iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** X **Month of publication:** October 2025

DOI: https://doi.org/10.22214/ijraset.2025.74757

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue X Oct 2025- Available at www.ijraset.com

Petrographic Analysis of Medium-Grained Granite of Madagali Area, Northeastern Nigeria

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Abstract: The Madagali area of northeastern Nigeria lies within the Precambrian Basement Complex and is characterized by diverse lithological assemblages comprising granites, migmatite–gneiss complexes, and schists that have undergone multiple tectonothermal events. This study focuses on the petrographic characterization of the medium-grained granite to determine its mineralogical composition, texture, and formation history. A total of six representative samples were collected and processed into twelve thin sections, which were examined under plane-polarized light (PPL) and cross-polarized light (XPL) using a polarizing microscope. The results revealed that the medium-grained granite consists predominantly of quartz, orthoclase, plagioclase feldspar, microcline, and biotite as essential minerals, with minor muscovite, and iron oxide as accessory constituents. The quartz grains exhibit undulose extinction and irregular boundaries, while feldspars display Carlsbad and tartan twinning, indicating slow cooling and magmatic crystallization within a plutonic environment. Myrmekitic intergrowths observed between quartz and feldspar suggest late-stage magmatic differentiation. Comparisons with previous studies in the Gulani and Kaltungo areas highlight mineralogical similarities, especially in the dominance of quartz and feldspar, though variations such as the absence of hornblende and sphene in the Madagali granite reflect local geochemical differences. The textural and mineralogical attributes indicate that the Madagali medium-grained granite is of igneous origin, likely emplaced during the Pan-African orogenic episode. The study contributes valuable petrographic data toward understanding the geological evolution of the Mandara Hills region and provides a foundation for future geochemical and geotechnical investigations.

Keywords:
Petrography; Medium-grained granite; Madagali; Northeastern Nigeria; Pan-African Orogeny; Mineral composition; Plutonic rocks; Granitoids; Optical mineralogy; Basement Complex.

I. INTRODUCTION

The Madagali area, situated in northeastern Nigeria, forms part of the Precambrian Basement Complex and is characterized by a diverse assemblage of metamorphic and igneous rocks. The dominant lithologies include medium- to coarse-grained granites, migmatite-gneisses, schists, and quartzites, which have undergone multiple phases of metamorphism and deformation. Baba (2011) and Siddig (2012) identified the granitoids in the area as predominantly calc-alkaline, ranging from granodiorite to monzogranite. The occurrence of migmatites suggests partial melting and anatexis, while the presence of schists and gneisses indicates medium- to high-grade metamorphic conditions associated with regional tectonothermal events.

Structurally, the Madagali area has experienced significant deformation attributed to the Pan-African orogeny, leading to complex folding, faulting, and shearing. Bassey (2006a) documented both deformed and undeformed granites, indicating multiple tectonic episodes. The dominant structural trends include N-S to NE-SW orientations, with additional NW-SE shear zones aligning with major regional geological features such as the Benue Trough and the Chad Basin rift system. Evidence of brittle deformation is also prevalent, with shear zones, fractures, and fault networks playing a crucial role in the region's structural evolution.

Beyond its structural complexity, the Madagali area exhibits economic potential due to reported occurrences of mineralization. Baba et al. (1991) documented the presence of economically viable mineral resources, while Baba (2011) analyzed the geochemical characteristics of the granitoids, suggesting their potential for mineralization. The combination of lithological diversity, structural complexity, and mineralization prospects underscores the geological significance of the Madagali area within northeastern Nigeria.

Geographically, the Mandara Hills form a prominent feature within the study area, covering part of sheet 136 NW Madagali. The region lies between latitudes 13°30' E and 13°45' E and longitudes 10°45' N and 11°00' N. Accessibility is facilitated by the Bama–Mubi road, with several minor roads and footpaths providing routes into the Republic of Cameroon (Barber et al., 1960). The terrain, characterized by rugged hills and low-lying granitoid outcrops, significantly influences geological mapping and field investigations in the area (Fig. 2).

This research focuses on the petrographic analysis of the medium-grained granite in the Madagali area, aiming to investigate its mineralogical composition and textural characteristics. The study seeks to examine the essential and accessory minerals present in the medium-grained granite and conduct a microscopic analysis to classify its mineral constituents, including those of the associated coarse-grained granite.

II. REGIONAL GEOLOGY OF THE STUDY AREA

The northeastern region of Nigeria is underlain by diverse lithological units that reflect a long and complex geological history. The area is composed primarily of Precambrian Basement Complex rocks, which are represented by the Migmatite–Gneiss Complex and the Older Granite Suites. These are overlain in parts by Cretaceous to Recent sedimentary formations deposited mainly within two major basins, the Upper Benue Trough and the Chad Basin, as well as by Tertiary to Quaternary volcanic rocks that occur locally.

The topography of the study area is characterized by distinct highlands and lowlands. The rugged Mandara Hills form the dominant highland feature, extending from Pulka in the north to Gulak in the south, with the Madagali Hills reaching an average elevation of about 670 metres above sea level. Other prominent highlands include Godogum, Belel, Mildo, and Bapura in the south-central to southwestern portions of the area, and Limankara and Takaskala in the northeast, with elevations ranging between 500 and 550 metres.

In contrast, the lowlands consist of gently undulating terrains and low-lying granitoid outcrops that occupy much of the northwestern part of the study area. These geomorphic features, together with the structural and lithological variations, reflect the region's complex tectonothermal evolution associated with the Pan-African Orogeny. The geological framework described by Siddiq (2014) highlights that the combination of migmatitic, granitic, and sedimentary sequences, along with localized volcanic activity, makes the Madagali area an important segment of the northeastern Nigerian Basement Complex, both structurally and economically.

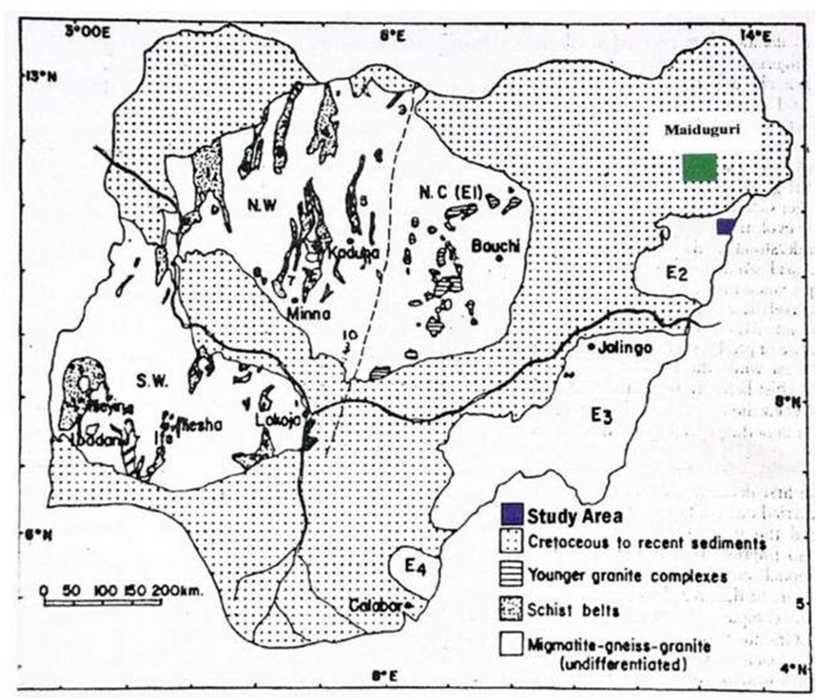

Fig. 1: Geological map of Nigeria showing the study area (C.A Kogbe, 1989)

