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Geology and Occurrence of the Mineralized Lithium Granite Pegmatite of Nunku and Environs, Nasarawa State, North Central Nigeria

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Abstract: *The energy transition challenges faced by modern civilization have significantly enhanced the demand for critical metals like lithium resulting in improved methods to explore, extract, and utilize these metals. In this paper, we discuss a geological and structural study of the Precambrian Basement rocks around Nunku, Akwanga LGA (Nasarawa State, Nigeria), revealing granite pegmatite suites intruding a gneiss basement host. Representative samples were analyzed petrographically. Mineral assemblages include quartz + feldspar + mica ± biotite. The results refine lithological mapping of Sheet 188, Jema'a NE and highlights potential for lithium mineralization. Results also confirm that the granites are fertile, silicic (quartz-rich) and peraluminous, probably suggesting an S-type origin, resulting in the crystallization of Al-rich minerals like Muscovite. Accordingly, the development of the lithium mineralization is related to granite magmatism.*

Keywords: Lithium, Mineralized, Nunku, Granite pegmatite.

INTRODUCTION

The Nigerian Basement Complex constitutes one of the best-exposed fragments of the Late-Proterozoic Pan-African mobile belt in West Africa [1, 2]. It lies south of the Tuareg Shield and is flanked by the West African Craton to the west and the Congo Craton to the southeast (Figure. 1.1). This region records a poly-orogenic history spanning >2.5 Ga, involving at least four major tectono-thermal events: The Liberian (≈2.7 Ga), Eburnean (≈2.0 Ga), Kibaran (≈1.1 Ga) and Pan-African (≈0.6 Ga) orogenies [3, 4]. Each episode imparted distinctive structural, metamorphic and magmatic signatures that are preserved in the present-day outcrop pattern.

Geological Setting: The study area, centered on the small settlement of Nunku in Akwanga Local Government Area, Nasarawa State bounded by latitudes 9° 6′ N – 9° 9′ N and longitudes 8° 23′E – 8° 25′E (Figure 1.1). The area is accessible via the Akwanga–Andaha-Gwantu road, on a trunk A road with other secondary laterite roads and footpaths linking surrounding settlements. Relief is characterized by gently undulating lowlands with scattered hills formed by resistant granitic bodies, while drainage is dendritic to sub-dendritic, dominated by seasonal streams and tributaries flowing toward the Mada and Sanga River systems [5].



Figure 1.1: Location Map of the Study Area

Geologically, the area belongs to the Migmatite–Gneiss Complex of the Nigerian Basement and is intruded by Pan-African Older Granites [2]. The Akwanga axis, including Nunku and environs (part of the Central Pegmatite Field; [6]) is notable for its pegmatite intrusions that are commonly associated with rare elements/rare metals like Sn–Nb–Ta mineralization [7–10]. Structural fabrics in the region are strongly influenced by Pan-African tectonics, with dominant NE–SW foliation and shear zones and subordinate fracture sets trending NW–SE and E–W [11, 12]. Petrographic studies in this area also report schistose rocks with quartz-feldspar-mica and quartz-chlorite-sericite assemblages, recording amphibolite-facies metamorphism [13, 14].

Previous reconnaissance-scale investigations [15] highlighted the complex lithological assemblages and multiple deformation fabrics, but detailed petrographic, geochemical and structural data at the 1: 25,000 scale remain sparse. The paucity of high-resolution studies (especially, remote sensing and GIS and petrogenesis) hampers robust tectonic correlation within the Pan-African belt and obscures the economic potential of the numerous granitic pegmatites that intrude the basement of the study area.

MATERIALS AND METHODS

The material of interest used in this research work are fresh rock samples. Methods employed related to petrography entails macroscopic and microscopic examinations, modal mineralogy and QAP classification [16] scheme.

Petrography

The field mapping employed a scale of 1:100,000 topographic sheet detailed to 1: 25,000 and GPS-controlled traverses. Strike/dip data were collected with a clinometer compass. Sixty-eight (68) fresh rock samples (AA1–AA68) were collected from outcrops along Andaha-Nunku-Anguwan Makama road. Macroscopic hand specimen samples were examined for textures, mineralogy, structures and colour.

