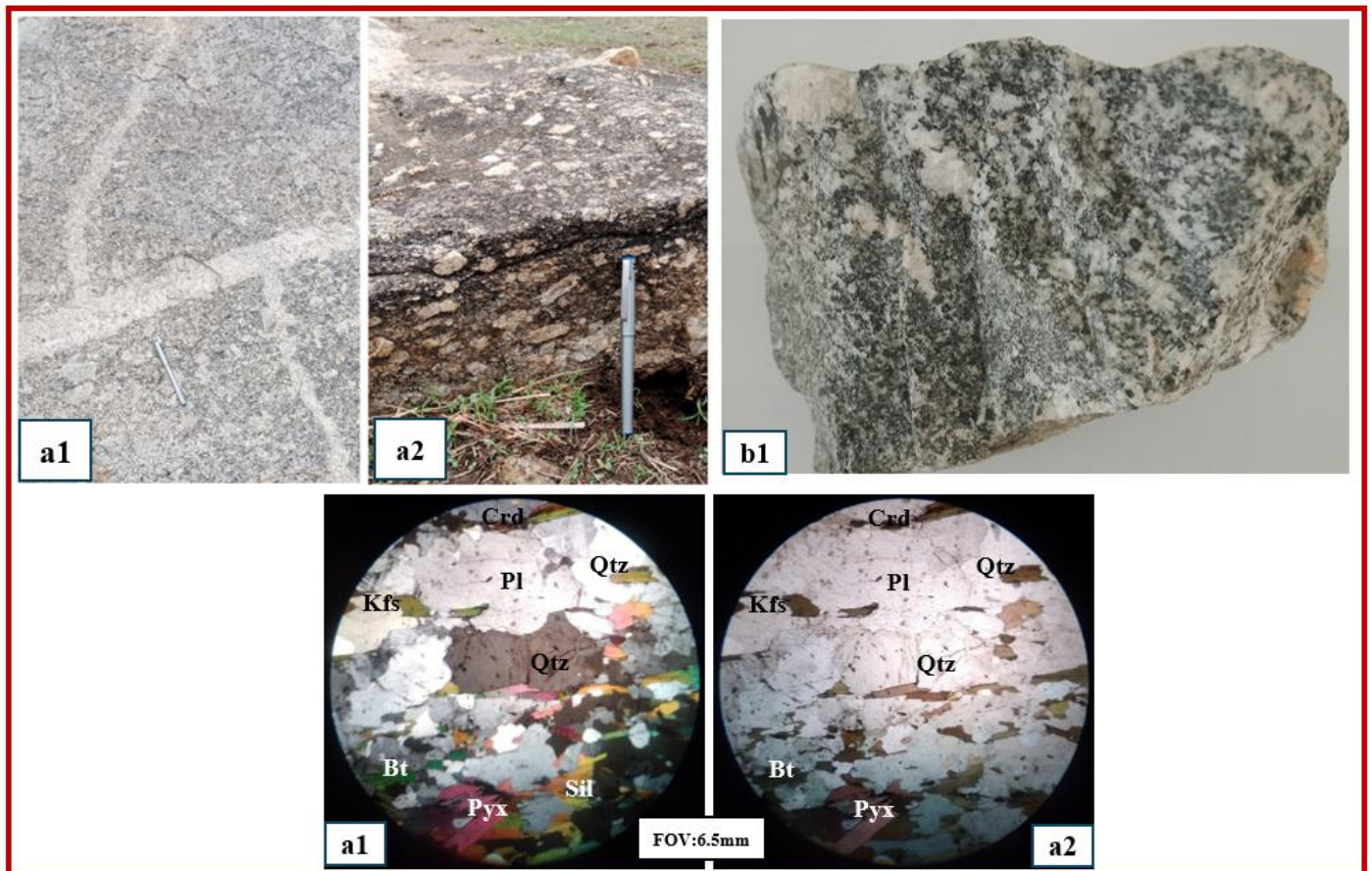


Plate 3. Field photograph of Nebulitic migmatite (a1) Leucocratic nebulite intruded pegmatitic veins (a2) nebulite typified by feldspar porphyroblasts, (b1) hand specimen sample of Nebulite, (a1, a2) photomicrograph of nebulite.