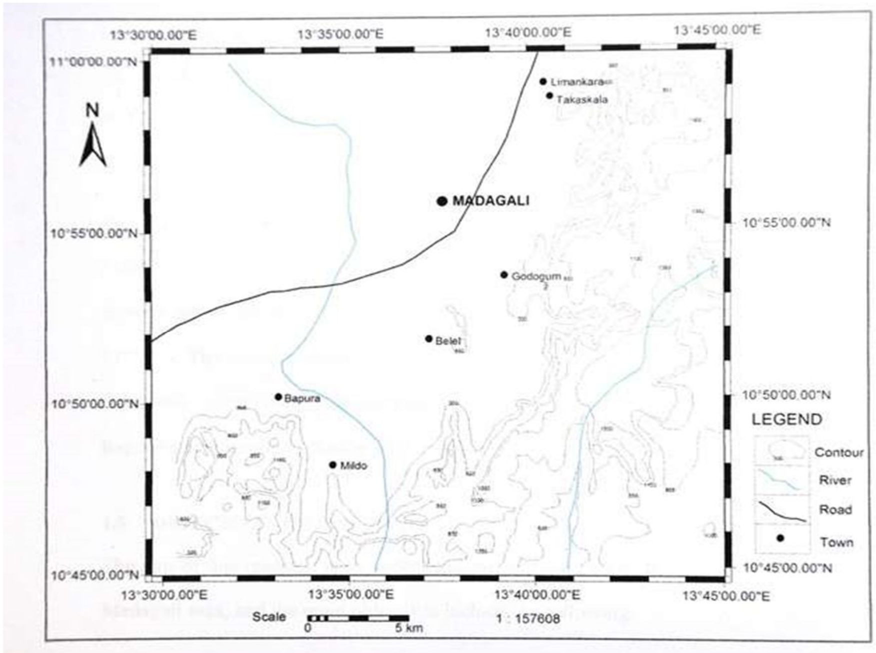

Fig. 2: Topographic Map of Madagali Area (Siddiq, 2014)

A. *Basement Complex*

The Precambrian Basement Complex of northeastern Nigeria has been extensively studied by various researchers, who have documented its lithology, structural geology, and mineralization potential. Carter et al. (1963) first described the region's basement as consisting of highly metamorphosed sedimentary remnants and diverse granitic intrusions, collectively termed the Older Granites. These lithologies include hornblende gneisses, biotite gneisses, quartzofeldspathic gneisses, marble, and quartzite, alongside plutonic units such as gabbro, diorite, pyroxenite, granites, and quartz-diorite. Islam et al. (1986, 1989) later classified the basement into major and minor rock types, subdividing it into the Mandara Mountains, the Alantika Mountains, the Shebshi Mountains, and the Adamawa Massif based on aerial photo analysis, field mapping, and laboratory studies.

Research on the petrology and mineralization of specific regions has provided valuable insights. Baba et al. (1991) documented economic mineral resources around Mandara Hill, while Baba et al. (2006) found that the Gwoza and Pulka rocks exhibited textural variability but were mineralogically and chemically similar. Baba (2011) further investigated the Madagali granitoids, concluding they ranged from calc-alkaline through granodiorite-monzogranite to granite, a finding supported by Siddig (2012), who confirmed the cogenetic nature of the gneisses and the calc-alkaline signature of the granitoids. Similarly, Ntekim and Adekeye (2004) studied Song in the southern Hawal Massif, identifying granite gneisses, migmatites, older granites, and granodiorites with gradational contacts among major rock units but sharp boundaries with surrounding sediments.

Structural investigations by Bassey (2006a-d, 2007) highlighted the tectonic evolution of Madagali, Uba, Chibok, and Michika areas, revealing evidence of migmatite gneisses, schists, and deformed Pan-African granites. His work linked the region’s tectonics to the Chad Basin Tenere Rift and Upper Benue Trough shear zones, identifying dominant NW-SE and NE-SW fault systems. In Chibok, satellite and structural data indicated similarities with Kaltungo and Wuyo-Gubrunde fault systems, while in Michika, brittle deformation and shear zones intruded by Pan-African granites were prominent.

B. *Migmatite-Gneiss Complex*

The Migmatite-Gneiss Complex (MGC) of northeastern Nigeria represents the oldest Precambrian basement rocks, primarily formed during the Pan-African Orogeny (600 ± 150 Ma) (Rahaman, 1988). It comprises high-grade metamorphic rocks such as migmatites, gneisses, granulites, and schists, intruded by Pan-African granites and pegmatites (Ajibade & Fitches, 1988). These rocks exhibit features like metamorphic banding, shear zones, and foliation, indicating extensive tectonothermal events and deformation (Black, 1980).

Petrographically, the migmatites display felsic leucosomes and mafic melanosomes, while gneisses are rich in quartz, feldspar, biotite, and garnet, indicating upper amphibolite to granulite facies metamorphism (Ekwueme, 1990).

The MGC also has significant economic potential, hosting gold, tin, columbite, and rare-earth elements, particularly within pegmatitic intrusions (Kankara et al., 2020). Additionally, its fractured zones serve as important groundwater reservoirs in the region (Oladipo et al., 2014).

The complex provides valuable insights into the geodynamic evolution of the West African Craton and Pan-African mobile belt, making it a key focus for geological research and mineral exploration. Its structural complexity and mineral wealth highlight its importance in both academic and economic contexts (Obaje, 2009).

C. Older Granite

The Older Granite suites of northeastern Nigeria are a group of Pan-African (600 ± 150 Ma) intrusive rocks that form a significant part of the Precambrian Basement Complex. These granitoids, which include granite, granodiorite, quartz-diorite, syenite, and diorite, were emplaced during the Pan-African orogeny and are associated with migmatites, gneisses, and schists (Carter et al., 1963; Rahaman, 1988). The suites are structurally controlled, occurring as massive plutons, sheet-like intrusions, and anastomosing veins, with evidence of deformation, shearing, and faulting. Studies in areas such as Madagali, Gwoza, Pulka, and the Mandara Hills indicate that these granites exhibit calc-alkaline geochemical signatures, suggesting derivation from crustal anatexis with mantle contributions (Baba, 2011; Siddig, 2012).

Geological mapping and petrological studies show that the Older Granites in this region have undergone metasomatism, deformation, and weathering, leading to mineralization of economic interest. These granitoids host gold, tin, columbite, and rare-earth elements, particularly in pegmatitic intrusions (Baba et al., 1991; Kankara et al., 2020). Structural studies also reveal that these granites were emplaced along major shear zones aligned in NE-SW and NW-SE orientations, correlating with the Kaltungo Fault and the Wuyo-Gubrunde inlier (Bassey, 2006d). The Older Granite suites provide key insights into the tectonomagmatic evolution of northeastern Nigeria, linking them to regional Pan-African deformation, magmatism, and mineralization processes (Dada et al., 1995).

D. The Mandara Hill

In northeast Nigeria, Islam et al. (1989) identified the following groups of rocks as part of basement complex

1) Migmatite-gneisses, quartzites, schist, and amphibolites
2) Older Granites (granites, pegmatites and mylonites).

Furthermore, Baba (1990) mapped the Liga hills (parts of Mandara Hills) and identified granite gneisses and granites of various textures.

Toteu (1987) identified gneisses, pre-late and post-tectonic granites in the northwestern side of northern Cameroon.

From the various divisions of the Nigerian basement complex, which comprise migmatite gneiss complex, and Pan-African granitoids as well as the unmetamorphosed basic and acid dykes, it is clear that Mandara Hills is composed of rocks similar to those in other parts of Nigerian Basement Complex.

E. Structural Trends

The Nigerian Basement Complex has undergone multiple deformation phases since the Precambrian, resulting in diverse structural features with distinct orientations. Oluyide (1988) identified four primary structural trends: N-S, E-W, NE-SW, and NW-SE, with N-S being the most dominant. Ene and Mbonu (1988) classified these trends based on age, linking E-W structures to the pre-Paleozoic, N-S to the middle Precambrian-Paleozoic, NE-SW to the Mesozoic, and NW-SE to the Santonian and younger periods.