Following standard procedures (cutting, grinding, polishing), the samples of rocks collected from the field were thin sectioned at the petrology laboratory of the geology department, Abubakar Tafawa Balewa University Bauchi, using a Black and Becker cutting & Polishing System. Through this method, a standard thin section was produced to a final desired thickness as thin as 30 microns. Petrographic microscopic study was conducted under plane-polarized (PPL) and crossed-polarized light (XPL) using a Zeiss Axio Petrographic Microscope. Modal compositions were estimated by point counting (300 points/section).

RESULTS AND DISCUSSION

Results

Field Occurrence and Sampling

Over nine field-days and 23 outcrop stations were mapped along the Andaha-Nunku-Anguwan Makama road and adjoining footpaths. Sixty-eight rock samples were brought back to the laboratory for studies. The lithologies encountered are grouped into:

(a) pegmatite dykes intruding leucocratic biotite muscovite granites
(b) Leucocratic biotite muscovite granites
(c) Dark, medium-grained biotite granite forming low-lying boulders
(d) Gneisses

Sample Description (Macroscopic Study)

The sixty-eight (68) samples gotten from the field were later regrouped into six (6) representative samples (AA1–AA6) based on similarities of textures, mineralogy, structures and colours identified in hand specimen studies (Plate. I). Their macroscopic features are summarized in Table 1.

Table 1 – Summary of Hand-specimen Macroscopic Features

Sample	Colour & Texture	Key Minerals (hand lens)	Field Rock Name
AA1	Dark, medium (3–6 mm)	Qtz, Bio, Pl ± Mus	Gneiss
AA2	Pinkish-grey, coarse	Qtz, Pl, Mus	Pegmatite
AA3	Light-grey, inequigranular	Qtz, Pl, Bio, Mus	Bio, Mus- Granite
AA4	Dark-grey, fine grained	Qtz, Bio	Biotite granite
AA5	Grey-brown, coarse	Qtz, Bio, Mus	Bio, Mus-Granite
AA6	Pinkish-white, coarse	Qtz, Kfs, Bio, Mus	Bio, Mus- Granite



Plate I: Hand Specimen Samples of; (a & b) Pegmatites (Sample AA2, (c) Biotite Muscovite Granite (Sample AA3, AA5 &AA6) (red delineated lines show zones of lithium enrichment), (d) Gneiss (Sample AA1) and (e) Biotite Granite

Plate I: Hand Specimen for Samples of Rocks of the Study Area.

Petrography (Microscopic)
All thin sections were examined at X- 40 magnifications. Key observations are given below.

Gneiss Samples (AA1)
Quartz is anhedral with undulous extinction. Has a low relief, up to 5 mm. Plagioclase is euhedral to subhedral with polysynthetic twinning (Plate II), perfect {001} cleavage, second-order interference colors.

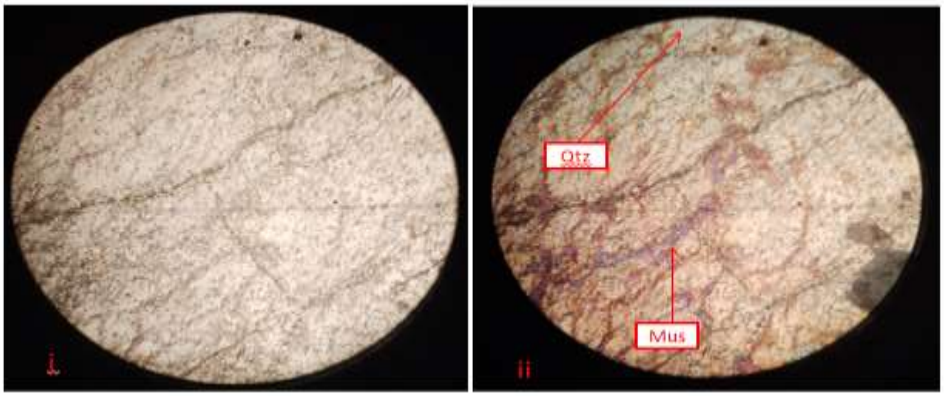


Plate II: Photomicrograph of sample AA1 showing muscovite (Mus) and quartz (Qtz) minerals. (i) PPL and (ii) XPL.
Magnification X40