Upgraded Schist

Schist appears as melanocratic, fine-grained, foliated rocks, typically interlayered with pegmatite and migmatites. It contains abundant muscovite and biotite flakes and displays signs of metamorphic recrystallization and tectonic brecciation. Petrographic investigation of the upgraded schist revealed the presence of quartz (Qtz), biotite+chlorite (Bt+Chl), pyroxene+sillimanite (Pyx+Sil), cordierite (Crd) and clinopyroxene (Cpx). Quartz is identifiable as colorless crystals with low relief, presence of deformational cracks, undulatory extinction and first order interference colors. Biotite is recognizable as brown flaky crystals with high relief, strong birefringence, perfect unidirectional cleavage and alteration to form chlorite, indicating low-medium grade metamorphism. Pyroxene appears brown with high relief, short prismatic habit, perfect cleavages in two directions, and exhibits second order interference colors and oblique extinction. Sillimanite occurs as fibrous with high relief, straight extinction indicating high temperature metamorphism. Cordierite is recognizable as pale blue crystals with moderate relief, subhedral form, and pleochroic with yellow to pale blue shades. Clinopyroxene occurs as pale brown crystal with high relief, two perfect cleavages at approximately 90°, stubby form and high order interference colors (Plate 4).

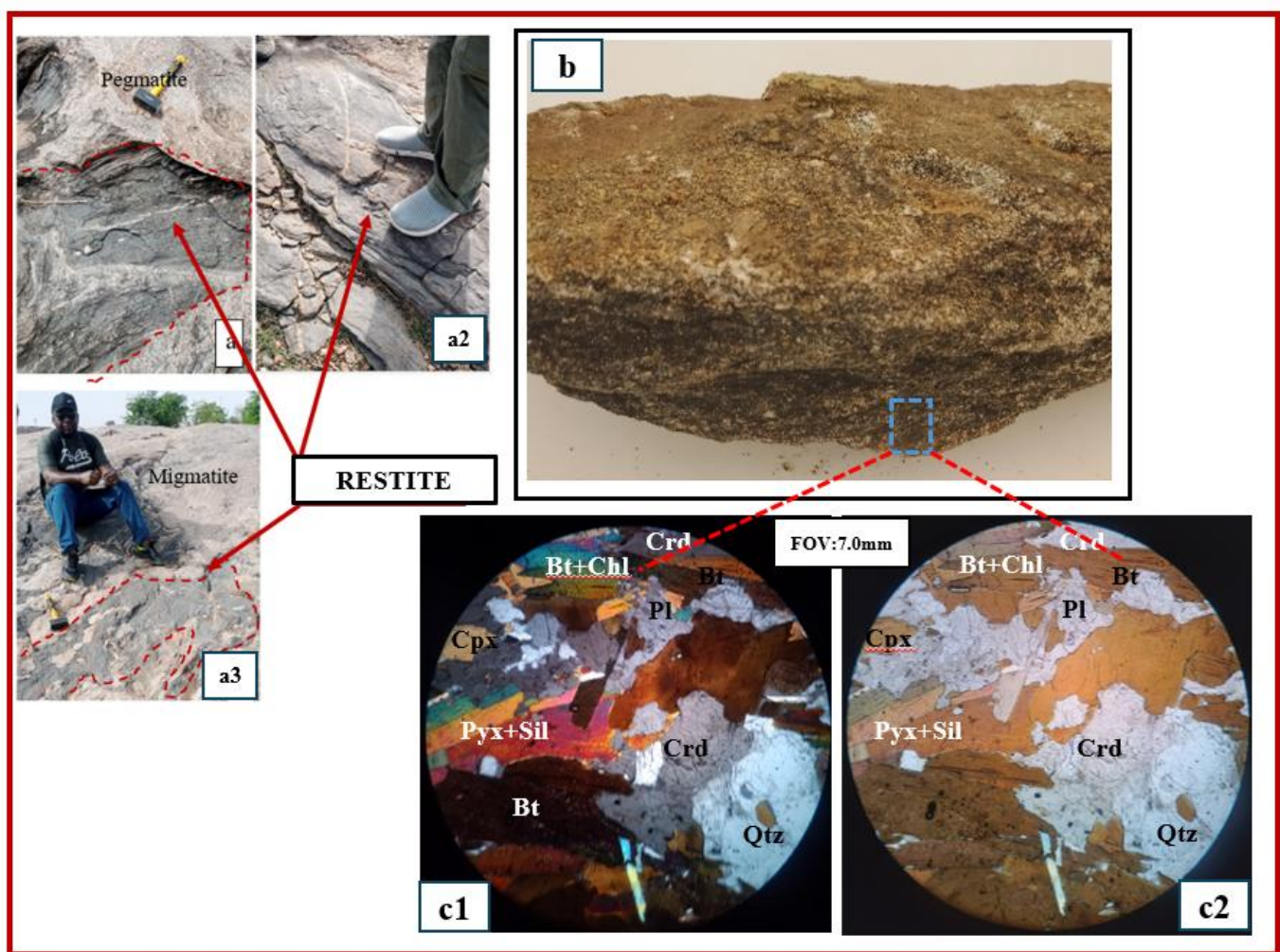


Plate 4. Field photograph of upgraded schist (a1) upgraded schist overlain by pegmatite (a2) exhumed ridge of upgraded schist (a3) upgraded schist intercalated with migmatite, (b) hand specimen sample, (c1, C2) photomicrograph of upgraded schist.

Pegmatite

