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Petrography and Geochemistry of Kadanyan Nagora and Its Environs, Sheet 79 Nw, Malumfashi L.G.A., Katsina State, Nigeria

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Research Article

Keywords:

Posted Date: November 17th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11499327/v1

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Additional Declarations: No competing interests reported.

PETROGRAPHY AND GEOCHEMISTRY OF KADANYAN NAGORA AND ITS ENVIRONS, SHEET 79 NW, MALUMFASHI L.G.A., KATSINA STATE, NIGERIA

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Abstract

This study investigates the petrography, geochemistry and structural characteristics of the crystalline rocks of Kadanyan Nagora and its environs, Sheet 79 NW, Malumfashi Local Government Area, Katsina State, northwestern Nigeria. Geological field mapping, structural observations, petrographic examination and whole-rock geochemical data were integrated to characterise the principal lithological units and their compositional variations. The mapped rocks comprise porphyritic granite, granite gneiss and mica schist, with subordinate phyllite, quartzite, pegmatite and quartz veins. Petrographic observations indicate that quartz, feldspar and biotite are the principal minerals in the granitic rocks, whereas the mica schist exhibits pronounced foliation and abundant micaceous minerals. The phyllite is fine-grained and fissile, reflecting its metamorphic fabric. Field observations also reveal joints, quartz and pegmatitic veins, mafic xenoliths in granite, and crenulations in gneissic rocks. Major-element analyses of seven samples show SiO_2 concentrations of 70.83–78.12 wt%, with a mean of 73.82 wt%. Reported K_2O concentrations range from 3.03 to 6.64 wt%, while Na_2O ranges from 0.06 to 0.43 wt%; these values require verification against the original analytical records. Trace-element concentrations vary among the analysed lithologies, indicating compositional heterogeneity within the study area. However, variation in the sums of the reported major oxides highlights the need to validate the analytical data before undertaking detailed geochemical classification or petrogenetic interpretation. The study provides a geological and petrographic framework for the area and a basis for further investigation using verified geochemical data and geochronological methods.

Keywords: Kadanyan Nagora; Nigerian Basement Complex; petrography; whole-rock geochemistry; porphyritic granite; granite gneiss; mica schist; structural geology.

1. Introduction

The Nigerian Basement Complex forms part of the Precambrian crystalline basement of West Africa and occupies a significant position within the Pan-African mobile belt. It comprises an assemblage of ancient crustal rocks that have undergone multiple episodes of deformation, metamorphism, partial melting and magmatic intrusion. The principal lithological components include the Migmatite–Gneiss–Quartzite Complex, the Schist Belts and the Pan-African granitoids, commonly referred to as the Older Granites. These units preserve evidence of complex crustal evolution and tectonothermal reworking, particularly during the Pan-African orogeny [1–3].

The northwestern Nigerian Basement Complex is characterised by the spatial association of granitoids, gneisses, schists and other metamorphic rocks, together with minor intrusions such as pegmatites and quartz veins. Their distribution, mineralogical composition and structural relationships provide important evidence for understanding the geological evolution of the region [1–3]. However, lithological similarities and field relationships alone are insufficient to establish definitive ages, magma sources or tectonic environments. Such interpretations require an integrated assessment of field evidence, petrography, whole-rock geochemistry and, where available, geochronological data.

Geological mapping at the local scale provides a basis for distinguishing lithological units, documenting structural features and evaluating the relationships between igneous and metamorphic rocks. Petrographic examination complements field observations by identifying mineral assemblages and textures, while whole-rock geochemical analyses help characterise compositional variations and assess possible petrogenetic relationships. The combined application of these methods is particularly useful in basement terrains where repeated deformation, metamorphism and intrusive activity may have modified the original characteristics of the rocks [1–3].

Despite the regional importance of the Nigerian Basement Complex, detailed locality-based descriptions remain valuable for documenting lithological variations and establishing geological

frameworks for further investigation. Kadanyan Nagora and its environs, within Malumfashi Local Government Area of Katsina State, provide an opportunity to examine the relationships among granitic rocks, granite gneiss and metasedimentary lithologies, together with associated fractures, quartz veins and pegmatitic intrusions.

This study integrates geological field mapping, structural observations, petrographic examination and available whole-rock geochemical data to characterise the geology of Kadanyan Nagora and its environs, Sheet 79 NW, Malumfashi, Katsina State, Nigeria. The specific objectives are to: (i) identify and map the principal lithological units; (ii) describe their mineralogical and petrographic characteristics; (iii) document the principal structural features and their orientations; (iv) evaluate the major- and trace-element compositions of the analysed samples; and (v) discuss the geological significance of the observed lithological, structural and geochemical variations. The findings provide a local geological reference for subsequent investigations of basement evolution, construction-material suitability and the mineralogical characteristics of associated veins and intrusive bodies.

2. Study Area

The study area is situated around Kadanyan Nagora in Malumfashi Local Government Area, Katsina State, northwestern Nigeria. It is referenced to Sheet 79 NW (Malumfashi) and is reported to cover approximately 50 km², within an approximate geographic range of 11°49′–11°55′ N and 7°32′–7°37′ E. The mapped area includes Kadanyan Nagora and nearby localities associated with the field traverses, including Sahalawo, Leggere, Unguwan Adada, Almajirawa, Kukasheka and Unguwan Sarkin Dange. These settlements and localities provided reference points for documenting outcrops, collecting rock samples and recording structural measurements.

Access to the study area was achieved through local roads, footpaths, cattle tracks and stream channels. These routes facilitated geological traverses across exposed bedrock and weathered terrain. Road cuttings and stream channels provided important exposures of metamorphic rocks, including mica schist, phyllite and quartzite, whereas granitic and gneissic rocks were observed in surface exposures and low-lying inselbergs. Exposure quality varied across the area because of weathering, soil cover and the discontinuous distribution of accessible outcrops.

The study area forms part of the northwestern Nigerian Basement Complex, where granitoids and metamorphic rocks occur in association with structures developed during the region's complex tectonothermal history. The mapped lithologies comprise porphyritic granite, granite gneiss, mica schist and phyllite, with associated quartzite, quartz veins, pegmatitic veins and superficial deposits, including alluvium, laterite and soil. The distribution and field relationships of these units provide the basis for examining the geological and structural characteristics of the area.

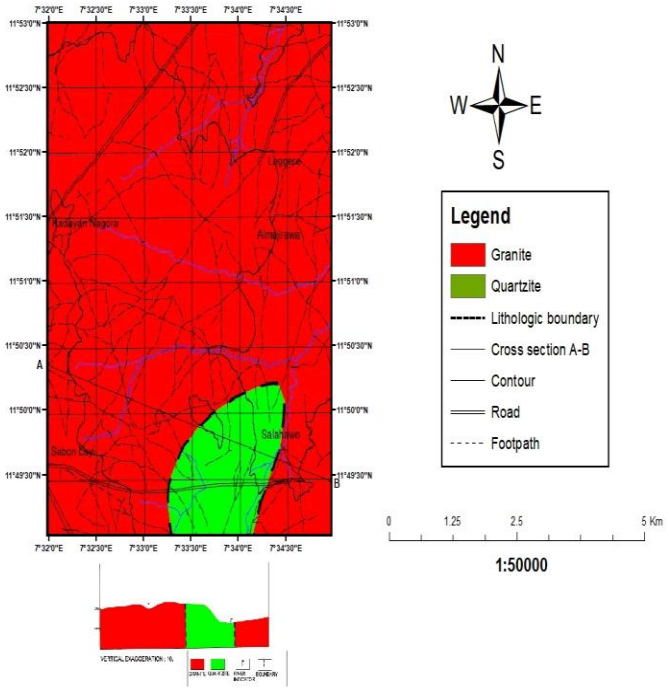


Figure 1: Geological Sketch Of The Study Area

2.1 Geology and Regional Setting of the Nigerian Basement Complex

The Nigerian Basement Complex forms an integral part of the Precambrian crystalline basement of West Africa and occupies a key position within the Pan-African mobile belt, between the West African and Congo cratons. It represents a complex assemblage of ancient continental crust that has undergone multiple episodes of crustal growth, deformation, metamorphism, partial melting and magmatic intrusion. The basement rocks are exposed extensively across central,

southwestern and northwestern Nigeria, where they are locally overlain by younger sedimentary successions. The geological evolution of the complex reflects the interaction of older crustal components with tectonomagmatic processes associated particularly with the Pan-African orogeny [1–3].

The geology of Nigeria is broadly divided into three major components: the Precambrian Basement Complex, the Mesozoic Younger Granite complexes, and the sedimentary basins developed mainly during the Phanerozoic. The Basement Complex comprises predominantly crystalline igneous and metamorphic rocks, whereas the Younger Granites represent anorogenic magmatic intrusions, particularly prominent around the Jos Plateau. The sedimentary basins include the Sokoto, Chad, Bida (Mid-Niger), Benue, Anambra, Niger Delta and Dahomey basins. These geological provinces record different stages of crustal evolution, magmatism, sedimentation and tectonic development within Nigeria [1,4].

The Nigerian Basement Complex is commonly subdivided into three principal lithological assemblages: the Migmatite–Gneiss–Quartzite Complex, the Schist Belts, and the Pan-African granitoids, traditionally referred to as the Older Granites. Minor felsic and mafic intrusions, including pegmatites, aplites, microgranites and dolerite dykes, form an additional component of the basement assemblage [1,5]. These units differ in lithology, metamorphic grade, structural characteristics and geological history, but their field relationships demonstrate that the complex evolved through several interconnected episodes of crustal reworking and magmatism.

