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Petrography and Structural Studies of Rocks of Kufai and Environs, Kaltungo Inlier of Hawal Massif, Northeastern Nigeria

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ABSTRACT

The crystalline basement rocks of Kaltungo inlier is composed mainly of granitic rocks which were later ruptured by volcanic rocks. We employed petrographical and structural studies with the aim to preliminary classify the rock suites, their relationship and structures of Kufai and environs. The granite suites comprised of porphyritic biotite granite and equigranular granites; they both show similar mineralogy that comprised of quartz (~55 vol. %), K-feldspar (~25 vol. %), plagioclase (~10 vol. %), biotite (~10 vol. %). The volcanic suites comprised of trachyte and basalt, the basalt is made up of plagioclase (~37 vol. %), olivine (~20 vol. %), augite (~10 vol. 5%) and Fe-oxides (28 vol. %) while the trachyte is composed of K-feldspar (~70 vol. %), plagioclase ((~10 vol. %), biotite (~10 vol. %) and quartz (~10 vol. %). The structures observed are joints and quartzo-felsdpathic veins. The veins show a dominant trend of NE-SW while the joints show a dominant trend of NW-SE; this is consistent with the major NE-SW lineaments of the Pan-African basement. The gradational contact between the porphyritic biotite granite and equigranular granite indicates they are coeval, and the sharp contacts between the granitic and volcanic suggest a later event. Based on the mineralogical and structural features of the studied rock, the granite suites is part of the Pan-African basement whereas the volcanic rocks are likely part of Tertiary volcanics of northeastern Nigeria.

Keywords: Kaltungo inlier, Quartz-trachyte, K-feldspar, Petrography, Northeastern Nigeria

INTRODUCTION

Over three decades, igneous rock classification is a subject of debate in order to create a comprehensive grouping of these rocks (Le Bas and Streckeisen, 1991; Middlemost, 1991; Le Maitre et al., 2002; Lustrino et al., 2024). Early attempts of classifications varied, some were based on petrography and mineralogy, and few looked into the chemistry of rocks (Le Bas and Streckeisen, 1991; Le Maitre et al., 2002). The chemistry most times produced a complex nomenclature to categorize each rock, thus never found global acceptance (Le Bas and Streckeisen, 1991). Mineralogical and chemical approach gain more recognition in rock classification as the basis for distinguishing igneous rocks. This approach involves the identification of mineral assemblages to distinguish one rock from another, most common for coarse-grained granite but for fine-grained is difficult to get the accurate mineral assemblages without the chemistry of the rock (Le Bas and Streckeisen, 1991; Middlemost, 1991; Le Maitre et al., 2002; Lustrino et al., 2024).

International Union of Geological Sciences (IUGS) Subcommission on the Systematics of Igneous rocks brought up ten principles as the rationale to systematically distinguish one rock from another (Le Bas and Streckeisen, 1991). The important tools used are the

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constituent minerals such as feldspar, feldspathoids and quartz as the major component for mineral classification. The classification differentiates and classifies igneous rock using QAPF ternary diagrams for volcanic and plutonic rocks having felsic minerals >10% and mafic minerals <90% by volume (Le Bas and Streckeisen, 1991; Le Maitre et al., 2002; Lustrino et al., 2024).

More than half of Nigeria is underlain by igneous rock of various ages ranging from Precambrian to Tertiary (Dada, 2008; Bute et al., 2020; Maurin et al., 1986; Bolarinwa and Bute, 2016). Many researchers had adopted the QAPF diagrams coupled with the structural features to group these rocks and fit them into the regional geodynamic context (Bute et al., 2022; Bute et al., 2020; Christopher et al., 2022). Kufai and environs, part of Kaltungo inlier of Hawal Massif, northeastern Nigeria comprised of both plutonic and volcanic rocks, thus is good laboratory for igneous rock classification and structural investigation. More so, Hawal Massif is amongst the least studied region in Nigeria (Bassey and Agbo, 2014).