Pegmatites occur in three morphologies: dykes, sills and lodes. They intrude the migmatite and schist both concordantly and discordantly. Texturally, they are coarse-grained and leucocratic, containing quartz, feldspar and large mica books. Some pegmatites exhibit pinkish coloration, suggesting lithium-bearing spodumene (possibly kunzite), and quartz veins hosting suspected tantalite. Fractures filled with K-feldspar and orthopyroxene suggest fluid saturation zones. Pegmatites in shear zones show signs of brecciation and lateritic weathering (Plate 5). Under the microscope the pegmatite consists of microcline (MI), quartz (Qz), biotite (Bt), sericite (Se) and myrmekite (Myr). Microcline is recognized as colorless, with low relief, perfect bidirectional cleavages, subhedral to anhedral form, cross-hatched twinning, gray to white first order interference colors and evidence of alteration to sericite. Quartz is colorless with low relief, weak birefringence, anhedral form and display straight extinction. Biotite appears brownish flakes, with unidirectional cleavage, vibrant yellow to brown to dark brown interference colors. Sericite occur as colorless with moderate relief, fibrous and flaky crystal which is observed to be replacing the microcline and exhibit straight extinction.

Microstructural investigation of the pegmatite revealed myrmekitic structure and sericitization alteration halo. The myrmekite is a vermicular (worm-like) inter growth of quartz within microcline feldspar which forms due to late-stage sub-solidus alteration and metasomatic reaction involving fluid-rock interaction during crystallization. Sericitization is marked by chemical alteration as a result of hydrothermal fluid alteration typically replacement of feldspars by white mica (sericite) which occurs as fine mica that gives a sheen texture of schistose mineral.