The Migmatite–Gneiss–Quartzite Complex is generally regarded as one of the oldest and most extensively developed components of the Nigerian basement. It consists of migmatites, banded and foliated gneisses, quartzites, amphibolites and associated metamorphic lithologies. Some rocks preserve evidence of early crust-forming and metamorphic events, although their original characteristics have been modified by subsequent deformation, recrystallisation and partial melting. Geochronological investigations provide evidence for early crustal evolution followed by substantial isotopic and structural reworking during later tectonothermal events, particularly the Pan-African orogeny [1,2,6].

The Schist Belts constitute another important component of the Nigerian Basement Complex. They comprise predominantly metasedimentary rocks, together with subordinate metavolcanic and associated lithologies, occurring mainly as narrow, approximately north–south-trending belts in western and northwestern Nigeria. Common lithologies include metaconglomerate, quartzite, quartz–mica schist, phyllite, amphibolite and other metamorphosed sedimentary or volcanic rocks. These belts are generally interpreted as supracrustal successions that were deposited on, or developed in association with, older basement rocks and subsequently deformed and metamorphosed. Their lithological diversity, structural relationships and variable metamorphic histories indicate that the belts do not necessarily represent a single, uniform geological sequence [1,4].

The Older Granites, more appropriately described as Pan-African granitoids, form a widespread suite of intrusive rocks emplaced during the Pan-African tectonothermal event. They include granites, granodiorites, tonalites, diorites, syenites and charnockitic rocks, with textures ranging from foliated and gneissic varieties to relatively massive, weakly deformed plutons. Their intrusive relationships with the Migmatite–Gneiss–Quartzite Complex and the Schist Belts provide important evidence for the relative timing of magmatism and deformation. Radiometric ages associated with these rocks span a broad interval, although individual bodies differ in age, composition and emplacement history [1–3]. The granitoids are significant for interpreting crustal reworking, magma generation and the structural evolution of the Nigerian Basement Complex.

Minor intrusive rocks constitute an additional component of the basement terrain. These include pegmatites, aplites, microgranites, quartz veins and mafic dykes, which locally cut across older metamorphic rocks and granitoids. Their cross-cutting relationships are useful for establishing relative geological chronology and identifying late-stage magmatic or hydrothermal activity. Pegmatites may also be associated with minerals of economic interest, depending on their mineralogical composition and geochemical evolution. The distribution and characteristics of these intrusions vary across the basement terrain and are influenced by local structures and the history of magmatic activity [2,3].

The geological evolution of the Nigerian Basement Complex is commonly related to several Precambrian tectonothermal episodes, including the Liberian, Eburnean and Pan-African events; some regional syntheses also discuss a Kibaran-age episode. These events are associated with varying degrees of crustal formation, deformation, metamorphism, magmatism and isotopic resetting. The Pan-African event, broadly associated with the development of the mobile belt, is particularly important because it reworked older crust and involved tectonic interactions between the West African Craton and adjoining continental domains. Consequently, the present-day basement geology reflects both the preservation of older crustal components and their subsequent reactivation during later tectonic events [2,7].

In northwestern Nigeria, the Basement Complex is characterised by the occurrence of migmatitic and gneissic rocks, schist belts and Pan-African granitoids, with local pegmatites, quartz veins and other minor intrusions. The relative abundance and spatial arrangement of these lithologies vary from one locality to another, reflecting differences in protolith composition, metamorphic grade, deformation and intrusive history. The region's geological significance is further enhanced by mineralised zones and lithologies that provide evidence for the complex evolution of the Precambrian crust [8]. Understanding this regional setting provides the geological basis for investigating the lithology, petrography, geochemistry and structural characteristics of individual study areas within the northwestern Nigerian Basement Complex.

For the study of Kadanyan Nagora and its environs, this regional framework provides a basis for examining the relationships among granite, granite gneiss, mica schist and associated quartz veins or pegmatitic bodies. However, the regional geological classification should not be used alone to assign a specific age or tectonic origin to the rocks exposed in the study area. Such interpretations should be supported by field relationships, petrographic observations, geochemical evidence and, where available, geochronological data.

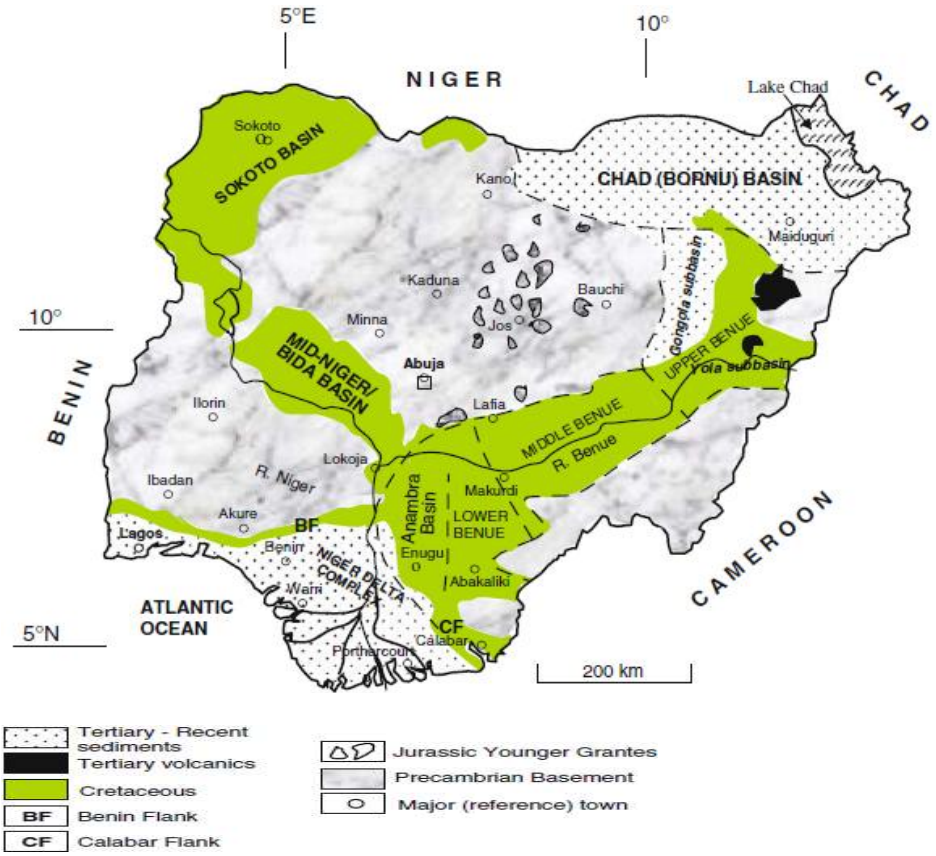


Figure 2.1. Geological sketch map of Nigeria showing the major geological components: Basement Complex, Younger Granites and sedimentary basins (after,Obaje (2006);.

3. Materials and Methods

3.1 Desk Study and Data Sources

The study commenced with a review of existing geological literature, regional geological maps and topographic maps covering Kadanyan Nagora and its environs, within Sheet 79 NW,

Malumfashi, Katsina State, Nigeria. The available topographic map, originally at a scale of 1:50,000, was enlarged to a working scale of 1:25,000 to facilitate field observations and the delineation of lithological boundaries. The desk study provided preliminary information on the regional geology, expected lithological associations and potential geological structures, and informed the planning of field traverses.

3.2 Geological Field Mapping and Structural Measurements

Field investigations commenced with a reconnaissance survey conducted with the project supervisor, followed by detailed geological mapping carried out by the author over approximately one week. Systematic traverses were undertaken on foot along accessible roads, footpaths, cattle tracks and stream channels to obtain representative coverage of the study area, which covers approximately 50 km².

Field mapping involved the identification and description of exposed rock units based on their colour, mineralogical composition, grain size, texture, degree of weathering, structural characteristics and contact relationships. Particular attention was given to the distribution of granite, granite gneiss, migmatitic gneiss, quartzitic rocks, phyllite and associated quartz veins and intrusive features. Lithological boundaries and significant geological features were recorded on the enlarged topographic base map.

Structural measurements were obtained in the field using a compass-clinometer. Where observable, the orientations of foliation, joints, veins and other planar structures were recorded as strike and dip or by the appropriate orientation convention. Evidence of fractures, veins, cross-cutting relationships and possible displacements was documented where present. A handheld Global Positioning System (GPS) receiver was used to record outcrop locations and estimate elevation. Distances between exposures were estimated by pacing where direct measurement was not available.

Representative outcrops and geological structures were documented using field photographs, sketches and written descriptions in a field notebook. Rock specimens were collected from selected in-situ exposures, assigned sample identifiers and linked to their corresponding field

locations. These records were subsequently used to compile the geological map and interpret the spatial relationships between the lithological units.

3.3 Field Equipment

The principal equipment used during field mapping included a geological hammer, compass-clinometer, handheld GPS receiver, topographic base map, field notebook and camera. The geological hammer was used to expose relatively fresh rock surfaces and collect representative specimens. The compass-clinometer was used to measure the orientations of planar geological structures, while the GPS receiver was used to determine geographic positions and record elevation estimates. The topographic base map provided the reference for plotting outcrop locations and geological boundaries. A camera and field notebook were used to document lithological characteristics, structural features, field relationships and other relevant observations.

3.4 Sampling and Sample Preparation

Rock samples were collected from selected outcrops representing the principal lithological units exposed in the study area. The reported sampling programme included porphyritic granite, granite gneiss, migmatitic gneiss, quartzitic rock and phyllite. Sampling locations were selected according to outcrop availability, lithological variation and the suitability of the exposed rocks for petrographic and geochemical investigations. Samples were collected from in-situ exposures where possible, with attention given to obtaining representative material and avoiding visibly weathered surfaces where fresh rock was accessible.