In southeastern Nigeria, Ekwueme (2003) observed dominant N-S and NE-SW trends with minor NW-SE and E-W structures, while Rahaman (1988) reported similar orientations in northeastern Nigeria. These structural features are primarily linked to the Pan-African orogeny, with older E-W and NW-SE fractures attributed to pre-Pan-African deformation. Major basement faults, particularly in the east, are associated with transcurrent movements and align with the ENE-WSW trend of the Benue Trough (Rahaman, 1988).

Oluyide (1988) emphasized that fractures and faults in the basement complex result from shearing and brittle deformation, with N-S fractures being the most prominent. In north-central Nigeria, Ike (1988) identified NE-SW shear faults as dominant, with localized NW-SE trends. Similarly, Islam et al. (1989) mapped NNE-SSW as the dominant fault trend in the Mandara Hills, with younger N-S fractures also present.

Overall, the Nigerian Basement Complex is defined by three major structural trends: N-S, NE-SW, and NNW-SSE. E-W fractures, though more challenging to observe in the field, are considered the oldest structural features.

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Volume 13 Issue X Oct 2025- Available at www.ijraset.com

F. Mineralization

Northeastern Nigeria hosts a diverse range of mineral deposits, including metallic, non-metallic, and gemstone minerals, many of which have economic significance. Carter et al. (1963) documented occurrences of low-grade iron ore, coal, limestone, diatomite, and salts in parts of Adamawa, Bauchi, and Borno provinces. Islam and Baba (1990) and Baba et al. (1991) identified quartz, feldspar, manganese ore, chalcopyrite, pyrite, galena, kaolin, and granite within the pegmatites of the Mandara Hills, with quartz and feldspar occurring in commercial quantities. Abaa and Najime (2006) suggested that mineralization in Nigeria's Basement Complex may extend from central regions to the Mandara and Gwoza areas, potentially hosting cassiterite, wolframite, galena, barite, and gemstones.

Uranium mineralization in the region has been classified into two types: primary deposits within granitic terrains (e.g., Ghumchi, Mika, and Kanawa) and sediment-hosted deposits within the Bima Sandstone (e.g., Zona, Mayo-Lope, and Dali). The primary uranium deposits are localized along brittle deformation zones in granitic rocks, while the secondary deposits are structurally controlled, occurring at fault intersections (Funtua et al., 1992; Suh and Dada, 1997).

Gypsum mineralization has been reported in the Nafada area, occurring as intercalations within the Fika Shale, with chemical analyses indicating its suitability for cement and plaster of Paris production (El-Nafaty and El-Nafaty, 2000). Similar deposits occur in the Lamurde-Lau area within carbonate-rich black shales (Ntekim and Orazulike, 2004).

Magnesite mineralization in the Tsakasimta area, described as a crypto-crystalline variety, has been attributed to the alteration of ultrabasic rocks by carbonated hydrothermal fluids. Chemical analysis indicates a high MgO content (35.8 wt%), with total mineable reserves estimated at over 523 million metric tons (Shettima, 2000; Mohammed, 2005).

Other mineral occurrences include pyrite deposits within Gombe Hill, hosted in Bima Sandstone, with stable sulfur isotope studies suggesting a freshwater origin (Joseph et al., 2008). Additionally, epigenetic barite-copper mineralization has been reported in the Gulani area within the Gongola Arm of the Upper Benue Trough, occurring in Bima and Yolde Formations and linked to the Pb-Zn-Cu-F metallogenetic belt of the Benue Trough (El-Nafaty, 2015; Farrington, 1952).

III. METHODOLOGY

This study employed a combination of geological mapping, systematic sample collection, thin-section preparation, and laboratory-based petrographic analysis. Field and laboratory procedures were conducted using appropriate geological equipment and standard analytical techniques to ensure precision and reliability. The methodological framework was divided into two main stages: the first involved geological mapping and sample collection, while the second focused on laboratory preparation and petrographic examination of representative samples.

A. Geological Mapping

The study area, covering approximately 750.75 km² within Sheet 136 NW (Madagali), was mapped at a scale of 1:50,000 using the traverse mapping method. Essential geological tools employed included a compass–clinometer, geological hammer, Global Positioning System (GPS) receiver, digital camera, measuring tape, field notebook, pens and pencils, indelible markers, masking tape, acid bottle, sample bags, and topographic maps.

Representative rock samples were systematically collected from exposed outcrops. Each sample was carefully chipped, labeled, and its location accurately recorded using GPS coordinates (latitude and longitude), which were later plotted on a base map. During field observations, key macroscopic characteristics such as color, texture, mineral composition, and structural features were documented to support rock identification and classification. Measurements of strike and dip of veins and other structural elements were obtained using a compass–clinometer, while dimensions were determined with a measuring tape.

All field data, including descriptions of lithological units and structural attributes, were meticulously recorded in a field notebook. Additionally, photographic documentation of significant geological structures and outcrops was undertaken using a digital camera to complement field notes and provide visual evidence of the lithological and structural relationships observed within the study area.

B. Petrographic Analysis

A total of 48 rock samples, comprising medium- to coarse-grained granites and migmatite–gneiss complexes, were collected from various locations across the study area. For detailed petrographic investigation, six samples of medium-grained granite were selected and processed at the Petrology/Mineralogy Laboratory, Department of Geology, University of Maiduguri. From each sample, two thin sections were prepared, producing a total of twelve (12) thin sections for microscopic examination.

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Thin-section preparation followed standard laboratory procedures. Each rock sample was first cut into thin slices using a rock-cutting machine, after which the slices were ground and polished with progressively finer abrasive powders to obtain a smooth surface. The polished slices were mounted on glass slides using araldite resin and gently heated on a hot plate for approximately 10 minutes to ensure firm adhesion. After cooling, the mounted slices were ground to a uniform thickness of 0.03 mm using abrasive powder on glass laps. A thin layer of Canada balsam was applied to the polished surfaces before carefully placing thin glass coverslips on top. Gentle pressure was applied to eliminate air bubbles and excess balsam, and the slides were left to cool and harden. Excess adhesive was then cleaned with an organic solvent, and each prepared slide was properly labeled for reference.

Microscopic examination was conducted using a petrological polarizing microscope following the procedure described by Kerr (1977). Each thin section was analyzed under plane-polarized light (PPL) and cross-polarized light (XPL) to identify rock-forming minerals and determine their optical and textural properties. Data obtained from the petrographic analyses were integrated with field observations to classify and interpret the rock units within the study area.

IV. RESULTS OF PETROGRAPHIC STUDIES

A total of forty-eight (48) rock samples were collected during fieldwork, comprising granite (coarse- and medium-grained varieties), migmatite–gneiss complex, and pegmatite lithologies. The present study focuses on the petrographic analysis of the medium-grained granite, which was selected as the representative lithology for detailed microscopic investigation. Six samples of the medium-grained granite were prepared for petrographic study, yielding twelve (12) thin sections labeled according to their field locations and sample numbers as follows: Thin Section 1 – L5.S5; Thin Section 2 – L5.S5; Thin Section 3 – L6.S1; Thin Section 4 – L6.S1; Thin Section 5 – L12.S1; Thin Section 6 – L12.S1; Thin Section 7 – L17.S1; Thin Section 8 – L17.S1; Thin Section 9 – L24.S1; Thin Section 10 – L24.S1; Thin Section 11 – L25.S1; and Thin Section 12 – L25.S1.

The thin-section descriptions are presented below, accompanied by their respective photomicrographs, which illustrate the mineralogical composition and optical characteristics observed under PPL and XPL. Petrographic examination reveals that the medium-grained granite consists predominantly of quartz, orthoclase, microcline, plagioclase feldspar, and biotite, with minor occurrences of muscovite, and iron oxides. The mineral grains exhibit hypidiomorphic to allotriomorphic textures and a medium-grained, inequigranular fabric, typical of slowly cooled granitic rocks within a plutonic environment. The mineral assemblage and textural relationships indicate a felsic composition, suggesting crystallization from a granitic magma that underwent fractional crystallization and late-stage alteration processes. Collectively, these petrographic features support the igneous origin and tectonic stability of the Madagali granite during emplacement.