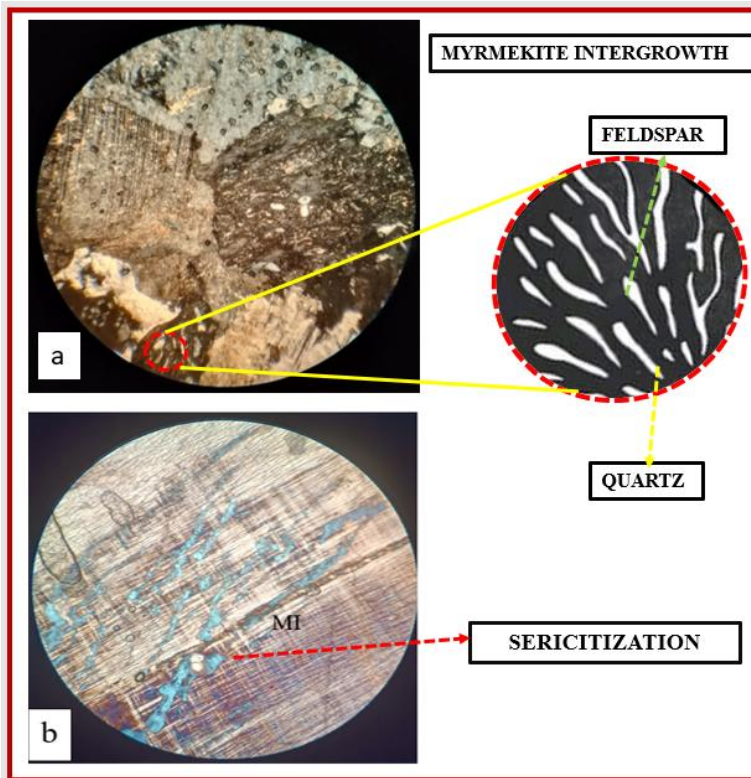
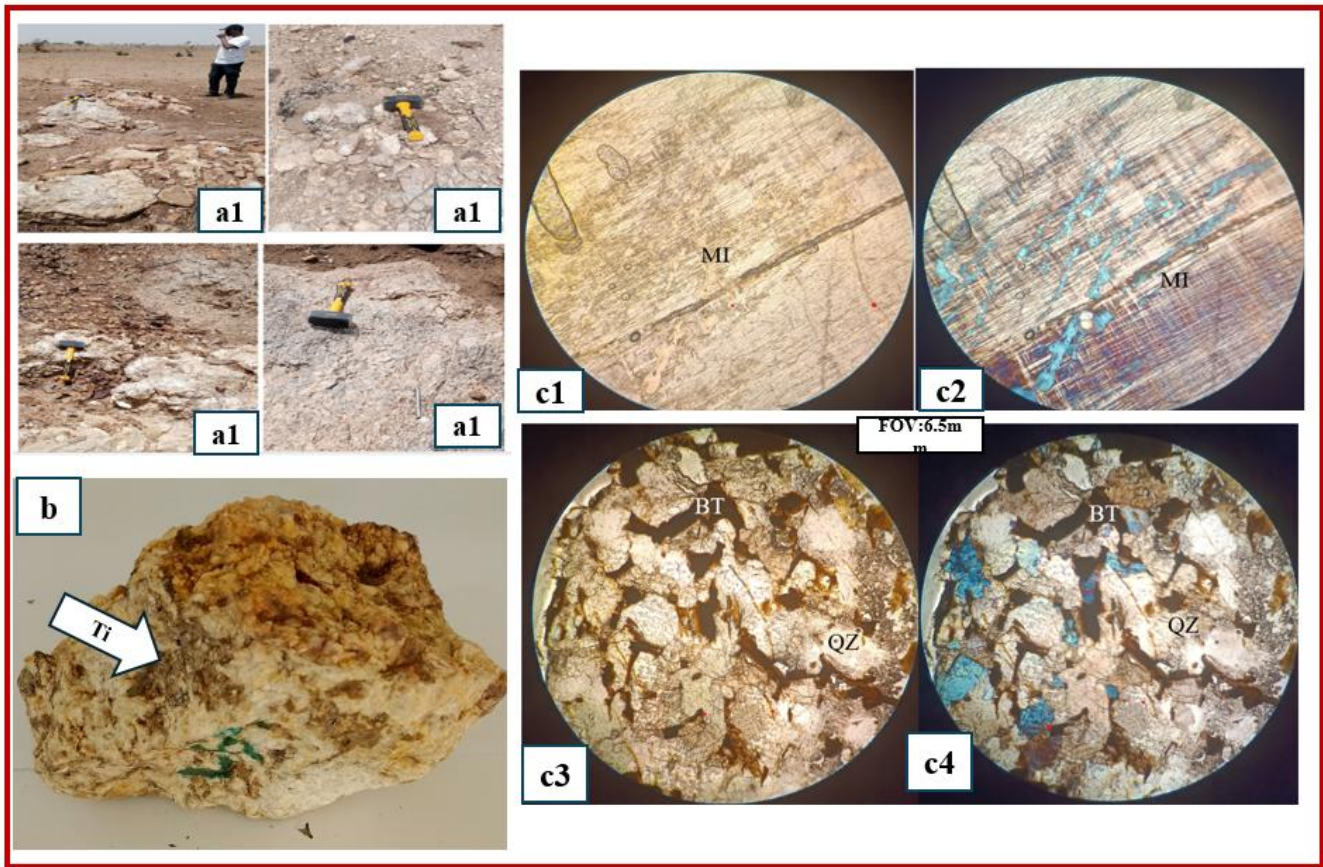