The collected specimens were labelled and documented according to their field locations and lithological descriptions. Samples intended for petrographic examination were submitted for thin-section preparation, while those selected for whole-rock geochemical analysis were crushed and pulverised to obtain fine powders suitable for laboratory analysis. The original notes indicate that thin-section preparation was undertaken through a geological laboratory in Minna, Niger State, while geochemical sample preparation was conducted at the Nigerian Geological Survey Agency (NGSA) laboratory in Kaduna.

3.5 Petrographic Analysis

Selected rock specimens were prepared as thin sections for petrographic examination. The thin sections were examined under a polarising petrographic microscope using plane-polarised light (PPL) and cross-polarised light (XPL). Mineral identification was based on observable optical properties, including colour, pleochroism, relief, cleavage, twinning, interference colours and extinction behaviour, as appropriate [9,10].

Petrographic descriptions focused on mineral assemblages, grain size, texture, mineral relationships and evidence of deformation or recrystallisation. These observations were used to support the field-based lithological classification and to characterise the principal rock types represented by the collected samples. Modal mineral percentages, where reported, should be treated as visual estimates unless quantitative point counting or image analysis was actually performed.

3.6 Whole-Rock Geochemical Analysis

Whole-rock geochemical analyses were reportedly undertaken at the National Geosciences Research Laboratory, No. 1 and 2, Aliyu Makama Road, Barnawa, Kaduna, under the Nigerian Geological Survey Agency. The supplied laboratory description indicates that major and trace elements were determined using X-ray fluorescence (XRF) and inductively coupled plasma-based analytical methods. It also refers to atomic absorption spectrometry (AAS); therefore, the exact analytical technique used for each element should be confirmed from the original laboratory report before submission.

The major oxides reported in the analytical programme included SiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, TiO_2 and P_2O_5, together with loss on ignition (LOI). The stated detection limit for the major oxides was 0.01%, according to the supplied methodology. Major-element concentrations were reported in weight percent (wt%), while trace-element concentrations should be expressed in parts per million (ppm), where applicable.

4. Results and Discussion

4.1 Field Geological Results

Geological mapping of the study area around Kadanyan Nagora, Sheet 79 NW, Malumfashi Local Government Area, Katsina State, revealed four principal lithological units: porphyritic granite, granite gneiss, schist and phyllite. Quartzite, quartz veins, pegmatite and superficial deposits, including alluvium, laterite and soil, also occur within the mapped area. The distribution and field characteristics of the principal lithologies are described below. Rock names are used descriptively, with formal plutonic-rock classification normally requiring mineralogical and modal information [11,12].

4.1.1 Porphyritic Granite

Field geology. The porphyritic granite occurs as intrusive bodies ranging from small outcrops and low-lying inselbergs to large, whaleback-shaped exposures. It is concentrated mainly in the eastern part of the study area. The exposures exhibit variations in texture and mineral composition, both between outcrops and within individual exposures. Joints and quartz veins are among the principal structural features observed in the granite.

Megascopically, the rock is coarse-grained and varies from whitish to pinkish in colour, depending on its mineral composition. It consists principally of plagioclase feldspar, alkali feldspar, quartz and mica. The feldspar phenocrysts are conspicuous in the groundmass, giving the rock its characteristic porphyritic texture. Mica occurs locally in elongated, discontinuous alignments. The relatively high proportion of feldspar observed in some exposures may contribute to the susceptibility of the rock to weathering.



Figure 4.1. Field photograph of porphyritic biotite granite in the study area, at 11°49′08″N, 7°34′51.8″E.

4.1.2 Granite Gneiss

Field geology. Granite gneiss and migmatitic gneiss occupy mainly the western part of the study area. The rocks occur as low-lying exposures and show variable degrees of weathering. Their outcrops display textural and mineralogical variations, as well as structural features including joints and crenulations.

In hand specimen, the granite gneiss is fine- to medium-grained and strongly banded. Alternating bands contain quartz, feldspar and biotite, with platy or elongate minerals displaying preferred orientations. The minerals form an interlocking texture, while the compositional banding is a prominent feature of the rock. The well-developed banding and mineral alignment distinguish the granite gneiss from the more massive porphyritic granite.



Figure 4.2. Field exposure of granite gneiss in the study area, at 11°51′26.7″N, 7°33′23.7″E.

4.1.3 Schist

Field geology. Mica schist is widely distributed in the study area and was estimated during field mapping to occupy approximately 60% of the mapped area. It is generally soft, fine- to medium-grained, strongly weathered and poorly exposed. The best exposures occur along river channels and road cuttings. The schist occurs in spatial association with migmatitic gneiss, granite gneiss and biotite granite.

The rock is light grey to silver-grey in colour when relatively fresh and commonly weathers to rusty brown or reddish-brown. It is strongly foliated and contains more than 50% micaceous minerals, with quartz and feldspar making up the remainder of the observed mineral assemblage. These characteristics support its field identification as mica schist. The schist is interpreted as a pelitic metamorphic rock based on its mineralogical composition and field appearance. The measured structural orientation is generally northeast–southwest, with an average dip of approximately 40° towards the west.



Figure 4.3. Exposure of mica schist intercalated with quartz along a river channel in the study area, at 11°51′30″N, 7°31′44″E.

4.1.4 Phyllite

Field geology. Phyllite is exposed mainly along river channels and road cuttings, where it occurs interbedded with, and locally adjacent to, quartzite. The associated pelitic rocks include minor graphitic and feldspathic schists. The interbedded quartzite is predominantly massive, although well-bedded units several metres thick are also present. The quartzite is interpreted in the field as a detrital rock rather than a chemically precipitated iron–silica formation.

The phyllite is fine-grained and contains minute mica flakes that impart a characteristic fissility, allowing the rock to split along closely spaced foliation surfaces. It is generally grey to greenish-grey and exhibits a pronounced planar fabric. Its texture and foliation are consistent with metamorphism of a fine-grained sedimentary protolith, such as shale or slate. The associated quartzite is hard and quartz-rich.



Figure 4.4. Field exposure of phyllite interbedded with quartzite along a river channel in the study area, at 11°51′30″N, 7°31′44″E.

4.2 Petrographic Results

Petrographic examination was conducted using plane-polarised light (PPL) and cross-polarised light (XPL). The observed mineral assemblages and textural characteristics of the four principal lithological units are described below. Mineral identification is based on the optical properties reported in the available thin-section descriptions [9,10].

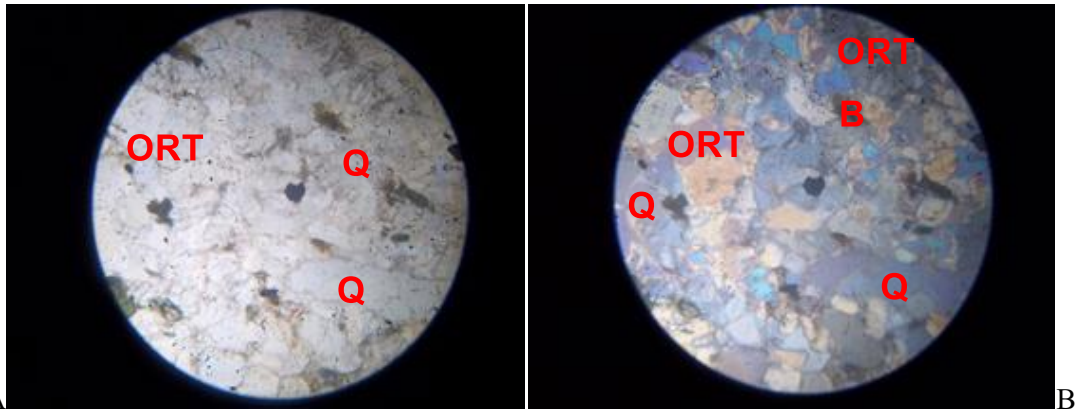
4.2.1 Petrographic Description of Porphyritic Granite

Under the microscope, the granite displays a coarse- to medium-grained texture. The principal minerals identified are quartz, orthoclase feldspar and biotite, together with other feldspar and accessory minerals. The minerals exhibit an interlocking arrangement, while the larger feldspar crystals contribute to the porphyritic character observed in hand specimen.

Quartz occurs as anhedral crystals and appears colourless under PPL, with bluish to milky interference colours reported under XPL. The mineral exhibits low relief. Biotite occurs as relatively large crystals with two prominent cleavage directions and a brown colour under PPL; its optical appearance varies under crossed polars. Orthoclase occurs as anhedral to locally

conspicuous crystals and is reported to exhibit Carlsbad twinning. It appears colourless under PPL and displays light-blue to milky interference colours under XPL.

The combination of quartz, feldspar and biotite, together with the coarse grain size and porphyritic texture, is consistent with the field identification of the rock as biotite-bearing porphyritic granite.



A B

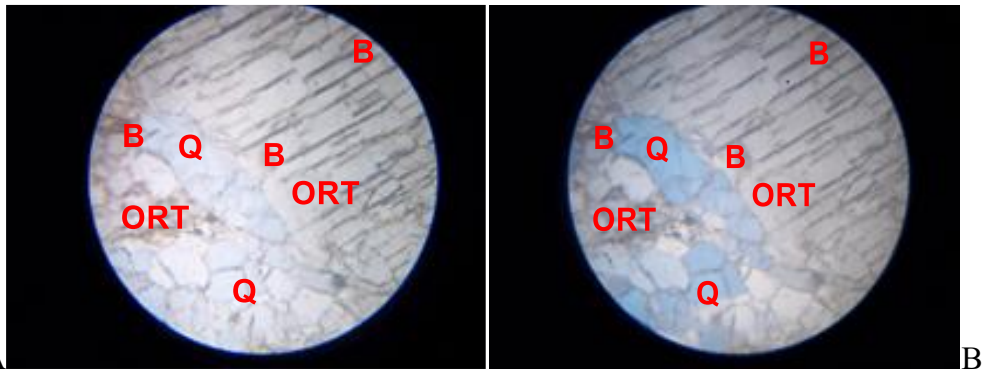
Figure 4.5. Photomicrographs of porphyritic granite under (A) XPL and (B) PPL, showing quartz (Q), biotite (B) and orthoclase feldspar (Or).