REGIONAL GEOLOGIC SETTING

Nigeria is situated in the West African sub-region and lies between longitudes 3^o and 14^{o}E and latitudes 4^o and 14^{o}N (Ajibade et al., 1987; Ferré et al., 2002; Obaje, 2009). The geology of Nigeria however, is made up of three major lithological units, namely; The Basement Complex; The Younger Granite; The Sedimentary Basins. The Basement Complex, which is Precambrian in age, is made up of the Migmatite-Gneiss Complex, the schist belts and the Older Granites (Dada, 2008; Islam and Baba, 1992). The Younger Granites comprises of several Jurassic magmatic ring complexes centered in Jos and other parts of north-central Nigeria. They are structurally and petrologically distinct from the Older Granites. The Basement Complex is one of the three major litho-petrologic components that make up the geology of Nigeria (Ajibade et al., 1987; Dade , 2006; Garba, 1988). The Nigeria Basement Complex forms part of the Pan-Africa mobile belt and lies between the West African and Congo cratons and south of the Tuareg Shield (Dada, 2008). It is intruded by the Younger Granites and is later overlain by Cretaceous younger sediments. The Nigeria basement was affected by the 600 Ma Pan-African Orogeny and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West Africa craton and the active Pharusian Continental margin (Dada, 2008; Ferre et al., 2002; Ferre et al., 1998).

The basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism, granitisation and remobilization corresponding to the Liberian (2,700±200 Ma), the Eburnean (2,000-200 Ma), the kibaran (1,100-200 Ma), and the Pan-Africa cycles (600-150 Ma). The first three cycles were characterized by intense deformation and isoclinals folding accompanied by regional metamorphism, which was further followed by extensive migmatization (Abba, 1983; Dada 2006; Dada 2008). The Pan-Africa deformation was accompanied by a regional metamorphism, migmatization and extensive granitisation and gneissification which produced syntectonic granite and homogeneous gneisses (Abaa, 1983). Late tectonic emplacement of granite, granodiorites and associated contact metamorphism accompanied the end stages of this last deformation (Mcurry, 1971; Islam and Baba, 1992).

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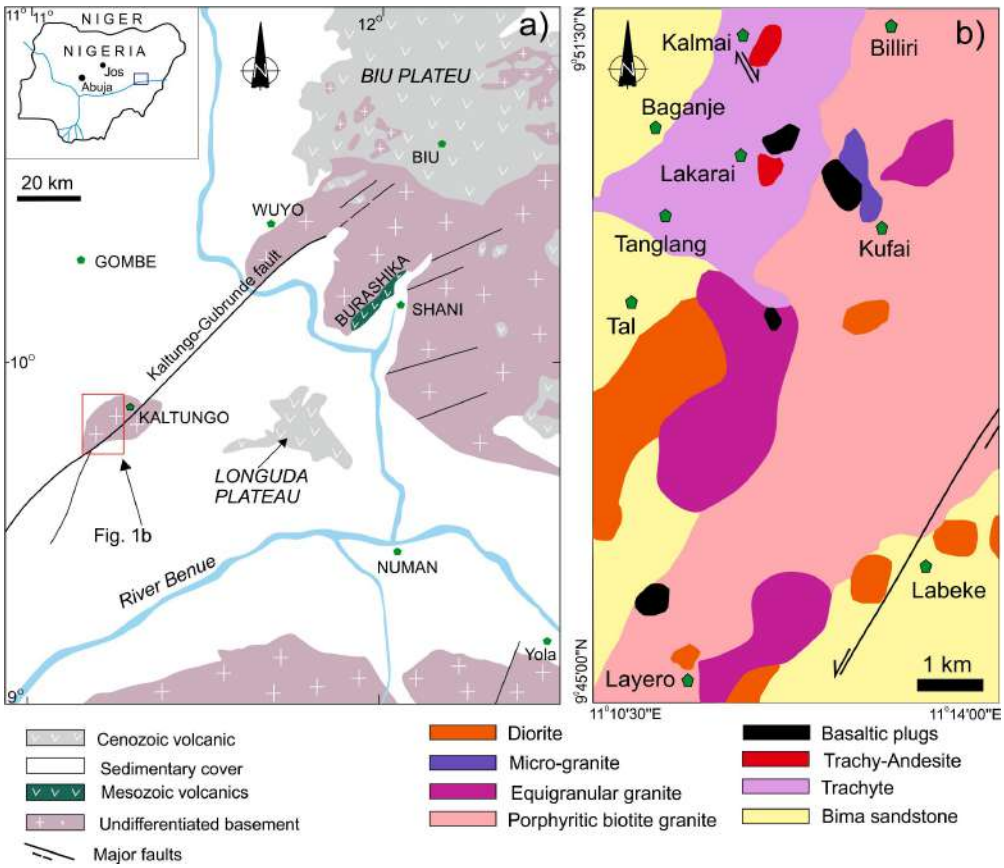