Plate 5. (a) Field photograph of pegmatite (b) hand specimen of pegmatite and photomicrograph of pegmatite exhibiting myrmekite and sericitization

Biotite Granite (Younger Granite)

This fine- to medium-grained granite constitutes approximately 3% of the area and forms a crescent-shaped ring dyke around Zaranda Hill. The granite is pinkish to grey, with sharp intrusive contacts with migmatite. It contains quartz, feldspar and biotite, with xenoliths of host rocks (Plate 6). The rock is fractured, with joints trending NNE-SSW, and is well exposed along the southern flanks of the hill. Petrographic investigation of biotite granite revealed the presence of quartz (QZ), microcline (MI), biotite (BT), muscovite (MU) and myrmekite (MY). Quartz is colorless, with relief, weak birefringence, anhedral form, parallel extinction. Microcline is recognizable as colorless crystals with low relief, weak birefringence, subhedral to anhedral form, perfect bidirectional cleavages and characteristic cross-hatched twinning. Biotite occurs as brown, with high relief and strong birefringence, having unidirectional cleavage. Muscovite is colorless with low relief and weak birefringence, perfect unidirectional cleavage, tabular form, high order interference colors and display parallel extinction. Intergrowth of quartz within microcline feldspar exhibiting myrmekitic texture was also observed.