4.2.2 Petrographic Description of Granite Gneiss

The granite gneiss displays a fine- to medium-grained texture. Quartz, orthoclase feldspar and biotite are the principal minerals identified during microscopic examination. The minerals occur in an interlocking arrangement, while the preferred orientation of the elongate or platy minerals is consistent with the banded fabric observed in the field.

Quartz is anhedral and is reported to show low to moderate relief. It appears colourless under PPL and bluish to milky under XPL. Orthoclase occurs mainly as anhedral grains and is described as colourless under PPL, with milky interference colours under XPL. Carlsbad twinning is reported in some feldspar grains. Biotite occurs as elongate to locally well-formed crystals and displays two cleavage directions. Its brown to dark-brown appearance and optical characteristics help distinguish it from the colourless quartz and feldspar.

The mineral assemblage and interlocking texture are consistent with the field identification of granite gneiss. The preferred orientation of biotite and the compositional banding observed in the outcrops provide additional evidence of the gneissic fabric.



A B

GN1PP180M GN1XP180M

Figure 4.6. Photomicrographs of granite gneiss under (A) PPL and (B) XPL, showing orthoclase feldspar, quartz and biotite.

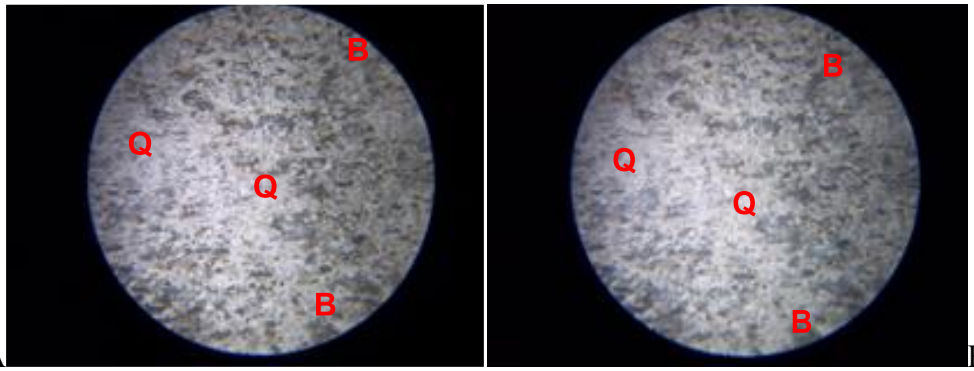
4.2.3 Petrographic Description of Schist

Microscopic examination shows that the mica schist is fine- to medium-grained. Quartz and biotite are the principal minerals identified in the available thin-section descriptions. The mineral grains exhibit variations in shape, ranging from anhedral quartz to more regularly shaped biotite crystals. The abundance of micaceous minerals is consistent with the pronounced foliation observed in hand specimen.

The original field and petrographic estimates indicate that micaceous minerals constitute approximately 60% of the rock, while quartz and feldspar together account for the remaining approximately 40%. In the separate mineral description, biotite was estimated at approximately 60% and quartz at approximately 30%. These values represent the estimates reported for the respective observations; the remaining proportion should not be assigned to a specific mineral without further modal analysis.

Quartz is described as anhedral and colourless under PPL, with bluish to milky interference colours under XPL. Biotite is reported as the dominant mineral and exhibits brown to dark-

brown colours and two cleavage directions. The predominance of mica and the resulting planar fabric support the classification of the rock as mica schist.



A B

SCH1PP72M SCH1XP72M

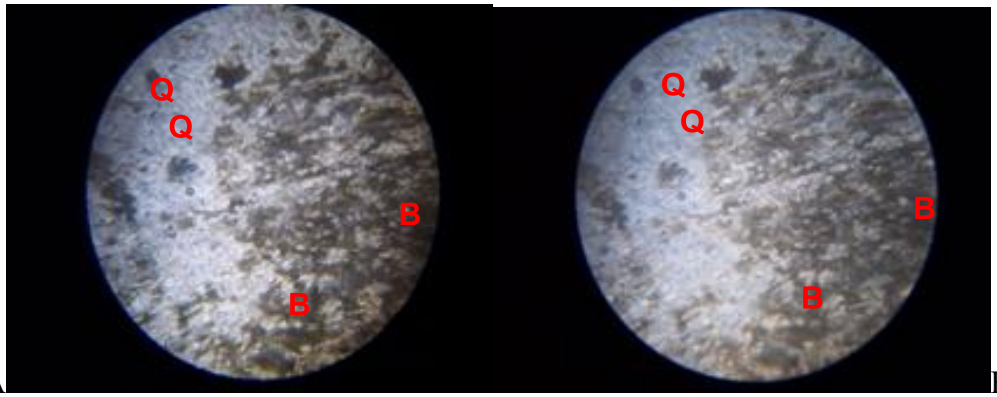
Figure 4.7. Photomicrographs of mica schist under PPL and XPL, showing the principal mineral phases, including quartz and biotite.

4.2.4 Petrographic Description of Phyllite

The phyllite displays a fine- to medium-grained texture in thin section. Quartz and biotite are the principal minerals reported in the available petrographic description. Quartz occurs as anhedral grains, whereas biotite forms platy or more regularly shaped crystals. The fine grain size and presence of micaceous minerals are consistent with the fissile character and foliation observed in the field.

Quartz is described as having low relief and appearing colourless under PPL, with bluish to milky interference colours under XPL. Biotite is reported to show two cleavage directions and brown to dark-brown colours. The association of quartz and mica, together with the fine-grained fabric, supports the field identification of the rock as phyllite.

The petrographic description is based on the minerals reported in the examined thin section. More detailed mineral proportions and diagnostic optical properties would require additional modal estimates and confirmation from the original photomicrographs.



A B

SCH2PP72M SCH2XP72M

Figure 4.8. Photomicrographs of phyllite under (A) PPL and (B) XPL, showing quartz and biotite.

4.3 Mineralogical Descriptions

4.3.1 Mineralogy of Porphyritic Granite

Quartz. Quartz occurs as anhedral crystals and is reported to constitute approximately 40% of the minerals described in the granite. It is colourless under PPL and displays bluish to milky interference colours under XPL. Its low relief and anhedral crystal form are consistent with its occurrence as an interstitial and framework mineral within the granitic texture.

Biotite. Biotite occurs as relatively large crystals with two prominent cleavage directions. It is described as brown under PPL and constitutes approximately 10% of the observed mineral assemblage. Its occurrence is consistent with the identification of the rock as biotite-bearing granite.

Orthoclase. Orthoclase occurs as anhedral crystals, including conspicuous feldspar crystals associated with the porphyritic texture. It is reported to constitute approximately 10% of the minerals described. The feldspar appears colourless under PPL and displays light-blue to milky interference colours under XPL. Carlsbad twinning is reported in the original petrographic observations.

The reported modal estimates do not account for the entire rock composition. Therefore, the remaining proportion should not be assigned to other minerals without additional modal analysis.

4.3.2 Mineralogy of Granite Gneiss

Quartz. Quartz occurs as anhedral grains and is described as having low to moderate relief. It appears colourless under PPL and bluish to milky under XPL. Its interlocking relationship with feldspar and biotite contributes to the granitic mineral assemblage of the rock.

Orthoclase feldspar. Orthoclase is reported as anhedral and generally colourless under PPL, with milky interference colours under XPL. Carlsbad twinning is described in the original observations. Its association with quartz and biotite is consistent with the granitic composition of the gneiss.

Biotite. Biotite occurs as elongate or locally well-formed crystals with two cleavage directions. It is described as brown to dark-brown and contributes to the preferred mineral orientation and compositional banding observed in the rock. Its occurrence, together with quartz and feldspar, is consistent with the identification of the unit as granite gneiss.

4.3.3 Mineralogy of Schist

Biotite. Biotite is described as the most abundant mineral in the examined schist sample, with an estimated proportion of approximately 60%. It is reported to exhibit brown to dark-brown colours, pleochroism, low relief and second-order birefringence. Its abundance is consistent with the micaceous character and strong foliation of the rock.

Quartz. Quartz is described as the second most abundant mineral in the sample, with an estimated proportion of approximately 30%. It occurs as anhedral crystals and appears colourless under PPL, with bluish to milky interference colours under XPL. Quartz occurs with biotite in the fine- to medium-grained fabric of the schist.

The mineral estimates indicate a biotite-rich assemblage. However, the proportions should be regarded as visual estimates rather than precise modal percentages unless they were determined through a quantitative point-counting procedure.

4.3.4 Mineralogy of Phyllite

Quartz. Quartz occurs as anhedral grains and is reported to display low relief. It appears colourless under PPL and bluish to milky under XPL. Its occurrence with biotite is consistent with the mineral assemblage described for the phyllite.

Biotite. Biotite is described as locally well-formed or elongate, with two cleavage directions. It exhibits brown to dark-brown colours in the reported optical observations. The presence of mica is consistent with the foliation and fissility observed in the hand specimen.

The available mineralogical observations identify quartz and biotite as the principal minerals in the examined phyllite. Quantitative mineral proportions were not provided and are therefore not assigned in this section.