Thin Section 1 (L5.S5)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, no cleavage; irregular boundaries; common undulose extinction	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief, often cloudy; poor cleavage; may show perthitic intergrowths	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic texture visible
Microcline (K-feldspar)	Colourless, low relief; slightly turbid; similar to orthoclase	Low 1st-order gray/white interference colours; distinct cross-hatched (tartan) twinning
Biotite	Strong pleochroism from light to dark brown; perfect cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; basal cleavage distinct
Muscovite	Colourless, non-pleochroic; high relief; perfect cleavage	2nd-order pastel interference colours (pink/green); straight extinction
Iron Oxides (Magnetite/Ilmenite)	Opaque, black in PPL; subhedral to anhedral grains	Remains opaque (black); isotropic

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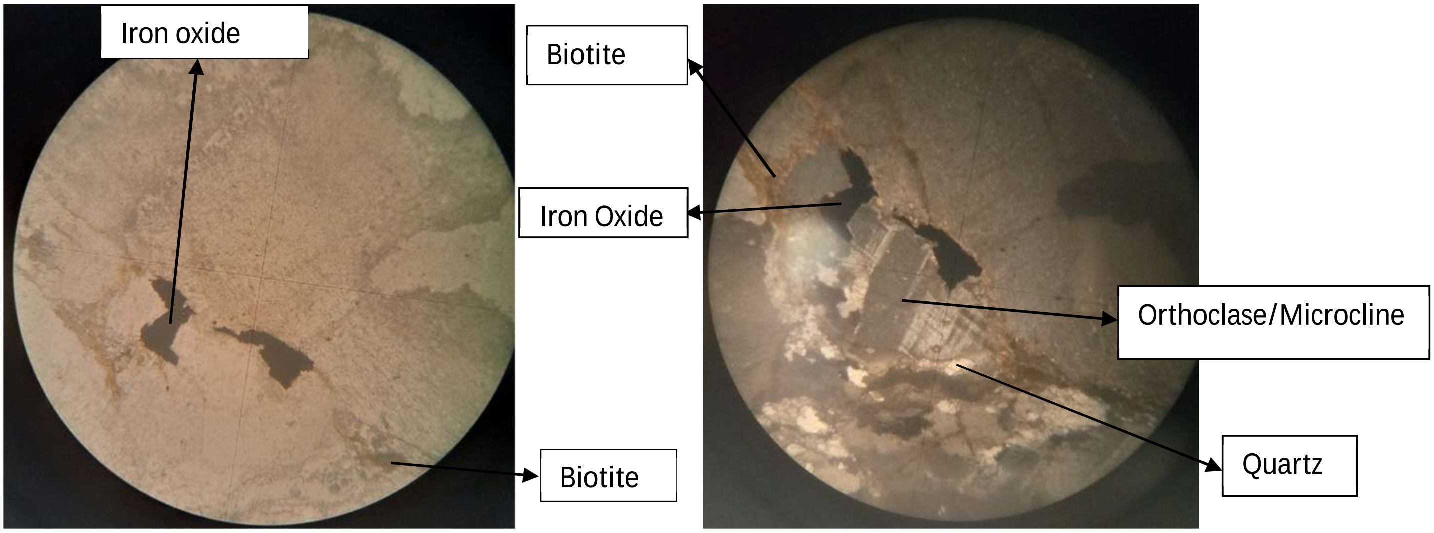

Thin Section 1 (L5.S5):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, microcline, biotite, and iron oxide. Magnification: X100.

Thin Section 2 (L5.S5)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, no cleavage; irregular boundaries; common undulose extinction	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief, often cloudy; poor cleavage; may show perthitic intergrowths	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic texture visible
Plagioclase Feldspar	Colourless, low relief; may show two cleavages at ~90°; sometimes sericitized	1st-order gray/white interference colours; characteristic polysynthetic (albite) twinning; zoning common
Biotite	Strong pleochroism from light to dark brown; perfect cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; basal cleavage distinct
Iron Oxides (Magnetite/Ilmenite)	Opaque, black in PPL; subhedral to anhedral grains	Remains opaque (black); isotropic

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Thin Section 2 (L5.S5):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, iron oxide, and biotite. Magnification: X100.

Thin Section 3 (L6.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, anhedral to subhedral; irregular margins; interstitial	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief, often turbid or cloudy; poor cleavage	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic intergrowth common
Plagioclase Feldspar	Colourless, low relief; tabular habit; two cleavages nearly at 90°	Low 1st-order gray/white interference colours; polysynthetic (albite) twinning; zoning evident
Biotite	Pale to dark brown pleochroism; strong cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; basal cleavage visible
Iron Oxide (Magnetite)	Opaque; black under PPL; anhedral grains	Remains opaque (black); isotropic

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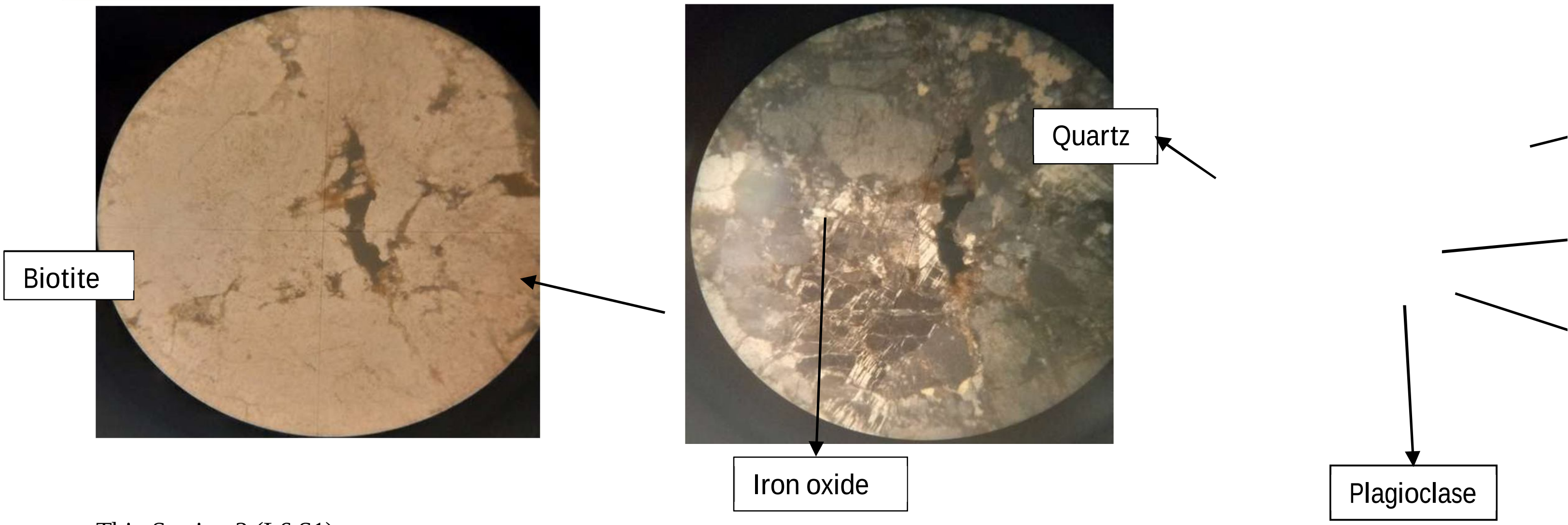

Thin Section 3 (L6.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, plagioclase feldspar, iron oxide, and biotite. Magnification: X100.