Pegmatite

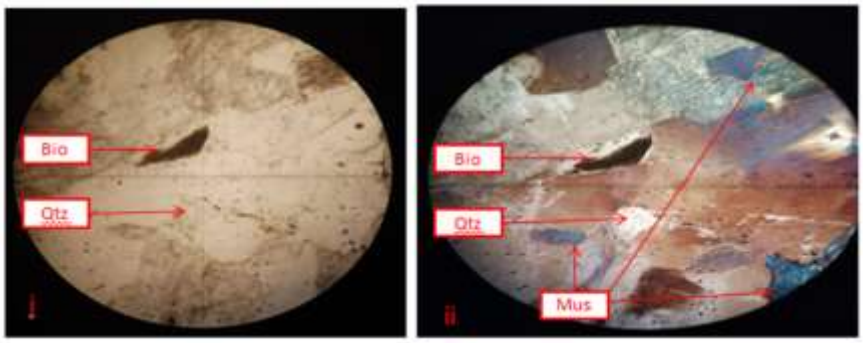


Plate III: Photomicrograph of sample AA2 in (i) PPL and (ii) XPL. Minerals include; Muscovite (Mus) Biotite (Bio) and Quartz (Qtz) Magnification X40

Biotite Granites (AA4)
Biotite is strongly pleochroic yellow-brown, kink bands, partly chloritized along cleavages. Quartz has sutured grain boundaries, sub-grain development (Plate IV). Opaque minerals (<1 %).

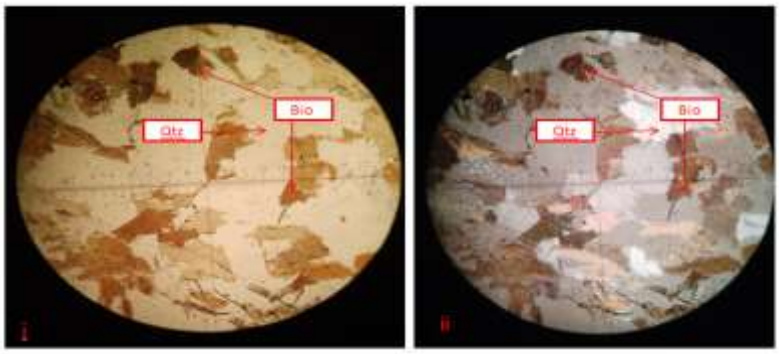


Plate IV: Photomicrograph of sample AA4 in (i) PPL and (ii) XPL. Minerals include; Biotite (Bio) and Quartz (Qtz). Magnification X40

3.1.3.3 Biotite Muscovite Granite (Sample AA3)

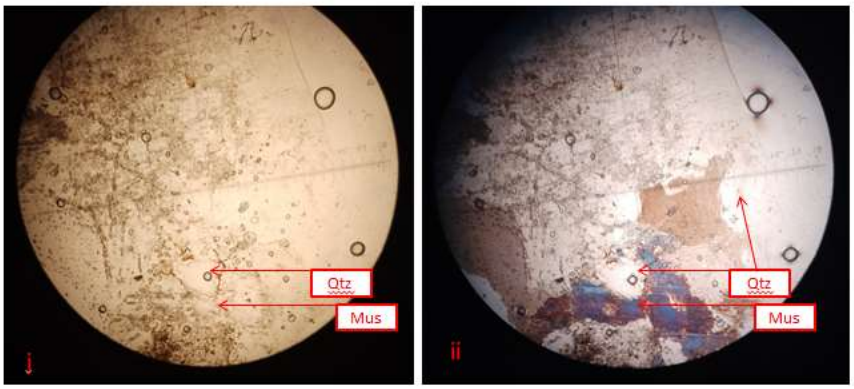


PLATE V: Photomicrograph of sample AA3 in (i) PPL and (ii) XPL. Minerals include;

Muscovite (Mus) and Quartz (Qtz). Magnification X40

Samples (AA5 – AA6)

Sample AA6 has orthoclase with characteristic Carlsbad twinning and perthitic exsolution lamellae. Muscovite is altered to its green secondary enrichment variety (Muscovite is colorless in PPL and blue to green XPL), replacing feldspar along fractures. Quartz is mostly colorless in PPL and light brown in XPL (Plate VII)