Figure 1: (a) Regional geological map of Upper Benue Valley showing the Kaltungo-Gubrunde inliers (modified from Maurin et al., 1986); (b) Geological map of Kufai and environs (Western Kaltungo inlier), modified from Tabale et al., (2017).

The Kaltungo inlier to a large extent is part of the Hawal Massif (Figure 1a). The Kaltungo and Gubrunde inliers form the western part of the Hawal Massif in the Eastern Nigeria Terrane (ENT). These inliers are structurally controlled by the Kaltungo-Gubrunde fault which trends NE-SW (Figure 1a). The Precambrian basement rocks and the Tertiary to Recent volcanics dominate the western Hawal Massif (Bolarinwa and Bute, 2016), while the Mesozoic bimodal volcanics form only a minor portion exposed in Burashika (Figure 1a). The Tertiary to Recent volcanic rocks forms the prominent hills including the Biu Plateau in the northeast and Longuda Plateau in southeast (Figure 1a). Carter et al (1963) reported that the rocks of the Kaltungo inlier are dominantly the Pan-African granitoids, surrounded by the outcrop of the Cretaceous Bima Formation. Granites of the crystalline basement occur in the foreground. The volcanic plug forming the Tangale peak pierces gently the dipping Bima Sandstone (Carter et. al, 1963). In the Kaltungo inlier, small rafts of coarsely banded migmatite occur in the equigranular granites in the hills near Billiri (Carter et. al, 1963). Biotite-granite with very small amounts of muscovite occurs in strips along the northern, western and southern margins of the Kaltungo inlier (Figure 1b). The Kaltungo porphyritic biotite granite occupies the greater part of the Kaltungo inlier. It forms most of the hills between Kaltungo and Billiri and underlies

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the severally eroded 'badlands' in the central and north-eastern part of the inlier.

Geology of Kufai and Environs

Field investigation revealed that the area consists of three lithologic unit comprising the Pan-African granitoids, Cretaceous sandstone and Tertiary basalts. The Pan-African granitoids comprises of porphyritic biotite granite, equigranular biotite granite and micro-granite as well as intermediate rocks that vary in composition from diorite to quartz monzonite and granodiorite. These rocks are mostly localized in the northern part within Billiri and Kufai towns extending to Layero in the south. The rock outcrop**s** as rugged hills, massive boulders, and highly weathered granite pavements.

The Tertiary volcanics are mainly trachyte, andesite and basalts. The trachyte is well exposed in the northwest occupying about 20% of the study area while the andesite and basalt occur as plugs. The tertiary volcanics form prominent hills within Baganje, Kalmai and Lakarai. The Cretaceous sedimentary cover which is mainly sandstone occupies about 10% of the western and southern fringe of the study area, localized at Tal in the north and Labeke at the south.

Porphyritic biotite granite

The porphyritic biotite granite is the most widespread rock in the study area (Figure 2a-b). Larger part of the Kufai and Billiri hills is underlain by the porphyritic biotite granite. The unique textural feature of this rock type is the presence of large microcline phenocryst (0.2 cm x 0.3 cm to 0.4 x 0.5 cm) hosted within the medium to coarse-grained matrix (~2.5 x 3mm). They are mesocratic to leucocratic having a grey color. The porphyritic biotite granite is made up of simple mineralogy comprised of quartz, microcline, plagioclase and biotite.