Thin Section 4 (L6.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, anhedral to subhedral; irregular margins; interstitial	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief; often turbid or cloudy; poor cleavage; perthitic texture common	Low 1st-order gray interference colours; simple Carlsbad twinning; microperthitic intergrowths visible
Plagioclase Feldspar	Colourless, low relief; tabular habit; two cleavages nearly at 90°	Low 1st-order gray/white interference colours; polysynthetic (albite) twinning; faint zoning evident
Biotite	Pale to dark brown pleochroism; strong cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; bird's-eye texture locally
Iron Oxide (Magnetite)	Opaque; black under PPL; anhedral grains	Remains opaque (black); isotropic

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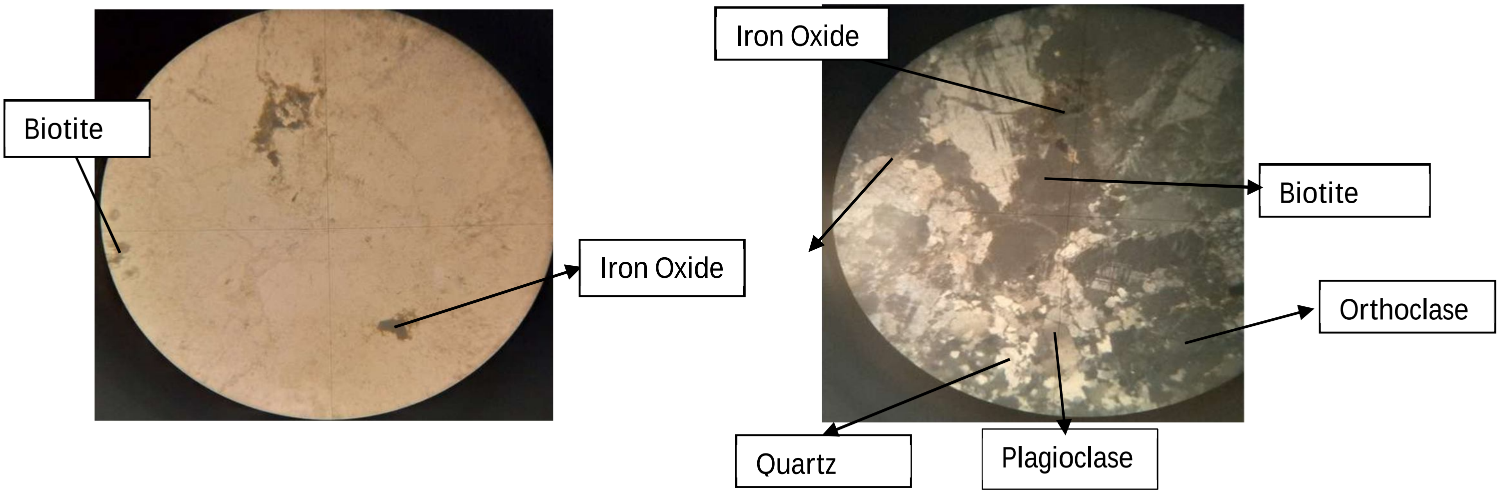

Thin Section 4 (L6.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, plagioclase feldspar, iron oxide, and biotite. Magnification: X100.

Thin Section 5 (L12.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, anhedral to subhedral; irregular margins; interstitial	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief; often turbid or cloudy; poor cleavage; perthitic texture common	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic intergrowths visible
Plagioclase Feldspar	Colourless, low relief; tabular habit; two cleavages nearly at 90°	Low 1st-order gray/white interference colours; polysynthetic (albite) twinning; faint zoning evident
Biotite	Pale to dark brown pleochroism; strong cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; bird's-eye texture locally
Iron Oxide (Magnetite)	Opaque; black under PPL; anhedral grains	Remains opaque (black); isotropic

Quartz

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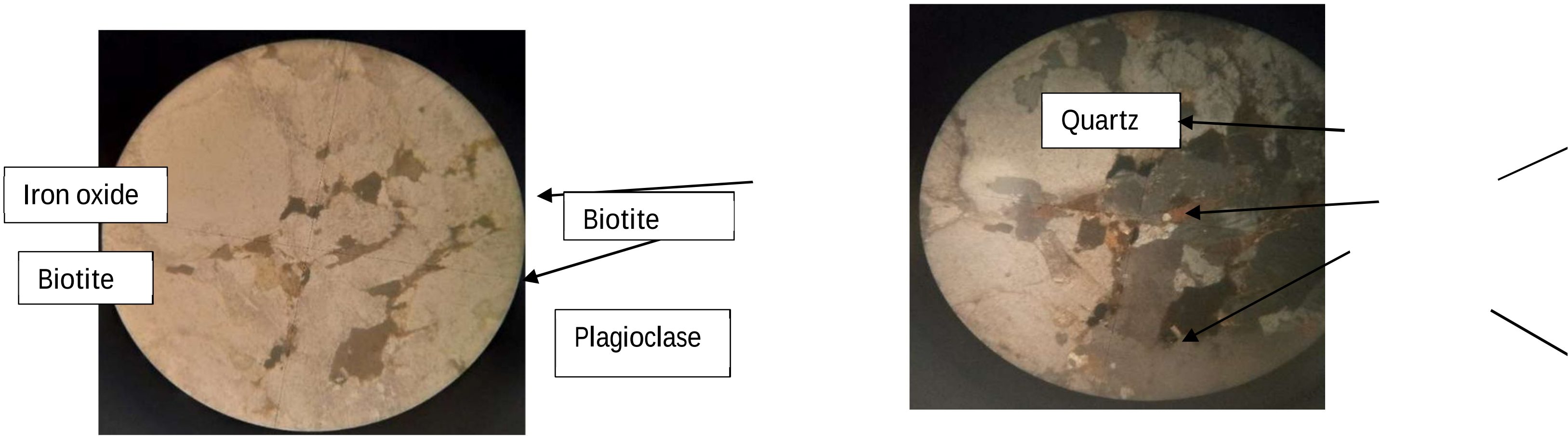

Thin Section 5 (L12.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, plagioclase feldspar, biotite, and iron oxide. Magnification: X100.

Thin Section 6 (L12.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, no cleavage; irregular boundaries; common undulose extinction	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief, often cloudy; poor cleavage; may show perthitic intergrowths	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic texture visible
Microcline (K-feldspar)	Colourless, low relief; slightly turbid; similar to orthoclase	Low 1st-order gray/white interference colours; distinct cross-hatched (tartan) twinning
Plagioclase Feldspar	Colourless, low relief; may show two cleavages at ~90°; sometimes sericitized	1st-order gray/white interference colours; characteristic polysynthetic (albite) twinning; zoning common
Biotite	Strong pleochroism from light to dark brown; perfect cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; basal cleavage distinct
Iron Oxides (Magnetite/Ilmenite)	Opaque, black in PPL; subhedral to anhedral grains	Remains opaque (black); isotropic

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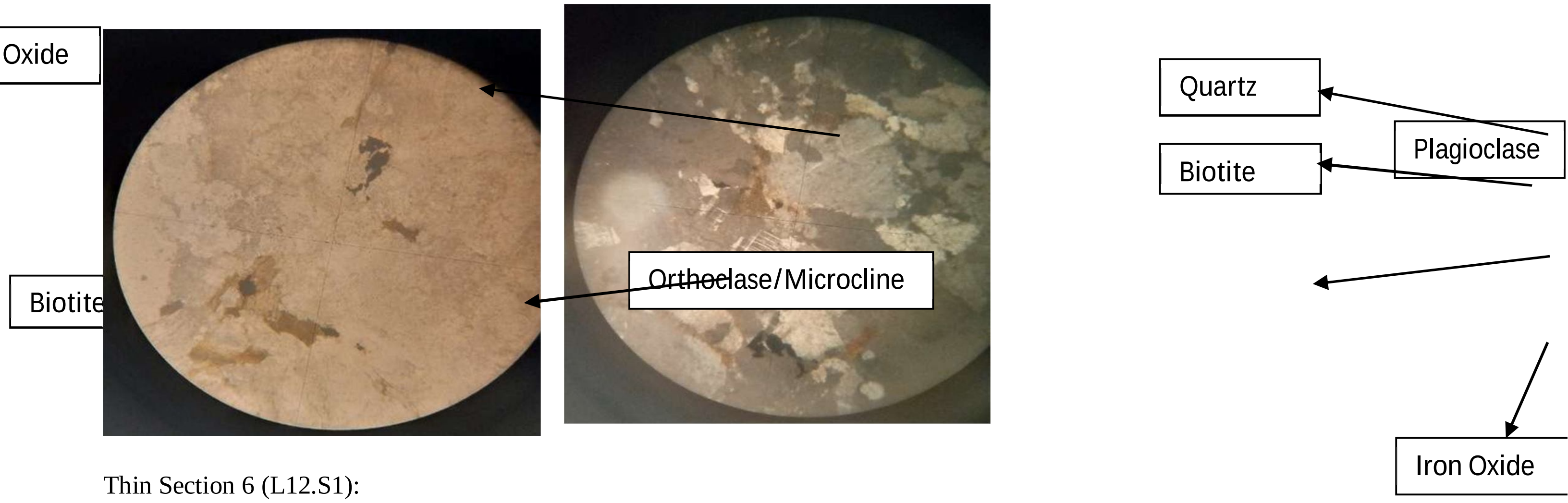