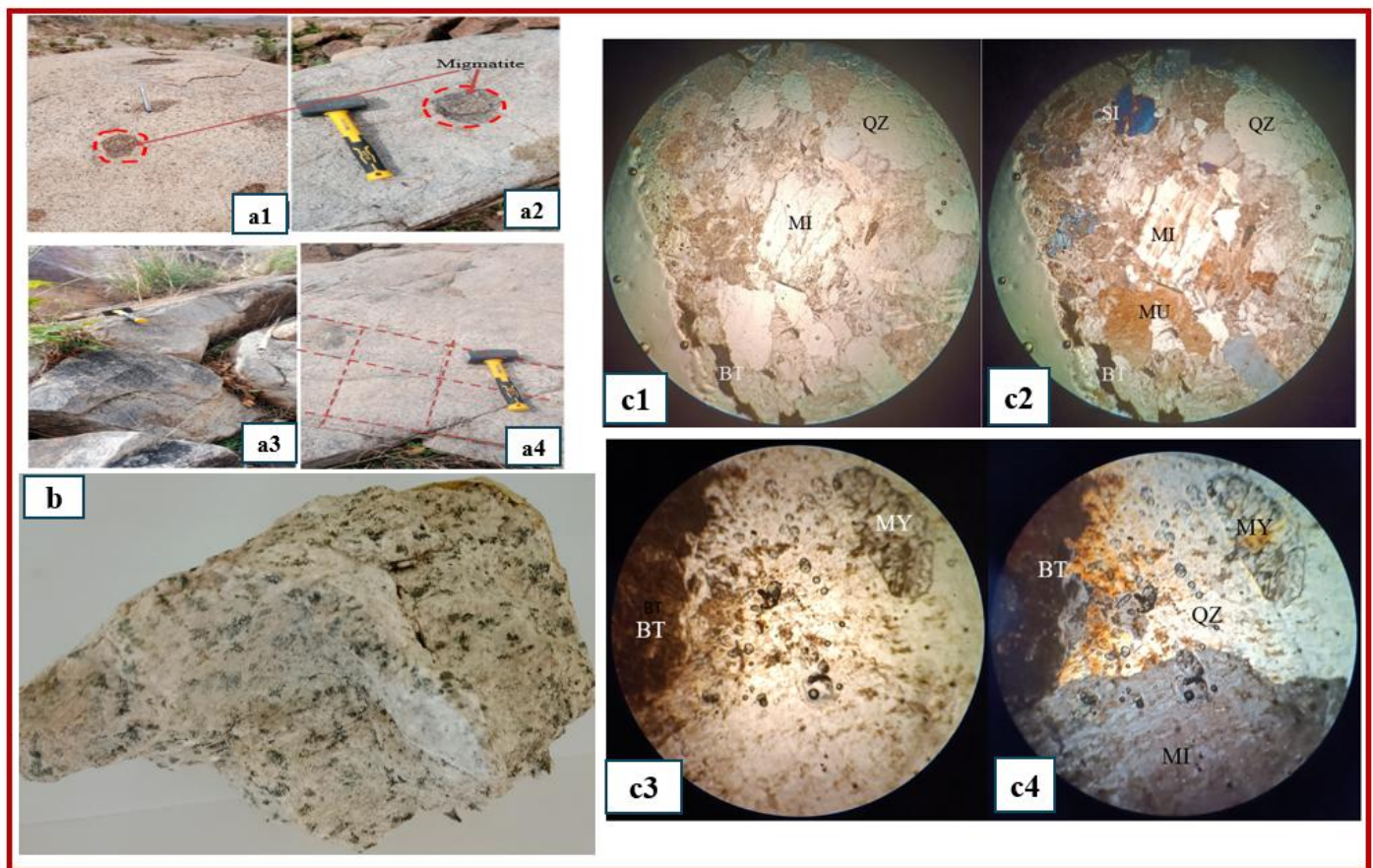


Plate 6. (a) Field photograph of biotite granite, (b) Hand specimen sample, (c) photomicrograph of biotite granite.

Rhyolite

Rhyolite dykes are present in two forms: melanocratic, fine-grained massive types, and leucocratic rhyolite porphyries that are weathered and brecciated. Rhyolite dykes, up to 1m thick and 10m long, intrude the migmatite and contain feldspar laths within a finer matrix. Thin section study showed that the rhyolite is composed mineralogically of plagioclase laths (Pl-lath), sanidine (Sn) and opaque minerals (Op). The plagioclase is colorless, lath-like habit and display polysynthetic twinning. Sanidine appears colorless, irregular and Carlsbad twinning. Opaque minerals occur as tiny grains disseminated randomly in the rock which is suspected to be monazite (Plate 7).