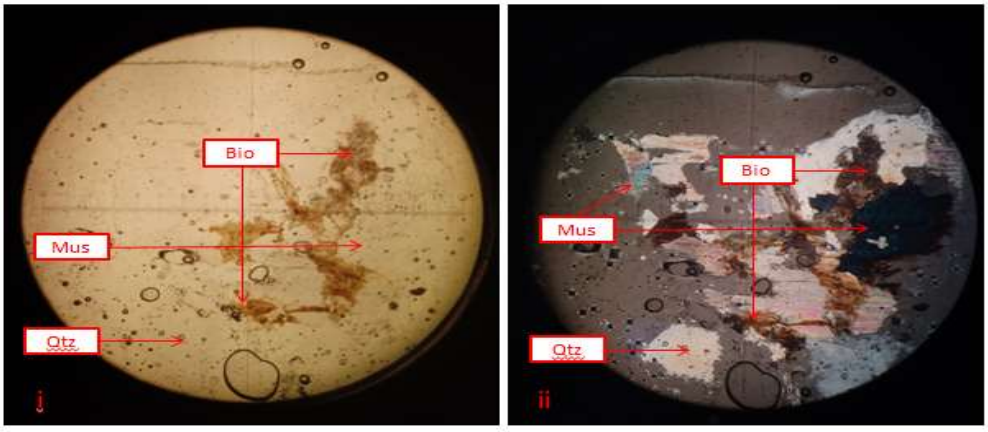


Plate VI: Photomicrograph of sample AA5 in (i) PPL and (ii) XPL. Minerals include; Muscovite (Mus) Biotite (Bio)

and Quartz (Qtz). Magnification X40

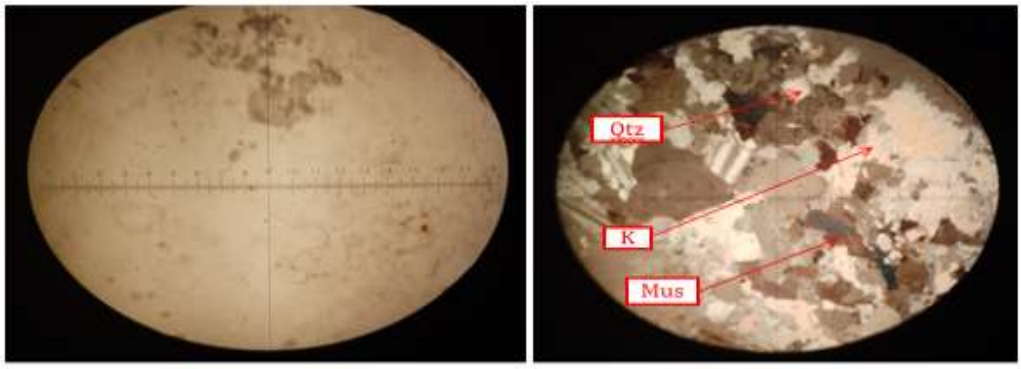


Plate VII: Photomicrograph of sample AA6 in (i) PPL and (ii) XPL. Minerals include; Muscovite (Mu), Quartz (Qtz) and Orthoclase (K). Magnification X40