Thin Section 6 (L12.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase/ Microcline, plagioclase feldspar, biotite, and iron oxide. Magnification: X100.

Thin Section 7 (L17.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, no cleavage; irregular boundaries; common undulose extinction	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief, often cloudy; poor cleavage; may show perthitic intergrowths	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic texture visible
Microcline (K-feldspar)	Colourless, low relief; slightly turbid; similar to orthoclase	Low 1st-order gray/white interference colours; distinct cross-hatched (tartan) twinning
Plagioclase Feldspar	Colourless, low relief; may show two cleavages at ~90°; sometimes sericitized	1st-order gray/white interference colours; characteristic polysynthetic (albite) twinning; zoning common
Biotite	Strong pleochroism from light to dark brown; perfect cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; basal cleavage distinct
Iron Oxides (Magnetite/Ilmenite)	Opaque, black in PPL; subhedral to anhedral grains	Remains opaque (black); isotropic

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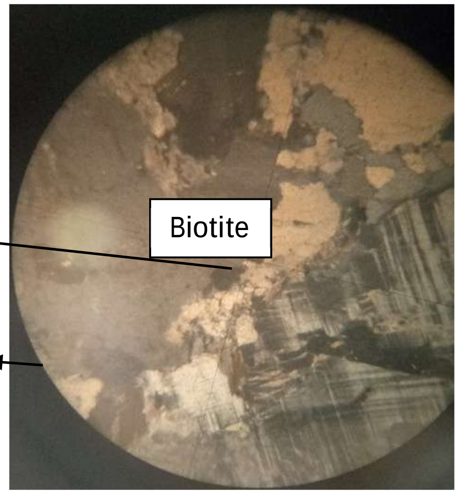
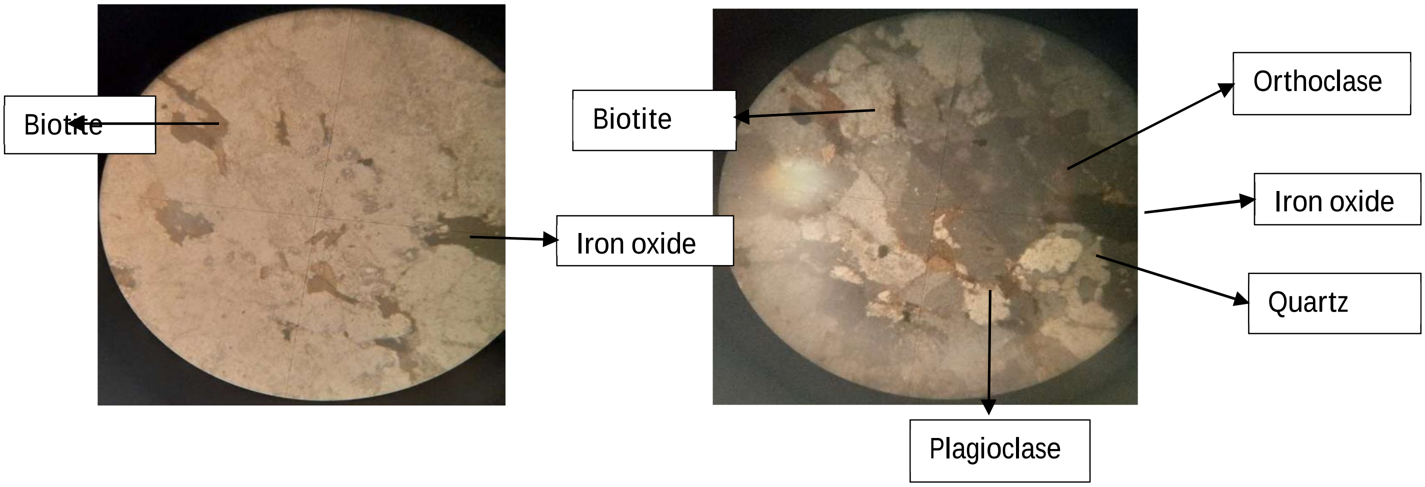


Thin Section 7 (L17.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase/ Microcline, plagioclase feldspar, biotite, and iron oxide. Magnification: X100.

Thin Section 8 (L17.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, anhedral to subhedral; irregular margins; interstitial	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief; often turbid or cloudy; poor cleavage; perthitic texture common	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic intergrowths visible
Plagioclase Feldspar	Colourless, low relief; tabular habit; two cleavages nearly at 90°	Low 1st-order gray/white interference colours; polysynthetic (albite) twinning; faint zoning evident
Biotite	Pale to dark brown pleochroism; strong cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; bird's-eye texture locally
Iron Oxide (Magnetite)	Opaque; black under PPL; anhedral grains	Remains opaque (black); isotropic



Thin Section 8 (L17.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, plagioclase feldspar, biotite, and iron oxide. Magnification: X100.

Thin Section 9 (L24.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, anhedral to subhedral; irregular margins; interstitial	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief; often turbid or cloudy; poor cleavage; perthitic texture common	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic intergrowths visible
Plagioclase Feldspar	Colourless, low relief; tabular habit; two cleavages nearly at 90°	Low 1st-order gray/white interference colours; polysynthetic (albite) twinning; faint zoning evident
Biotite	Pale to dark brown pleochroism; strong cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; bird's-eye texture locally
Iron Oxide (Magnetite)	Opaque; black under PPL; anhedral grains	Remains opaque (black); isotropic

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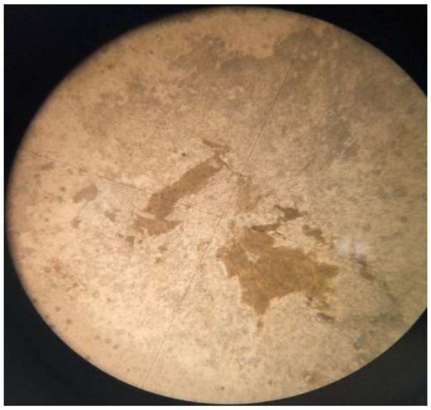

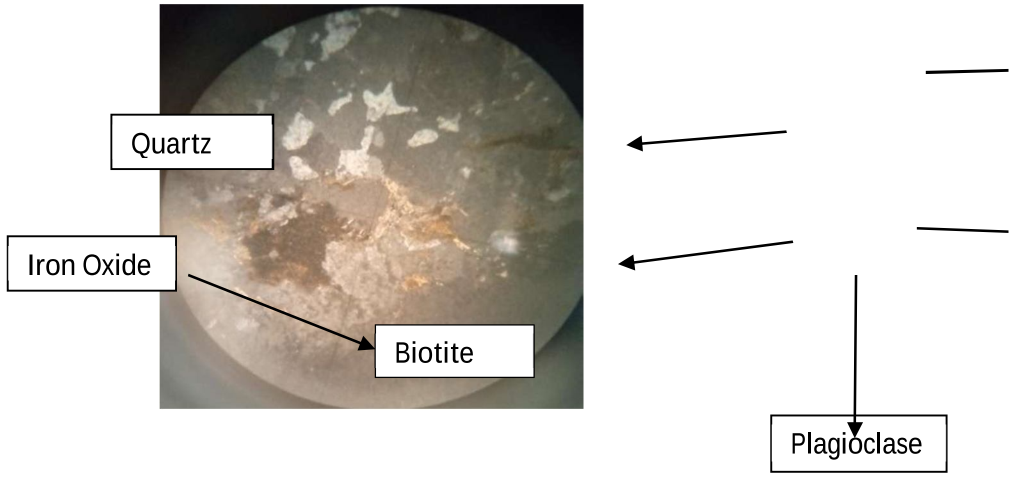

Thin Section 9 (L24.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and under cross-polarized light (XPL) displaying quartz, orthoclase, plagioclase feldspar, biotite, and iron oxide. Magnification: X100.