4.4 Discussion of Field and Petrographic Relationships

The field and petrographic observations demonstrate lithological variation across the study area, from porphyritic granite to strongly foliated metamorphic rocks, including granite gneiss, mica schist and phyllite. These units can be distinguished by their field occurrence, grain size, mineral assemblage and structural fabric.

The porphyritic granite is distinguished by its coarse-grained texture and conspicuous feldspar crystals. Its quartz–feldspar–biotite assemblage is consistent with a granitic composition. The occurrence of joints and veins indicates that the rock has undergone brittle fracturing, although the timing and origin of these structures cannot be established from the observations presented here alone. The classification of the rock as granite remains descriptive unless supported by quantitative mineral proportions and the appropriate classification procedure [11,12].

Granite gneiss is distinguished by its fine- to medium-grained texture, compositional banding and preferred orientation of minerals. These features differentiate it from the more massive porphyritic granite. The association of quartz, feldspar and biotite supports its granitic mineral composition, while the banded fabric records a pronounced gneissic structure.

Mica schist is characterised by abundant micaceous minerals, strong foliation and a tendency to weather readily. Its mineral assemblage and planar fabric distinguish it from the granite and granite gneiss. The measured northeast–southwest structural orientation and average westward dip provide additional information on the orientation of the foliated rocks in the mapped area.

Phyllite is generally finer-grained and more fissile than the schist, with quartz and mica identified in the examined thin section. Its occurrence interbedded with quartzite indicates an association of contrasting lithologies within the metasedimentary sequence. The field and petrographic characteristics are consistent with a metamorphic origin, although the precise protolith and metamorphic conditions cannot be determined from the available observations alone. General principles of igneous, metamorphic and mineral-fabric interpretation provide a context for these descriptions [13,14].

Overall, the integration of field relationships and thin-section observations provides a basis for distinguishing the four principal lithological units in the study area. These results establish the geological framework for further interpretation alongside structural measurements, geochemical data and the geological map.

4.5 Structural Features

4.5.1 Syn-Tectonic and Emplacement-Related Features

4.5.1.1 Xenoliths

Xenoliths are fragments of pre-existing rock enclosed within an igneous rock that differs in composition from the enclosed fragment. Mafic xenoliths were observed within granite exposures in the study area. They occur as darker inclusions contrasting with the surrounding granitic host and indicate the incorporation of material distinct from the granite during its geological development.

The occurrence of mafic xenoliths within the granite provides evidence of a compositional contrast between the enclosed material and the host rock. However, their precise origin and timing cannot be established from the field observation alone. Further interpretation would

require information on their mineralogy, contacts with the host granite, and any evidence of reaction or deformation at their margins.



Plate 4.13. Field photograph showing mafic xenoliths enclosed in granite in the study area, at 11°51′21.4″N, 7°34′02.9″E.

4.5.2 Post-Emplacement (Secondary) Structures

4.5.2.1 Joints

Joints are fractures in rocks along which no appreciable displacement has occurred. They may develop in response to different stress conditions, including extension, compression and shear, although the origin of a particular joint set cannot be determined from orientation alone. Their description and structural interpretation should be based on the observed fabric, field relationships and measured orientations [15,16].

The granite and gneiss exposures in the study area contain numerous joints. The joint systems are locally intersecting and, in some exposures, form approximately orthogonal patterns. Some fractures are open, whereas others are filled with minerals, including quartz and feldspar. Mineral-filled fractures are described separately as veins where appropriate.

The joint surfaces vary in spacing and continuity, and some fractures intersect or terminate against others. These relationships may help establish relative timing where the intersections are clearly exposed. In general, a joint that terminates against another may be younger than the joint it terminates against; however, this interpretation must be confirmed from the actual field

relationship. The observations also indicate that joints occur in more than one orientation, with northeast–southwest and other directional trends recorded in the field measurements.

The measured strike values for joints in porphyritic granite, granite gneiss and mica schist are compiled in Appendix I. These measurements provide the basis for the joint-orientation rose diagram.

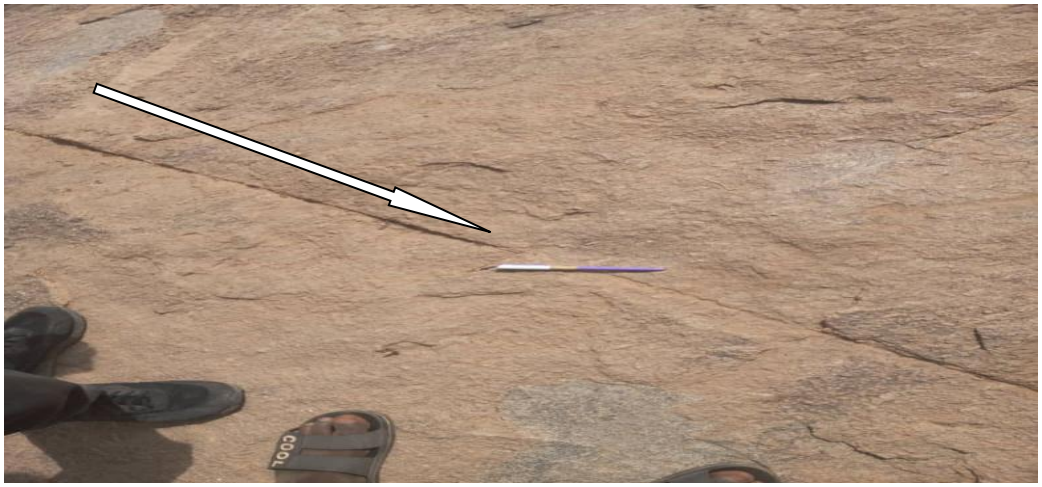


Plate 4.14. Field photograph showing jointed granitic rock in the study area, at 11°53′35″N, 7°35′56″E.



Plate 4.15. Low-lying granite exposure displaying joints in the study area, at 11°51′21.4″N, 7°34′02.9″E.

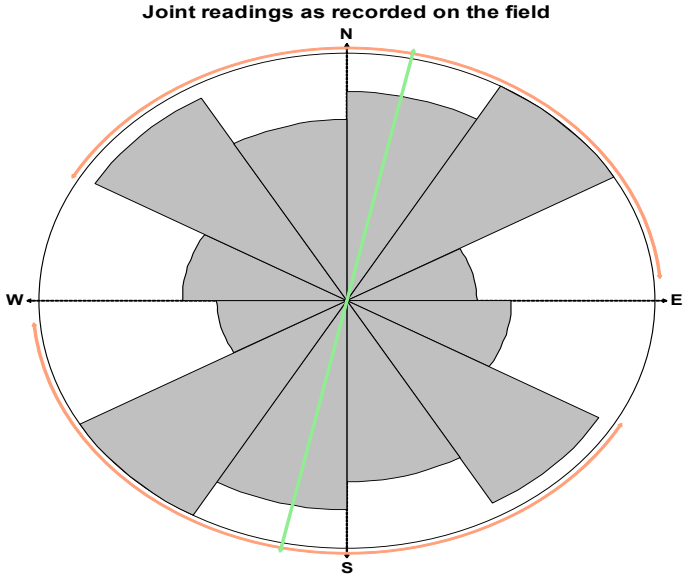


Figure 4.9. Rose diagram showing the distribution of measured joint strikes in the study area.

4.5.2.2 Mineral Veins

Mineral veins occur where minerals fill fractures or openings in pre-existing rocks. In the study area, mineral-filled fractures are associated with granite exposures and include quartz-rich and pegmatitic veins. The veins vary in thickness and orientation, reflecting differences in the geometry of the fractures and the conditions under which the minerals were deposited.

The occurrence of quartz and feldspar in the veins indicates the introduction or crystallisation of mineral material within fractures. Pegmatitic veins containing conspicuous quartz, feldspar and mica are consistent with crystallisation from a residual, volatile-rich magmatic melt. Nevertheless, the precise relationship between individual veins and the emplacement of the host granite would require additional evidence from their contacts, cross-cutting relationships and mineralogical characteristics.

The distribution of veins and their association with joints suggest that pre-existing fractures provided pathways for mineral-bearing fluids or residual melt. Where veins occupy joints, the fractures must have existed before or during vein filling. The relative timing of separate vein

generations should be established from field relationships rather than assumed from mineral composition alone.

4.5.2.3 Quartz Veins

Quartz veins are widely distributed in the study area and occur particularly within granite exposures. They occupy fractures and cracks in the host rocks and are readily recognised by their contrasting colour and resistance to weathering. The veins are generally narrow, ranging from a few millimetres to several centimetres in thickness. The average vein width recorded during field observation is approximately 2.1 cm.

Quartz forms the dominant mineral in these veins. Their occurrence along fractures indicates that the openings provided pathways for quartz-bearing fluids or mineral deposition. The resistant nature of quartz allows the veins to remain prominent on weathered rock surfaces.

Strike measurements were collected from quartz veins at several localities, including Kadanya Nagora, Leggere, Unguwan-Adada, Almajirawa, Sahalawo and Unguwan Sarkin Dange. The recorded measurements are presented in Appendix II and provide the basis for the quartz-vein rose diagram. The observed directional variation indicates that the quartz veins do not all share a single orientation. The dominant trend should be described quantitatively from the completed rose diagram rather than inferred from selected measurements alone.