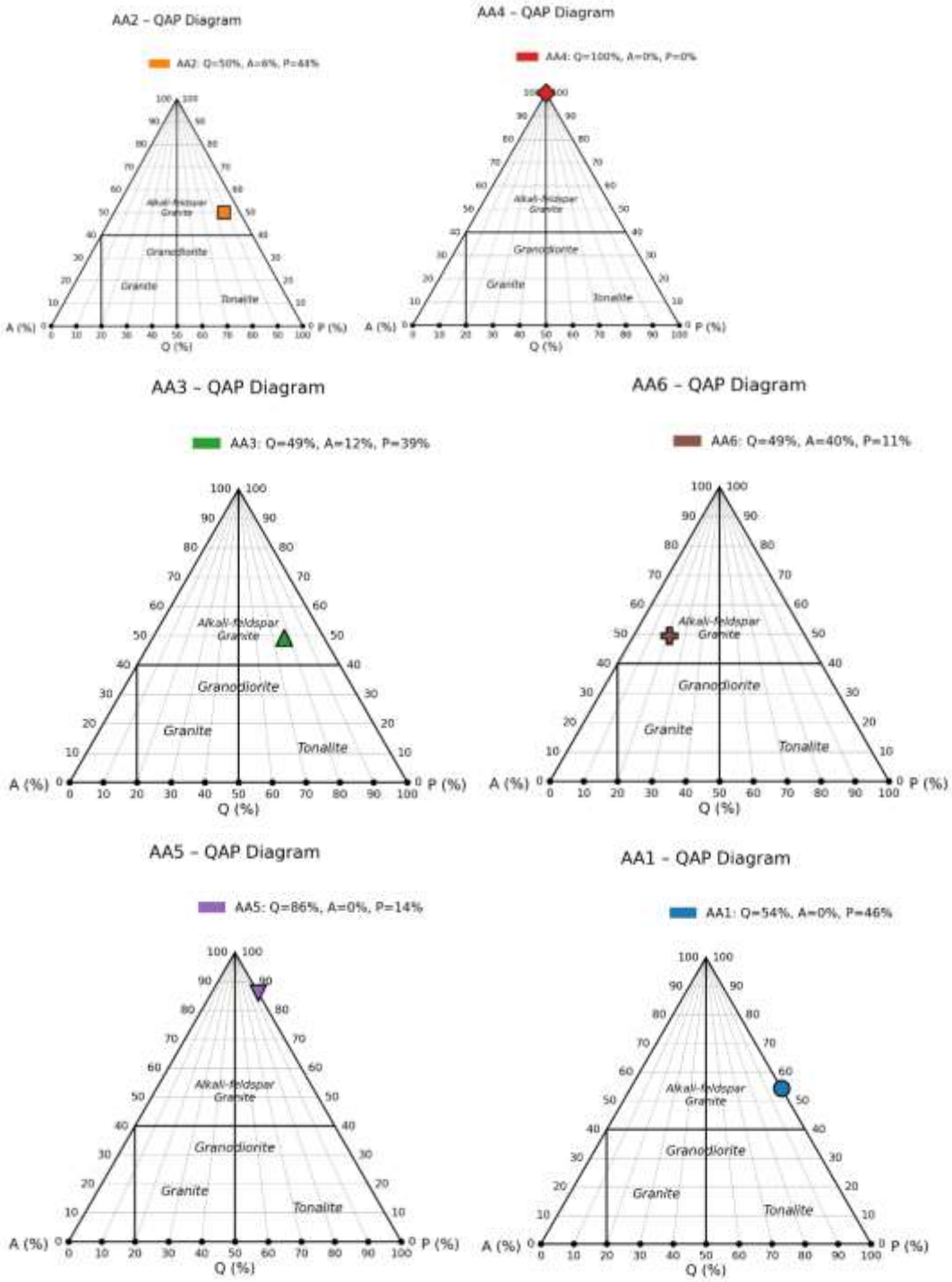
Modal Mineralogy

Point-counting results (300 points each) are presented in Table 2.

Table 2 – Modal abundances (vol %)

Sample	Qtz	Pl	Kfs	Mus	Bio	Others
AA1	38	32	–	-	25	5
AA2	40	35	5	18	–	2
AA3	42	33	10	10	5	–
AA4	45	–	–	–	40	15
AA5	43	7	–	28	15	7
AA6	37	8	30	15	5	5

QAP Classification [16] confirms granite to alkali-feldspar granite fields (Figures 3.1– 3.6).



Figures 3.1 -3.6: QAP Diagrams for sample AA1-AA6

(a) AA1 – Gneiss
Sample AA1 plots on the QAP diagram at Q = 54 %, A = 0 %, P = 46 %, falling squarely in the granite field [16]; Figure 3.6). The pronounced plagioclase dominance over alkali feldspar, together with a moderate quartz content, is consistent with a peraluminous, S-type granite emplaced at shallow crustal levels [13].

(b) AA2 – Pegmatite
At Q = 50 %, A = 6 %, P = 44 %, AA2 also resides within the granite field (Figure 3.1). The slight rise in alkali-feldspar proportion relative to AA1 reflects incipient K-metasomatism during late-magmatic fluid infiltration, typical of Pan-African pegmatite in north-central Nigeria [15].

(c) AA5 – Biotite-Muscovite Granite
With measures of Q = 86 %, A = 0 %, P = 14 %, AA5 lies in the granite field near the Q-P boundary (Figure 3.5). The near-absence of Alkali Feldspar and the high quartz content are attributed to feldspar-depleted restite entrained during late-stage magma ascent [2].