Equigranular-biotite granite

This is the second most abundant rock type in the study area (Figure 2c). They are mesocratic to leucocratic, grey in colour; coarse to medium grained granite (Figure 2c). Mineralogically, comprised of quartz, feldspar with few biotite shards similar to the porphyritic biotite granite. The mineral grain sizes ranges between few millimetres to less than a centimetre. There is no sharp contact between these two types (equigranular and porphyritic biotite granite), gradational contact is well observed in the field (Figure 2c). The greater part of Tal and Layero hills constitute the equigranular granite.

Intermediate rocks

The intermediate phase of the granites ranges in composition from diorite, quartz-monzodiorite to granodiorite. They are distinguishable in the field from the other granitic suites by their high mafic mineral contents. They are mesocratic to melanocratic and vary in color from greenish to dark gray in color. This rock types occur as smaller bodies occupying some parts of Tal, Labeke and Layero hills.

Pegmatites

Pegmatite occurs as sporadic vein-like bodies, commonly within the porphyritic and equigranular biotite granite (Figure 2d). They are generally quartz-feldspar veins a few tens of meters in length and breadth of between 5 and 20 cm. The pegmatite veins are trending in NW-SE, N-S and NE-SW.

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Figure: 2 (a-b) Outcrop of porphyritic biotite granite displaying large K-feldspar phenocryst with intrusion of microgranite dyke, (c) Gradational contact between porphyritic biotite granite (PBG) and equigranular granite (EGG), (d) an outcrop of pegmatite hosted in the porphyritic biotite granite.

Basalt

The basalt in the study area occurs as columnar jointed outcrops adjoining the trachyte and porphyritic granite around kufai village (Fig, 3a). The rock appears dark grey to black in color, having plagioclase and olivine phenocryst. The fine matrix is indistinguishable by naked eye on hand specimen.

Trachyte

Trachyte is a rare extrusive rock of intermediate chemical composition volcanic rocks. The texture ranging from aphanites (fine-grain) to porphyritic (mixed fine- and coarse grain). Few smaller bodies of trachyte and phonolite are observed in the Kufai and Tal hills (Figure 3b). The major mineral of trachyte is alkali feldspar occurring as phenocryst.

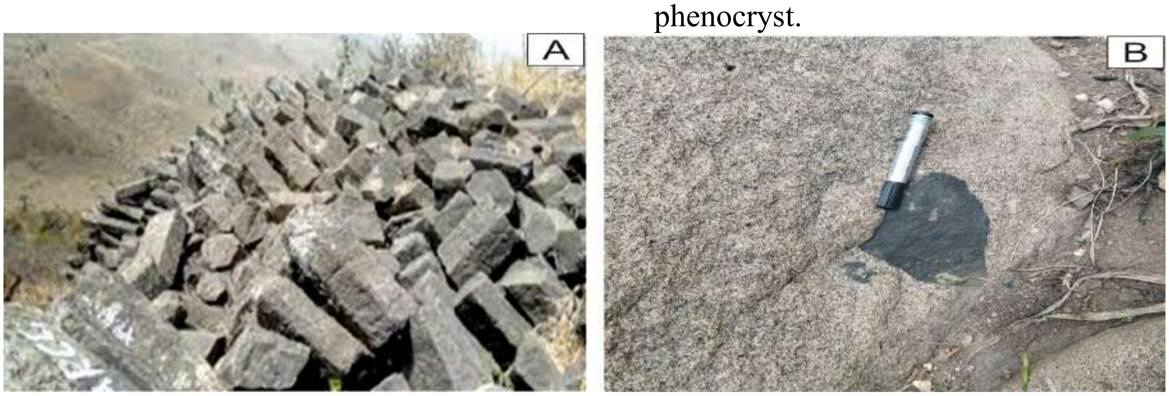

Figure 3: (a) Basalt at Kufai displaying columnar joints; (b) Massif outcrop of trachyte at Kufai showing mafic enclaves.