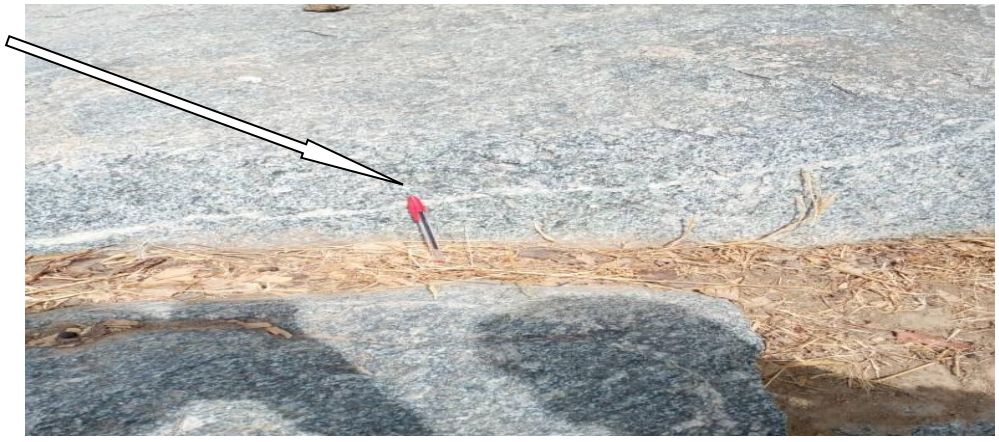


Plate 4.17. Field photograph showing quartz veins cutting granite in the study area.

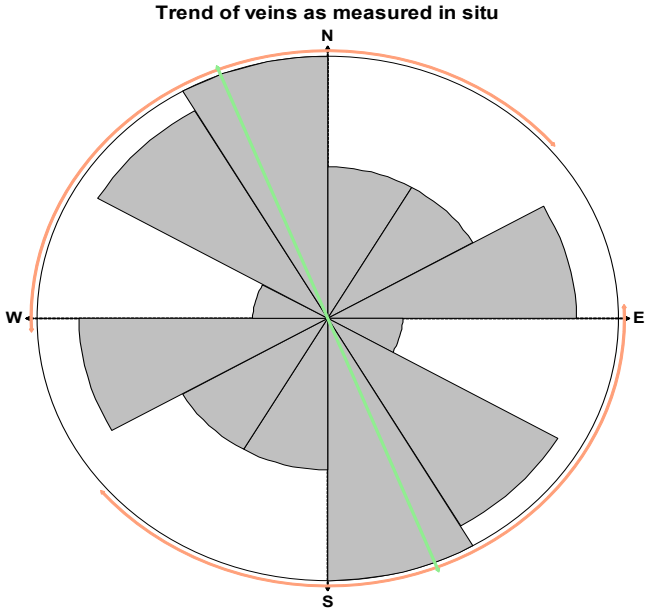


Figure 4.10. Rose diagram showing the distribution of measured quartz-vein strikes in the study area.

4.5.2.4 Pegmatitic Veins

Pegmatitic veins occur as intrusive bodies within the granite exposures of the study area. Pegmatite is an exceptionally coarse-grained igneous rock commonly composed of quartz, feldspar and mica. Its occurrence in veins within granite is consistent with the crystallisation of residual magmatic material during the later stages of magmatic evolution.

The pegmatitic veins are exposed at several outcrops, including those around Kukasheka, and exhibit variations in strike and dip. Their mineral composition and intrusive relationship with the granite distinguish them from the finer-grained host rock. Where the veins cut the granite, their emplacement postdates the formation of the fractures or openings they occupy. Their exact relationship to the final crystallisation of the host granite, however, requires supporting field and petrographic evidence.



Plate 4.18. Field photograph showing pegmatitic veins intruding granite in the study area.

4.5.2.5 Crenulations

Crenulations are small-scale folds or undulations affecting an existing planar fabric, commonly observed in foliated metamorphic rocks. Crenulation cleavage may develop where an earlier foliation is folded and a new cleavage or preferred orientation forms during subsequent deformation. Such features are interpreted using established structural geology concepts, but the precise deformation sequence requires measured structural evidence [15,16].

Crenulations were observed in gneissic exposures in the study area. Their occurrence indicates that the existing planar fabric was affected by deformation after its initial development. This feature is structurally distinct from joints and veins because it involves the modification of an earlier fabric rather than simply the opening or filling of fractures.

The presence of crenulations in the gneiss therefore provides evidence of more than one stage of fabric development or deformation. However, the orientation of the earlier foliation, the crenulation axes and any associated cleavage would need to be measured to establish the

deformation geometry and assess the relationship between this feature and the other structures in the mapped area.



Plate 4.19. Field exposure of granite gneiss showing crenulation of the pre-existing fabric in the study area.

4.6 Geochemical Results and Discussion

Whole-rock geochemical data were available for seven samples: two granites, two granite gneisses and three mica schists. The results are presented as reported in the supplied dataset. Geochemical classification and tectonic interpretation should be treated cautiously because some oxide totals are below 100%, Na_2O values are unusually low, and trace-element records are incomplete. Standard geochemical data interpretation and discrimination diagrams can assist in comparing rock compositions, but should be used alongside petrographic evidence and verified analytical results [17–19].

4.6.1 Major-Element Composition

Table 4.1. Major-element composition of rocks from the study area (wt.%).

Major oxide	Granite	Granite	Granite	Granite	Mica	Mica	Mica

(wt.%)	1	2	gneiss 1	gneiss 2	schist 1	schist 2	schist 3
SiO_2	72.85	71.01	78.12	74.42	74.42	75.09	70.83
Al_2O_3	13.89	13.00	12.37	12.13	11.29	13.36	15.41
Fe_2O_3	2.48	6.29	1.38	1.44	5.46	3.05	2.54
MgO	1.04	1.00	1.90	0.98	1.09	0.28	0.39
CaO	2.04	1.11	0.79	1.02	0.07	0.01	0.08
MnO	0.04	0.16	0.03	0.08	0.11	0.01	0.02
Na_2O	0.10	0.20	0.12	0.06	0.24	0.10	0.43
K_2O	5.08	5.84	4.35	4.04	3.03	4.44	6.64
TiO_2	0.43	0.22	0.63	0.29	0.60	0.31	0.33
P_2O_5	0.12	0.11	0.12	0.11	0.08	0.03	0.04
Calculated sum of listed oxides	98.07	98.94	99.81	94.57	96.39	96.68	96.71

Discussion of Major-Element Composition

The analysed samples are silica-rich, with SiO_2 concentrations ranging from 70.83 to 78.12 wt.%. The highest concentration occurs in Granite gneiss 1 (78.12 wt.%), whereas Mica schist 3 has the lowest value (70.83 wt.%). These results indicate that all seven analysed samples have relatively high silica contents. However, silica concentration alone is insufficient to establish the precise petrogenetic history or tectonic setting of the rocks.

Al_2O_3 ranges from 11.29 to 15.41 wt.%. The highest value occurs in Mica schist 3, while Mica schist 1 has the lowest concentration. The variation may reflect differences in mineral composition and the relative abundance of aluminium-bearing minerals among the analysed lithologies.

Fe_2O_3 varies from 1.38 to 6.29 wt.%. Granite 2 records the highest concentration, while Granite gneiss 1 records the lowest. MgO ranges from 0.28 to 1.90 wt.%, and CaO varies from 0.01 to 2.04 wt.%. These differences indicate compositional variability among the samples. Their

interpretation should consider mineralogical observations and petrographic evidence rather than chemical values alone.

K_2O ranges from 3.03 to 6.64 wt.%, whereas Na_2O ranges from 0.06 to 0.43 wt.%. Potassium oxide exceeds sodium oxide in every sample. This is a notable feature of the reported dataset, but the unusually low Na_2O values should be checked against the original analytical record before conclusions are drawn about alkali enrichment, alteration or magma affinity.

TiO_2 ranges from 0.22 to 0.63 wt.%, while P_2O_5 varies from 0.03 to 0.12 wt.%. MnO ranges from 0.01 to 0.16 wt.%. These oxides occur at comparatively low concentrations in the dataset and may assist in characterising compositional differences when interpreted alongside the petrographic and trace-element evidence.

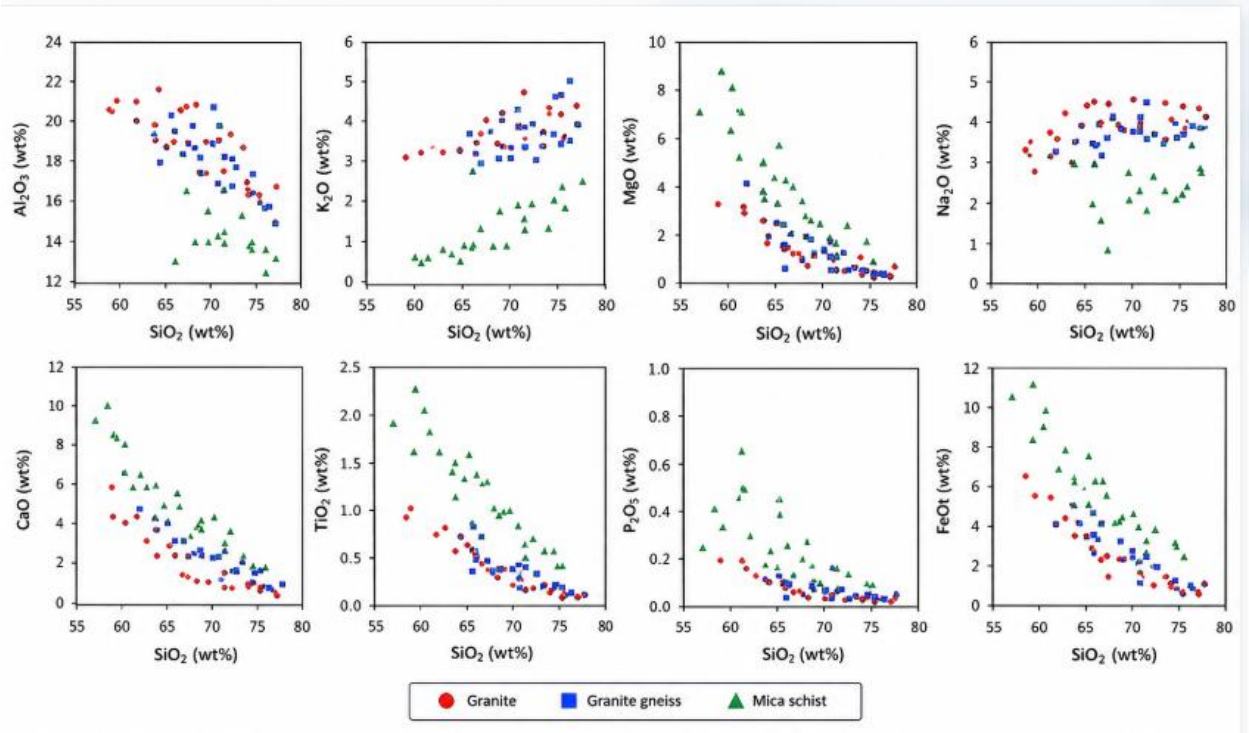


Figure 4.11. Scatter diagrams comparing major-element oxides against SiO_2 for granite, granite gneiss and mica schist from the study area. Panels show Al_2O_3, KO, MgO, Na_2O, CaO, TiO_2, P_2O5 and FeO_t plotted against SiO_2.