(d) AA6 – Biotite-Muscovite Granite
AA6 plots at Q = 49 %, A = 40 %, P = 11 %, firmly within the alkali-feldspar granite quadrant (Figure 3.4). The dominant alkali feldspar component signifies late-stage fractionation and volatile enrichment, corroborating field evidence of miarolitic cavities and enrichment of rear elements bearing pegmatite veins [5].

(e) AA3 – Biotite Muscovite Granite
AA3 occupies the granodiorite–granite boundary at Q = 49 %, A = 12 %, P = 39 % (Figure 3.3). The balanced quartz–plagioclase–alkali-feldspar ratio indicates a transitional calc-alkaline chemistry, suggesting hybrid magma sources involving both crustal anatexis and minor mantle contribution [3].

(f) AA4 – Biotite Granite
Landing at the Q apex (Q = 100 %, A = 0 %, P = 0 %), AA4 plots as pure quartz on the QAP template (Figure 3.2). This extreme enrichment likely reflects silica flooding along late fracture networks, overprinting the original granite protolith and producing a secondary quartz vein [17].

DISCUSSION

Geology of the Area
The geology of the study area includes gneisses, the two types of granites (biotite granite and biotite muscovite granite-two mica granite) and pegmatites. Their mineralogies include; quartz, biotite and plagioclase (biotite granite), quartz and biotite (gneiss), quartz, biotite, muscovite and feldspars (biotite muscovite granite) and quartz, muscovite, biotite, feldspars ± accessory minerals (pegmatites). The gneiss occupies about 20% by volume of the study area, about 30% for the biotite granite, 48% by volume biotite muscovite granite and 2% pegmatites (Figure 3.7).

The rocks include those of the Basement Complex rocks of Nigeria which were affected by the Pan – African signatures of NE – SW trend directions. The spatial association of pegmatite dykes of the area with NE–SW trend shear corridors indicate syn-kinematic emplacement.

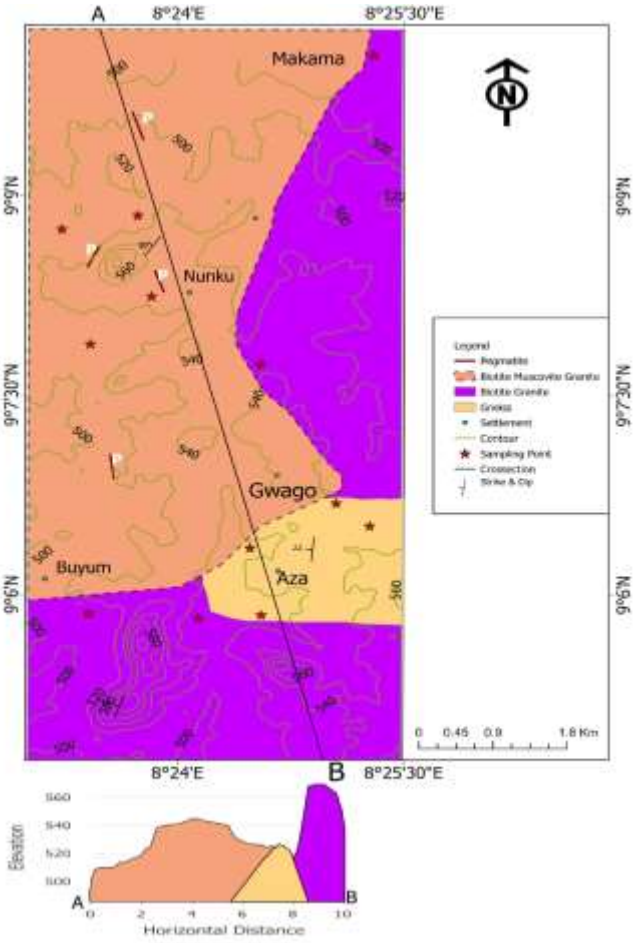


Figure 3.7: Geological Map of the Study Area.

Lithological Evolution

The leucocratic granites/pegmatites (AA3, AA4, AA5 & AA6 / AA2,) represent the felsic end-member of the Pan-African magmatic suite. Their coarse grain size and miarolitic cavities indicate emplacement at shallow crustal levels (<5 kbar). The biotite granites (AA4) are slightly more mafic, suggesting either:

(i) assimilation of metasedimentary enclaves, or

(ii) hybridization with coeval mafic magmas [3].