Thin Section 10 (L24.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, anhedral to subhedral; irregular margins; interstitial	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief; often turbid or cloudy; poor cleavage; perthitic texture common	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic intergrowths visible
Plagioclase Feldspar	Colourless, low relief; tabular habit; two cleavages nearly at 90°	Low 1st-order gray/white interference colours; polysynthetic (albite) twinning; faint zoning evident
Biotite	Pale to dark brown pleochroism; strong cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; bird’s-eye texture locally
Iron Oxide (Magnetite)	Opaque; black under PPL; anhedral grains	Remains opaque (black); isotropic

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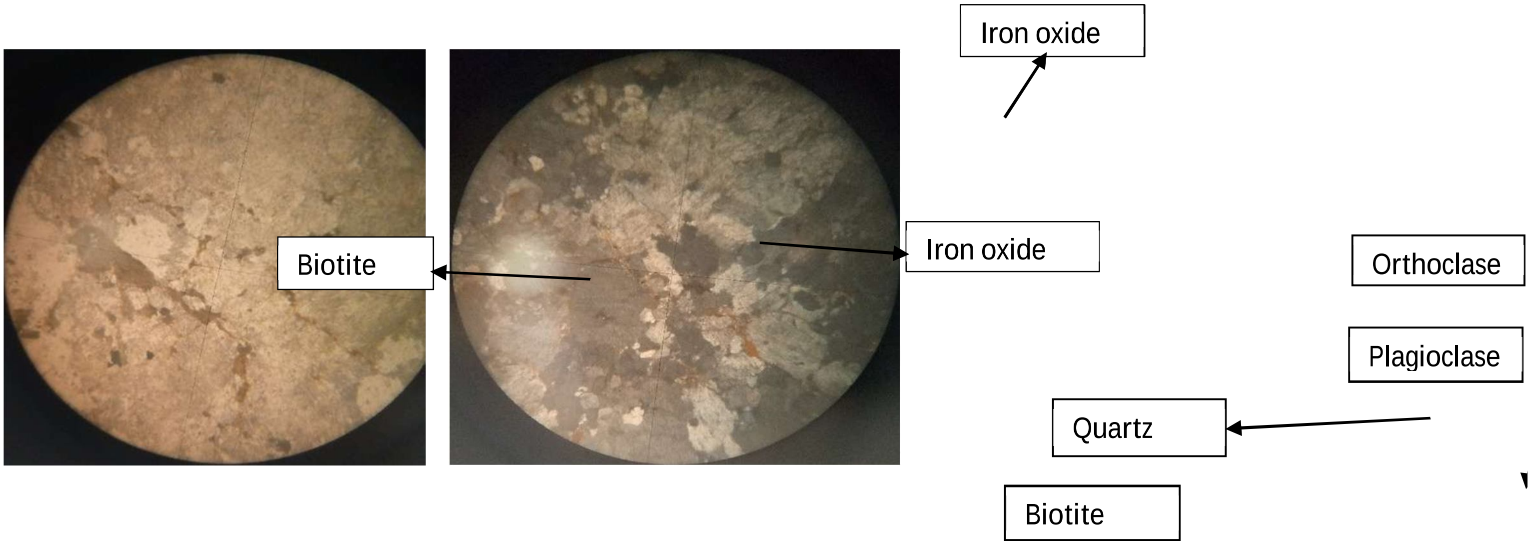

Thin Section 10 (L24.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, plagioclase feldspar, biotite, and iron oxide. Magnification: X100.

Thin Section 11 (L25.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, anhedral to subhedral; irregular margins; interstitial	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief; often turbid or cloudy; poor cleavage; perthitic texture common	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic intergrowths visible
Plagioclase Feldspar	Colourless, low relief; tabular habit; two cleavages nearly at 90°	Low 1st-order gray/white interference colours; polysynthetic (albite) twinning; faint zoning evident
Biotite	Pale to dark brown pleochroism; strong cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; bird's-eye texture locally
Iron Oxide (Magnetite)	Opaque; black under PPL; anhedral grains	Remains opaque (black); isotropic

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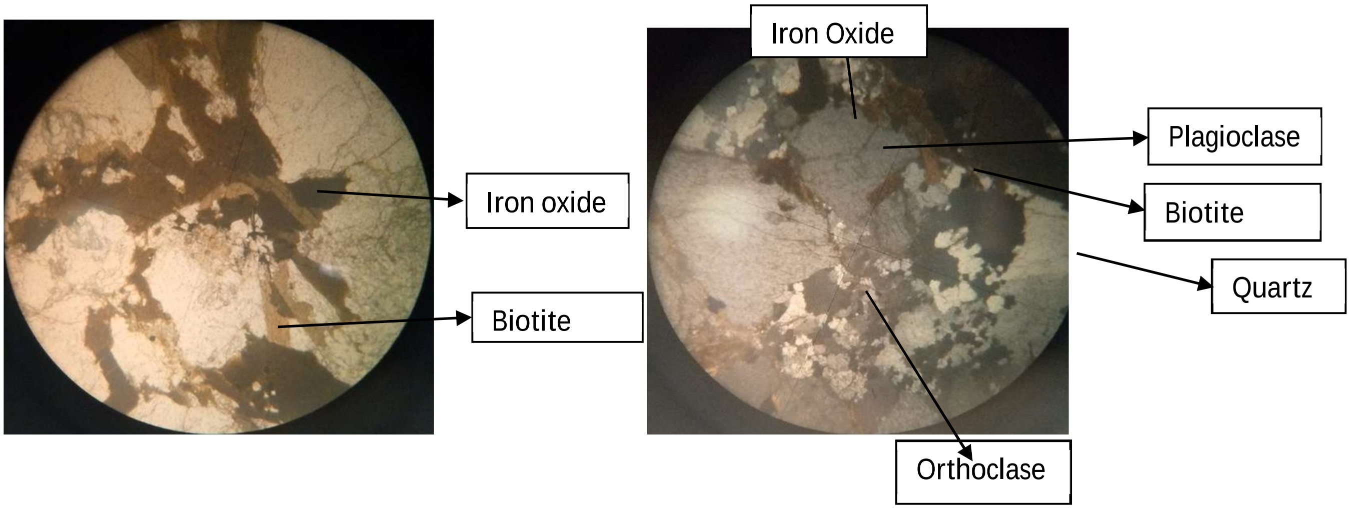
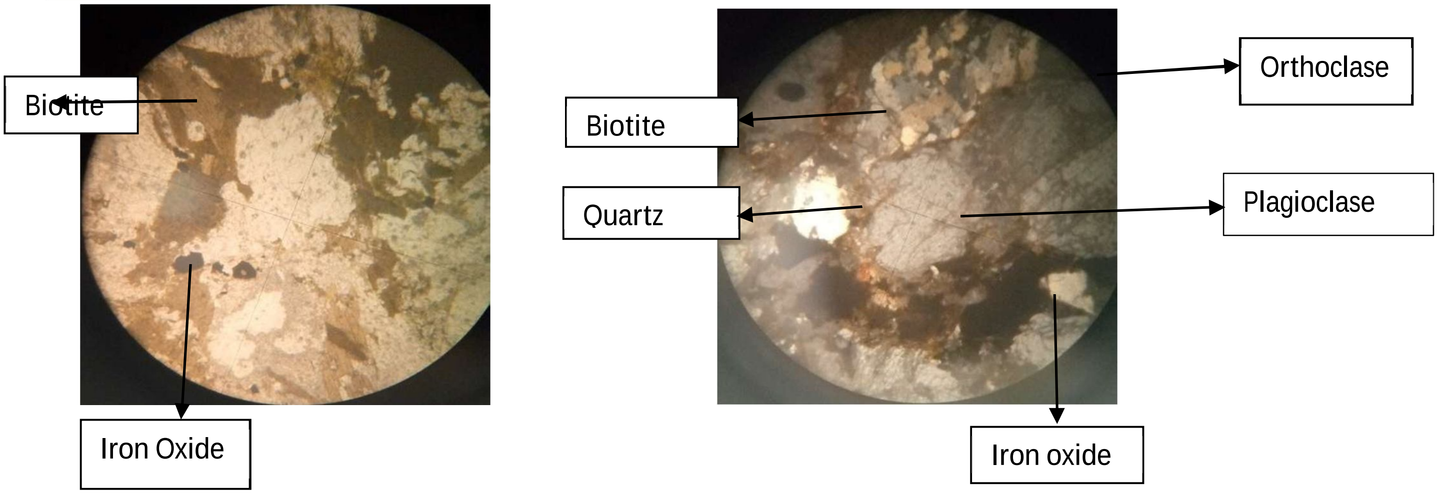