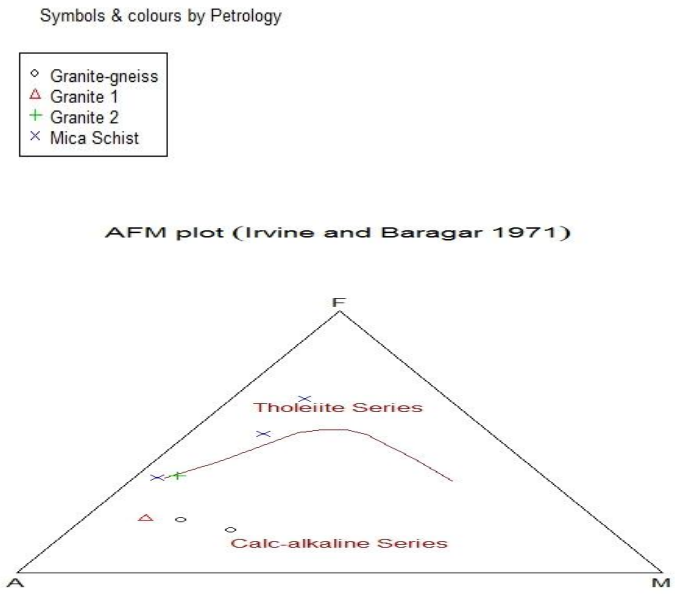
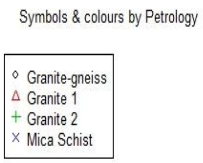


Figure 4.12. AFM discrimination diagram illustrating the reported positions of granite, granite gneiss and mica schist. [20].



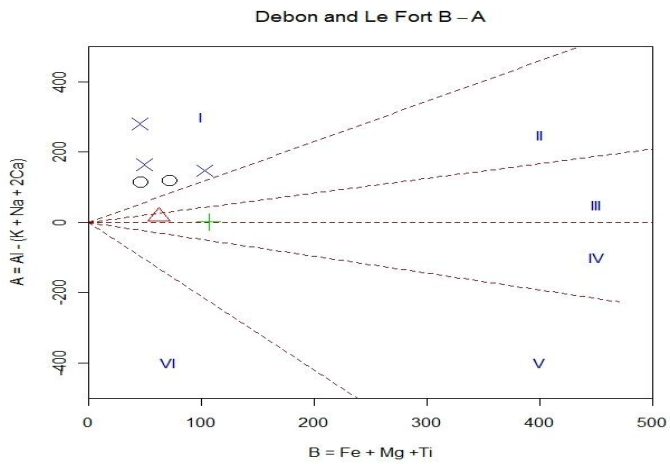


Figure 4.13. A–B geochemical plot of granite, granite gneiss and mica schist, with A calculated as Al − (K + Na + 2Ca) and B as Fe + Mg + Ti.[21]

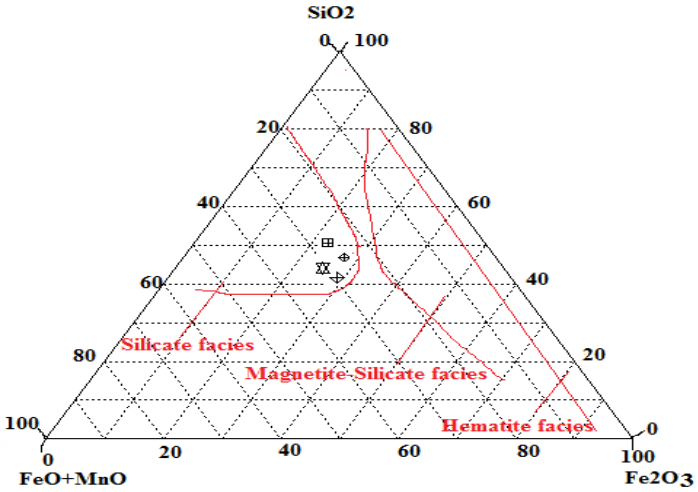


Figure 4.14. Ternary plot of SiO_2, FeO + MnO and Fe_2O_3 for granite, granite gneiss and mica schist. [22]

4.6.2 Trace-Element Composition

Table 4.2. Trace-element composition of rocks from the study area (ppm).[23-24]

Geochemical	Element	Granite	Granite	Granite	Granite	Mica	Mica	Mica

group		1	2	gneiss 1	gneiss 2	schist 1	schist 2	schist 3
LILE	Rb	134	107	11	5	176.6	198.8	260.2
LILE	Ba	1536	1619	258	140	522	367	948
LILE	Sr	242	323	20	13	25.1	25.3	41.3
HFSE	Zr	363	288	28	27	158	268.5	265.3
HFSE	Th	26.1	10	3.7	5.1	7.8	18.2	25
HFSE	U	1.4	1.0	2.0	1.0	2.6	1.7	4.3
HFSE	Y	32	29	15	14	28.7	46.4	65.6
Transition and other trace elements	Sc	21	10	3.8	2.8	—	—	—
Transition and other trace elements	V	137	70	33	76	103	18	17
Transition and other trace elements	Co	—	—	15	8	19.8	4.2	3.6
Transition and other trace elements	Ni	27	4	16	19	49.2	121.2	68.8
Transition and other trace elements	Cu	27	12	12	15	34.4	11.7	11.6
Transition and other trace elements	Zn	102	50	18	18	88	2	25
Transition and other trace elements	Ga	—	—	5	8	16.9	19.3	22.1

REEs	La	—	—	11	11.1	34.7	36.4	68.5
REEs	Ce	—	—	16	16	93.9	89.9	117.8
REEs	Nd	—	—	8	8	30.5	45.9	61.2
REEs	Sm	—	—	2.2	1.6	6.01	9.85	12.32
REEs	Eu	—	—	0.6	0.5	1.31	1.37	1.54
REEs	Tb	—	—	0.5	0.5	0.87	1.45	2.06
REEs	Yb	—	—	1.4	1.5	2.96	5.52	6.48
REEs	Lu	—	—	0.21	0.22	0.45	0.84	0.95

LILE: large-ion lithophile elements; HFSE: high-field-strength elements; REEs: rare-earth elements. A dash indicates that a value was not reported in the supplied dataset; it should not be interpreted automatically as zero or below detection.

Discussion of Trace-Element Composition

The trace-element data show differences among the analysed granite, granite gneiss and mica schist samples. Ba concentrations range from 140 to 1,619 ppm. The two granite samples contain 1,536 and 1,619 ppm Ba, respectively, while the granite gneiss samples contain 258 and 140 ppm. The mica schist samples range from 367 to 948 ppm. This distribution indicates substantial variation in Ba abundance among the analysed lithologies.

Rb concentrations range from 5 to 260.2 ppm. The granite samples contain 107 and 134 ppm Rb, compared with 5 and 11 ppm in the granite gneiss samples. The mica schists contain higher reported concentrations of 176.6–260.2 ppm. Sr shows a contrasting distribution: the granite samples contain 242–323 ppm, whereas the granite gneiss samples contain 13–20 ppm and the mica schists contain 25.1–41.3 ppm. These variations may reflect differences in mineral assemblages and geochemical evolution, but specific mineralogical or petrogenetic explanations require additional evidence.

Zr concentrations range from 27 to 363 ppm. The granite samples contain 288–363 ppm Zr, the granite gneiss samples contain 27–28 ppm, and the mica schists contain 158–268.5 ppm. Y ranges from 14 to 65.6 ppm, with the highest reported concentration in Mica schist 3. Th ranges

from 3.7 to 26.1 ppm, while U ranges from 1.0 to 4.3 ppm. These elements provide useful comparative data, although their significance should be assessed in conjunction with mineralogy and the analytical methods used.

Ni is particularly variable, ranging from 4 ppm in Granite 2 to 121.2 ppm in Mica schist 2. Cu ranges from 11.6 to 34.4 ppm among the reported samples. V varies from 17 to 137 ppm, while Zn ranges from 2 to 102 ppm. These differences suggest compositional heterogeneity among the samples. However, interpretations involving specific mineral sources, alteration processes or tectonic environments should not be based on individual trace-element concentrations alone.

Rare-earth element data are available for the two granite gneiss samples and the three mica schist samples, but not for the two granite samples in the dataset supplied here. La ranges from 11 to 68.5 ppm, Ce from 16 to 117.8 ppm, and Nd from 8 to 61.2 ppm. The reported Sm, Eu, Tb, Yb and Lu concentrations also vary between samples. The mica schists generally have higher reported concentrations of several REEs than the granite gneiss samples.