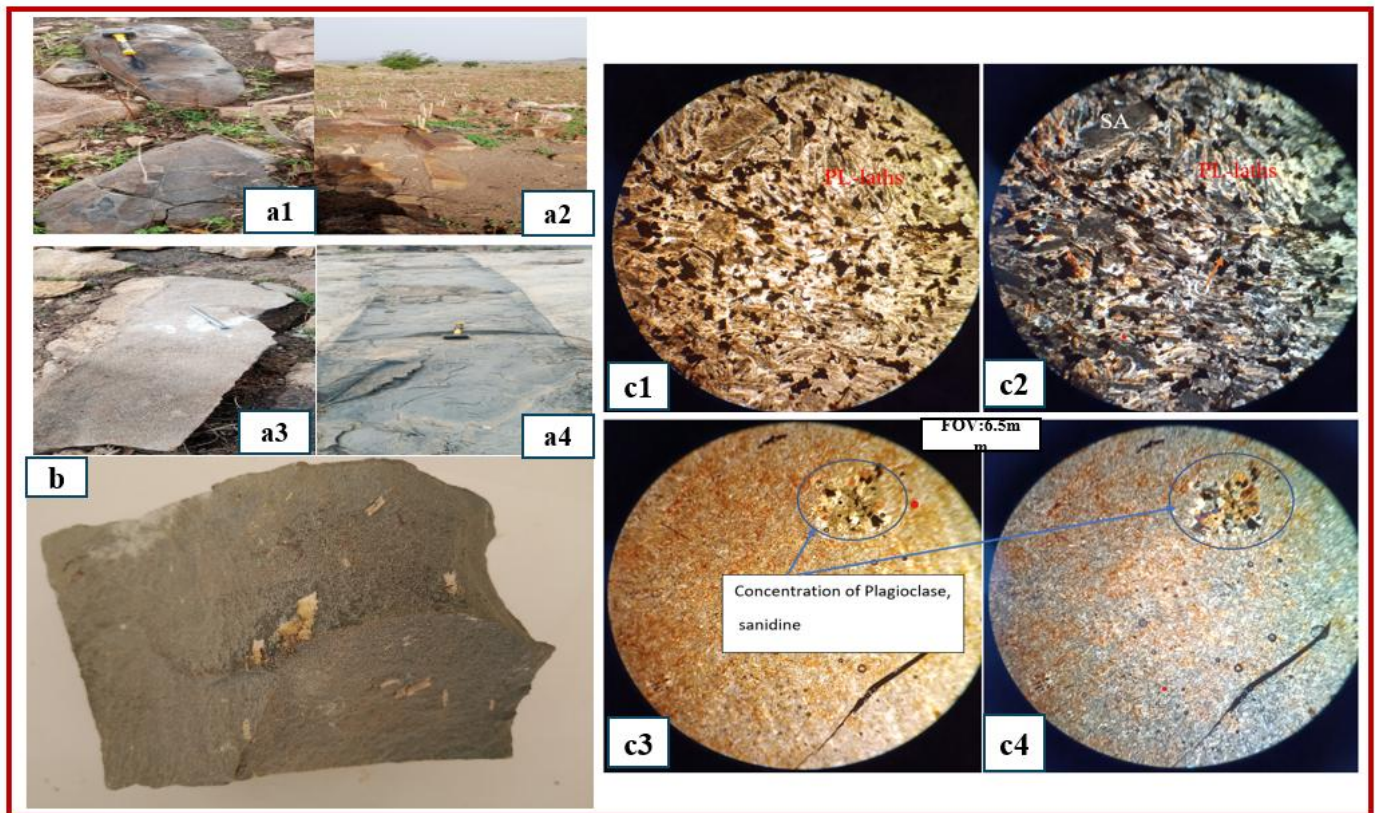


Plate 7. (a1-a4) Field photograph of rhyolite, (b) Hand specimen sample of rhyolite (c1-c4) photomicrograph of rhyolite.

4. DISCUSSION

The lithological assemblage and petrographic characteristics of the Zaranda area indicate a complex geological evolution marked by multiple episodes of high-grade metamorphism and partial melting and multiple phases of magmatism typical of the Nigerian Younger Granite Province (Okonkwo, 2012). The migmatite basement complex, comprising stromatic metatexite, banded orthogneiss metatexite, diatexite migmatite and nebulitic migmatite predominate the study area and accounts for extensive deep-seated crustal modification (Kayode, 2017).