Thin Section 11 (L25.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, plagioclase feldspar, biotite, and iron oxide. Magnification: X100.

Thin Section 12 (L25.S1)

Mineral (in order of decreasing abundance)	Behaviour under Plane-Polarized Light (PPL)	Behaviour under Cross-Polarized Light (XPL)
Quartz	Colourless, low relief, anhedral to subhedral; irregular margins; interstitial	1st-order gray to white interference colours; undulose extinction; no twinning
Orthoclase (K-feldspar)	Colourless, low relief; often turbid or cloudy; poor cleavage; perthitic texture common	Low 1st-order gray interference colours; simple Carlsbad twinning; perthitic intergrowths visible
Plagioclase Feldspar	Colourless, low relief; tabular habit; two cleavages nearly at 90°	Low 1st-order gray/white interference colours; polysynthetic (albite) twinning; faint zoning evident
Biotite	Pale to dark brown pleochroism; strong cleavage; moderate relief	2nd-order bright interference colours; parallel extinction; bird's-eye texture locally
Iron Oxide (Magnetite)	Opaque; black under PPL; anhedral grains	Remains opaque (black); isotropic



Thin Section 12 (L25.S1):
Photomicrograph of medium-grained granite under plane-polarized light (PPL) showing biotite and iron oxide, and under cross-polarized light (XPL) displaying quartz, orthoclase, plagioclase feldspar, biotite, and iron oxide. Magnification: X100.

V. DISCUSSION

The petrographic analysis of the medium-grained granite from the Madagali area in northeastern Nigeria offers valuable insights into its mineral composition, textural characteristics, and petrogenetic history. Twelve thin sections prepared from six representative rock samples were examined under plane-polarized (PPL) and cross-polarized light (XPL). The results show that the granite is predominantly composed of quartz, orthoclase, plagioclase feldspar, microcline, and biotite, with muscovite, sericite, zircon, and iron oxide occurring as accessory minerals. These minerals collectively define a felsic, medium-grained, hypidiomorphic texture typical of slowly cooled intrusive bodies.

Quartz occurs as anhedral to subhedral grains and displays undulose extinction, suggesting post-crystallization deformation or mild recrystallization. Orthoclase and microcline exhibit well-defined Carlsbad and tartan twinning, confirming their magmatic origin. The plagioclase feldspars are commonly sericitized and display polysynthetic twinning, while perthitic intergrowths observed in orthoclase indicate exsolution during slow cooling. Biotite shows pleochroism from light to dark brown and distinct basal cleavage, whereas opaque iron oxides occur as anhedral inclusions, representing late-stage oxidation. Myrmekitic textures developed between quartz and feldspar further support late-magmatic intergrowth and subsolidus crystallization.

The mineralogical composition of the Madagali granite closely resembles other Pan-African granitic intrusions in northeastern Nigeria. El-Nafaty (2015) documented that granites around the Gulani area consist mainly of quartz, microcline, and orthoclase with minor biotite and iron oxide. However, the Madagali granite is distinguished by the presence of additional accessory minerals such as muscovite and iron oxide, along with the occurrence of myrmekitic textures not found in the Gulani samples. Similarly, Sa'ad and Baba (2017) described the Kaltungo Inlier granites as containing quartz, feldspar varieties (albite, orthoclase, microcline, and andesine), biotite, hornblende, and muscovite, with accessory sphene, zircon, and iron oxide. Both the Kaltungo and Madagali granites share major felsic minerals such as quartz, feldspar, and biotite, indicating comparable igneous origins, while the absence of hornblende and sphene in the Madagali granite suggests a more evolved, felsic composition with lower mafic content.

Kamale (2017) studied the geology and mineralization potentials of the Liji and Yelwa areas of northeastern Nigeria, where the granitic rocks consist mainly of quartz, orthoclase, plagioclase, microcline, biotite, and muscovite, with accessory apatite, zircon, and opaque minerals. In contrast to the medium-grained granite of the Madagali area, the Liji and Yelwa granites show muscovite and plagioclase as dominant minerals, with the presence of apatite and opaque minerals being particularly significant. The medium-grained granite of Madagali, however, contains accessory muscovite, iron oxide, and exhibits myrmekitic textures within some quartz grains, features that are absent in the granitic rocks of Liji and Yelwa. This contrast highlights the mineralogical variability of Pan-African granitoids across northeastern Nigeria and reflects differences in magmatic evolution and post-emplacement alteration conditions.

Textural evidence, particularly the hypidiomorphic granular fabric and the absence of foliation, implies emplacement under stable tectonic conditions with minimal deformation after crystallization. The mineral assemblage and overall texture confirm that the rock represents a typical Pan-African medium-grained granite formed through the fractional crystallization of granitic magma. Furthermore, the occurrence of accessory zircon and iron oxide suggests the potential for trace element enrichment and localized mineralization. These observations affirm that the Madagali granite is of magmatic origin and shares a close genetic relationship with other Pan-African granitoids within the Nigerian Basement Complex.

VI. SUMMARY AND CONCLUSION

The petrographic study of the medium-grained granite from Madagali in northeastern Nigeria revealed that the area is largely underlain by granitic and gneissic rocks of Pan-African origin. Microscopic examination of twelve thin sections prepared from six samples showed that quartz, orthoclase, plagioclase, microcline, and biotite are the essential minerals, while muscovite, iron oxide, and myrmekitic intergrowths occur as accessory minerals. The mineral composition and textures, such as undulose extinction in quartz, perthitic and tartan twinning in feldspars, and a hypidiomorphic granular structure, suggest slow crystallization within a deep-seated plutonic environment. When compared with other granites in the region, the Madagali samples display similar mineralogical features, confirming their igneous origin and emplacement during the Pan-African tectonothermal episode. Overall, this study provides valuable insight into the petrogenesis and structural development of the Madagali Basement Complex.

VII. RECOMMENDATIONS

It is recommended that further geochemical investigations be conducted to complement the petrographic results and provide a clearer understanding of the geochemical evolution and petrogenesis of the Madagali granite. Such studies would help define the tectonic setting, source material, and potential for mineralization within the area. Geotechnical evaluations, including tests for crushing strength, aggregate impact value, and resistance to weathering, are also advised to assess the suitability of the granite for construction and other engineering uses. These additional investigations will enhance geological knowledge of the region and promote its potential for industrial development.

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