REE interpretation requires particular care because the data supplied do not include the two granite samples, and the normalisation procedure is not stated. Standard approaches to REE geochemistry use a clearly identified reference composition and appropriate normalisation when comparing patterns and assessing anomalies [21–23]. Consequently, a complete REE-pattern interpretation cannot be made without the missing granite values, confirmation of analytical completeness and an explicitly stated normalisation procedure.

Overall, the trace-element data demonstrate chemical variability among the analysed lithologies. The results provide a basis for comparison, but firm conclusions about magma source, tectonic setting, differentiation or metamorphic processes require verified analytical data and suitable geochemical plots.

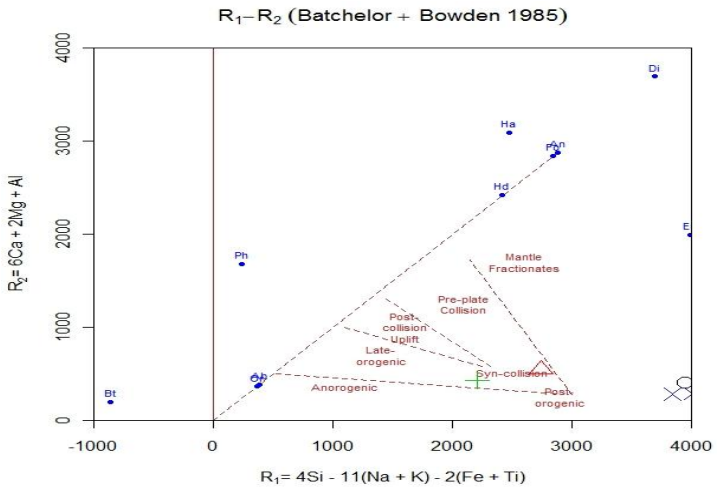


Figure 4.15. R1–R2 tectonic discrimination diagram for granite, granite gneiss and mica schist. [26]

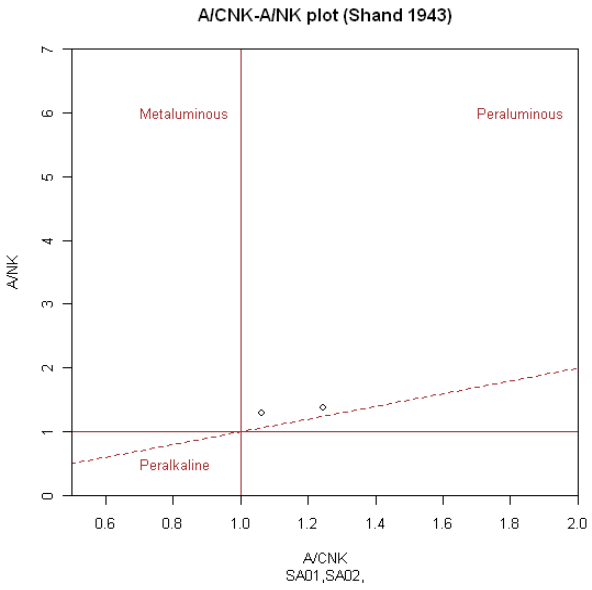


Figure 4.16. Tectonic discrimination diagram for the granite, granite gneiss and mica schist samples.[27].

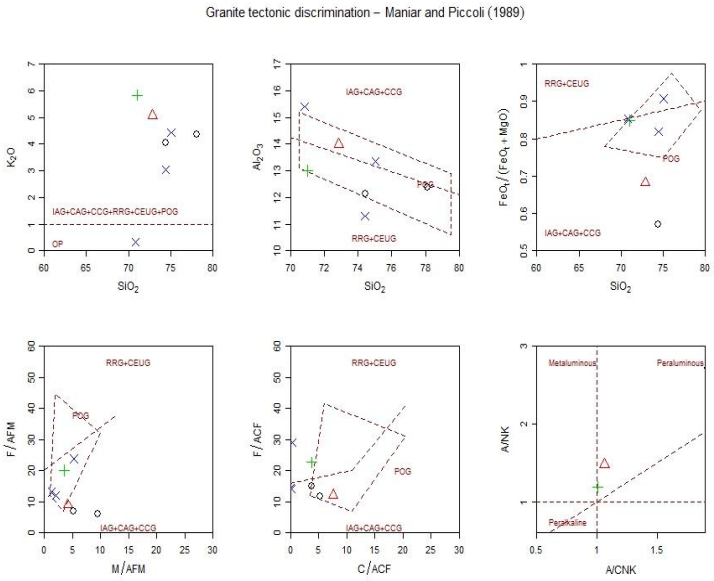


Figure 4.17. Tectonic discrimination diagram for the granite, granite gneiss and mica schist samples, attributed to Maniar and Piccoli [28]

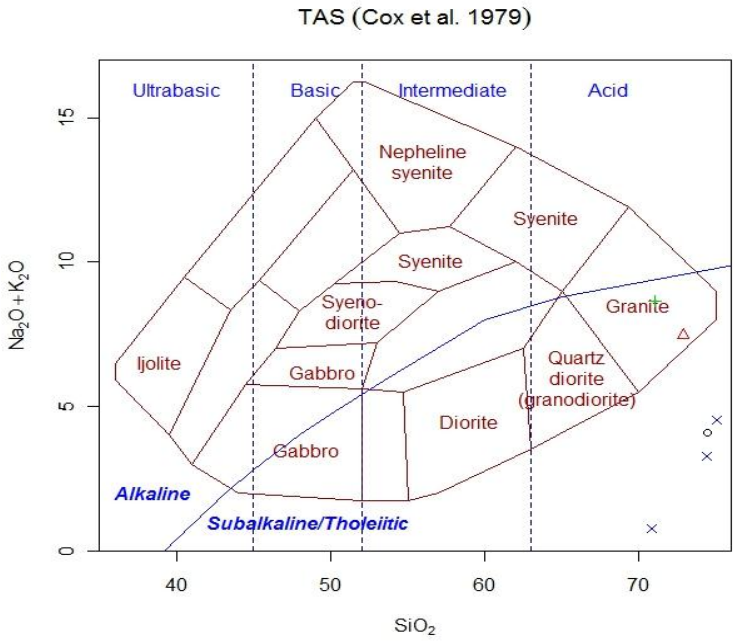


Figure 4.18. Total alkalis versus silica (TAS) diagram for the granite, granite gneiss and mica schist samples [29][30]

5. Conclusion

Geological mapping, petrographic observations and the available geochemical dataset were used to characterise the principal lithologies of Kadanyan Nagora and its environs, Sheet 79 NW, Malumfashi Local Government Area, Katsina State, Nigeria. The mapped rocks comprise granite, granite gneiss and mica schist, with subordinate phyllite, quartzite, pegmatite and quartz veins. The lithologies exhibit contrasting textural and structural characteristics that support their field differentiation.

The porphyritic granite is characterised by conspicuous feldspar crystals and a quartz–feldspar–biotite mineral assemblage. Granite gneiss displays compositional banding and preferred mineral orientation, whereas mica schist is distinguished by its strong foliation and abundance of

micaceous minerals. Phyllite is fine-grained and fissile, and its association with quartzite indicates lithological variation among the exposed metamorphic rocks. Petrographic observations broadly support the field-based identification of these units.

Structural observations include mafic xenoliths in granite, joints, quartz veins, pegmatitic veins and crenulations in gneissic rocks. These features demonstrate variation in the structural characteristics of the mapped lithologies. The measured joint and quartz-vein orientations provide a basis for analysing their directional distributions, although the identification of dominant structural sets and their tectonic significance should be based on verified measurements and completed rose diagrams.

The available geochemical data indicate that the analysed samples contain 70.83–78.12 wt.% SiO_2 and exhibit variations in major- and trace-element concentrations. The reported differences in Ba, Rb, Sr, Zr, Ni and selected rare-earth elements demonstrate compositional variability among the analysed granite, granite gneiss and mica schist samples. However, discrepancies between some reported major-element totals and the sums of the listed oxides, together with incomplete trace-element records, limit the strength of detailed petrogenetic interpretation.

The combined field and petrographic evidence establishes a useful geological framework for Kadanyan Nagora and its environs within the northwestern Nigerian Basement Complex. Nevertheless, definitive conclusions about the age, tectonic setting, magma sources and genetic relationships of the mapped rocks require verified laboratory results, appropriate geochemical classification and, where possible, geochronological data. Future work should prioritise confirmation of the analytical dataset, quantitative mineralogical analysis and additional structural and geochemical investigations.

Acknowledgements

The author(s) thank the Department of Geology, Bayero University Kano, Kano State, Nigeria, for the academic guidance and institutional support associated with this geological investigation. Appreciation is extended to all individuals who provided assistance during field mapping, sample collection, laboratory preparation, and the interpretation of geological observations. The author(s) also acknowledge the laboratory personnel who contributed to the petrographic and geochemical analyses reported in this study.

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Author Contributions

Abubakar Saidu: Conceptualisation, field investigation, geological mapping, sample collection, data compilation, interpretation of petrographic and geochemical data, writing of the original manuscript, and review and editing.

Mustapha Buji Mustapha: Contributions to be confirmed by the authors.

Mukhtar Salisu: Contributions to be confirmed by the authors.

All authors reviewed and approved the final manuscript.

Funding

This study was supported by Bayero University Kano (Grant No. BUK2025002).

Data Availability

All data generated or analysed during this study are included in this published article and its supplementary information files.

Declarations

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Competing Interests

The authors declare no competing interests..

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