The observed gradational contacts between pegmatite dykes and host granites support anatectic melting of the basement during Pan-African reheating.

Rare Element Enrichment from Petrological Evidence (Lithium Mineralization)

Pegmatites are coarse-grained igneous and metamorphic rocks that forms during the final stages of magma cooling processes. It is characterized by its coarse-grained texture with crystals often exceeding 1 cm in size. Pegmatites have unique characteristics which include, coarse grained textures, abundance of rare elements such as lithium, cesium and /tantalum, presence of unusual minerals and formation through slow cooling of magma.

Granites are igneous rocks that form from the slow cooling and solidification of magma deep within the earth's crust. It is characterized by its fine, medium and coarse-grained texture and distinctive mineral composition, which typically includes; quartz, feldspar, mica, amphibole and other mineral accessories. Granites and pegmatites basically contain quartz, feldspars and micas. Infiltration of trace elements converts them to many minerals ranging from uneconomic to economic [18]. The colour and texture of the minerals and their changes are the factors that determine their economic viabity [19]. Research shows that k-feldspar is abundant in barren granite, fertile granite and pegmatite. K-feldspar is pink and medium grained in barren granite, whereas in fertile granite and pegmatite, they are white and blocky. K-feldspar in pegmatite can also be grey, peach, pink or green [19]. The colour and texture of muscovite also change with fractionation. Muscovite in barren granite tends to be silver coloured and medium grained. In fertile granite and pegmatite, they are green, brown, silver, rarely pink and coarse grain. The green muscovite usually contains lithium and it shows fractionation, [19]. Plate III is a photomicrograph of pegmatites while Plates IV, V, VI and VII are photomicrographs of the granitoids within the study area. Pegmatite (Plate III) look barren because there is no evidence of development of greenish secondary muscovite implying that there is no enrichment of rare elements. On the other hand, granitoids Plate VI and VII are fertile since they show evidence of greenish secondary muscovite enrichment. Granite (Plate V) display a very coarse primary muscovite (traces of blue primary muscovite, but there is no development of green secondary muscovite and so no enrichment of rare elements). Granites (Plates VI and VII) display enrichment zones where the blue primary muscovite is converting to the greenish secondary muscovite at their transitional boundaries. These granites show enrichment of rare element and could be fertile which are suggested to be parental to the mineralized pegmatites bodies in the research area and are also the primitive and fertile granites that are the most productive and economical granite bodies.

Economic Implications

(a) Feldspar: K-feldspar in AA6 (30 %) is suitable for ceramics.
(b) Quartz: >35 % modal quartz in all samples meets industrial silica specifications.
(c) Mica: Muscovite books (up to 1 cm) in pegmatites are of sheet-mica grade.
(d) Mica: Lepidolite is the lithium bearing mica common in granites, source of lithium for battery and other high-tech industries, also valued for its ornamental uses.

CONCLUSIONS AND RECOMMENDATIONS

The petrographic and modal re-evaluation of studied samples from the Nunku basement confirms that the area records a poly-phase Pan-African history culminating in the emplacement of compositionally diverse felsic magmas. QAP classification [16] places AA1–AA3 and AA5 in the granite field, AA3 on the granite–granodiorite boundary, AA4 at the quartz apex, and AA6 in the alkali-feldspar-granite quadrant. These positions reflect a continuum from early, plagioclase-dominated pegmatitic granites to late-stage, alkali-feldspar-rich leucogranites and silica-flooded quartz veins. The spatial association of pegmatite dykes with NE–SW shear corridors indicate syn-kinematic emplacement, while the extreme quartz enrichment in AA4 documents post-magmatic hydrothermal reworking. Industrially, the high quartz (≥37 %) and feldspar (up to 46 %) contents of most samples constitute viable silica and ceramic-grade feedstock; the alkali-feldspar granite (AA6) additionally hosts Muscovites that meet sheet-mica specifications. We therefore conclude that the Nunku basement is prospective for both industrial minerals (quartz–feldspar–mica) and rare-metal pegmatites (lithium) mineralization and recommends a follow-up on ground geochemistry and geophysics to outline economic shoots.

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Conflict of Interest
The authors wish to declare that there is no conflict of interest.

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