Petrographically, the occurrence of quartz exhibiting undulose extinction, K-feldspar and plagioclase with albite twinning, together with mafic minerals such as biotite, chlorite and orthopyroxene, reflect medium – high grade metamorphism typically of granulite to amphibolite facie conditions (Olade, 2025). The development of textures such as crenulation cleavage, pygmatic folding and leucosome – melanosome segregation further signifies anatexis processes and deformation under compressional tectonic regimes (Sawyer, 2008; Hassan et al., 2025).

The banded orthogneiss is characterized by alternating felsic and mafic layers composed mainly of quartz, plagioclase, clinopyroxene and sillimanite, indicating high temperature metamorphic conditions. The occurrence of sillimanite and cordierite in both migmatites and upgraded schists indicates Aluminum-rich protoliths metamorphosed under high-temperature conditions, possibly during Pan-African orogenic events, later reworked during Mesozoic extensional phases (Halilu et al., 2025). Pegmatites occur as dykes, sills and lodes, intruding basement concordantly and discordantly. Their mineralogy are microcline, quartz, biotite, and sericite, along with myrmekitic texture and zones of sericitization indicating late-stage crystallization processes and hydrothermal alteration. The occurrence of pink colored spodumene (likely kunzite) and quartz veins with possible tantalite association implies Li-Ta-Nb-Sn mineralization potential, a characteristic feature of evolved pegmatites within the Younger Granite Province (Girei et al., 2020; Kamaunji et al., 2024). Structurally, their emplacement along NW-SE to NNW-SSE trending fractures reflects tectonic influence, in agreement with regional interpretations that associate rare-metal pegmatites with fracture systems in ring complex settings (Olade, 2025).

The biotite granite forming a crescentic ring dyke around Zaranda Hill, contains quartz, microcline, muscovite, and biotite with myrmekitic intergrowths, indicative of slow cooling in a subvolcanic setting. Its structural configuration aligns with anorogenic ring-complex emplacement during early Atlantic rifting event (Kamaunji et al., 2023). Dykes of rhyolite porphyries, characterized by presence plagioclase laths, sanidine crystals and opaque minerals unevenly disseminated in the rock reflects the acid extrusive magmatism of the complex. The rhyolite dykes cut-across all the lithologic units of the Zaranda area and the presence of feldspar phenocrysts imply late evolutionary phase during the waning stages of magmatic activity, typical of bimodal anorogenic suites (Ahmed et al., 2021; Dalorima, 2023).

Overall, the petrographic evidence confirms a polyphase evolution:

1. Basement formation and high-grade metamorphism producing migmatitic and schistose units.
2. Intrusion of Younger Granite magmas, forming biotite granite ring dykes and pegmatites
3. Late felsic volcanism with rhyolite emplacement and associated hydrothermal alteration.

The combination of structural controls evolved pegmatitic mineralogy, and hydrothermal features underscores the rare-metal mineralization potential and highlights the significance of the Zaranda Ring Complex necessitating comprehensive and focused geophysical and geochemical exploration of the complex.

5. CONCLUSION

Field relationship and thin-section examination of the Zaranda rocks revealed a complex interaction between intense basement metamorphism and successive stages of Younger Granite emplacement. Migmatitic rocks constitute the principal component of the basement, while biotite granite, rhyolite and pegmatite reflect episodic intrusion and fluid-related alteration.

Critically, the occurrence of lithium-bearing spodumene, quartz veins and indications of Sn-Ta mineralization in pegmatite veins and lodes showcase important rare-metal deposition, this along with tectonic influence exhibited by the annular dyke morphology and crustal tectonic domain makes the Zaranda Ring Complex a compelling target for future geophysical survey, geochemical profiling, and exploration campaigns.

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Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of interests

The authors declare that they have no conflicts of interests, competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data and materials availability

All data associated with this study are present in the paper.

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