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MATERIALS AND METHODS

Field Mapping

Desk study was first conducted in order to gather detail information from previous literatures and works conducted in the study area. After which reconnaissance survey was conducted in order to have a general understanding of the geology of the study area and to familiarize with ground attributes of geologic features as well as locating possible access routes to rock exposures. The mapping exercise involved identification and description of the different lithologic units, and obtaining representative fresh samples from the outcrops. Samples were obtained from different exposures and were first studied on the outcrops as well as the structural features. Samples were taken randomly guided by mineralogy and textural variation, and each rock sample was carefully placed into a polythene bag, labeled with its respective location using a permanent maker.

Thin Section

Samples collected from the western Kaltungo Inlier were prepared for mineralogical studies. Rock slides were prepared from the ten (10) samples that comprises of porphyritic biotite granite, equigranular granite, trachyte and basalt. Standard sized thin sections ~27×47 mm at nominal thickness 30 µm were prepared at the Petrological Laboratory, Department of Geology, Abubakar Tafawa Balewa University (ATBU), Bauchi. Section surfaces were polished with diamond pastes 6-31 µm on cloth, to obtain an immaculate mirror finish. Optical microscopy was undertaken using a transmitted electron microscope for mineral identification in both PPL and XPL views.

RESULTS

Petrography

Modal contents were assessed using an Endeeper Stage Ledge automated point counter and are presented in Table 1. A minimum of one thousand five hundred points was counted on each thin section.

Table 1: Average modal composition of rock in the study area (vol %).

Minerals	PBG (n=5)	EEG (n= 4)	Basalt (n=5)	Trachyte (n=5)
Quartz	55	53	5	10
K-feldspar	25	21	-	70
Plagioclase	10	15	37	10
Biotite	10	8		10
Olivine	-	-	20	-
Augite	-	-	10	-
Opaque	-	-	28	-
Accessory	3	3	-	-

Porphyritic biotite granite

The minerals observed in the porphyritic biotite granite are quartz (55 %), microcline (25 %), plagioclase (10%) and biotite (7 %). Quartz grains under the PPL are colorless, anhedral to sub-hedral in shape, non-pleochroic; under XPL show grey to white interference, birefringence is of 1st order and exhibits undulose extinction. Microcline is the most common feldspar in the porphyritic biotite granite, colorless to cloudy in appearance possibly due to alteration, sub-hedral to anhedral in shape, show low relief and fractured; under the XPL, the microcline

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interference color is grey to white, birefringence is of 1st order, exhibits tartan twinning and micro-perthitic exsolution lamellae (Figure 4a-b). Plagioclase occurs as colorless grains, sometimes cloudy likely due to alteration. One directional cleavage observed in some grains, sub-hedral to anhedral in shape, low relief, fractured under PPL; interference colour appears as alternation of grey and white lines and 1st order birefringence, exhibits simple to polysynthetic twinning. Biotite occurs either as an independent crystal (3mm to 1.5 mm), or interstitial crystals (< 1mm) occupying fractures in feldspars and quartz, sub-hedral in shape, brown in colour, non-pleochroic with some showing perfect directional cleavage and absence of fractures. Under the XPL, the biotite interference colour is light to dark green while bireferingence is of 2nd order. Zircon, apatite and iron-oxides occur as accessory minerals that constitute about < 3% of the modal composition of this rock.

Equigranular biotite granite

The mineralogy of the equigranular granite is similar to the porphyritic biotite granite. The minerals observed in this rock are quartz (53 %), microcline (21 %), plagioclase (15%) and biotite (8 %). Quartz occurs as anhedral to subhedral grains, colorless and none pleochroic; under the XPL, the interference color is grey to white, birefringence is 1st order, and extinction is not uniform depicting shadowy extinction. Microcline occurs as colorless to cloudy, sub-hedral to anhedral in shape with low relief; under the XPL, the microcline interference color is grey to white and birefringence is of 1st order, exhibits Carlsbad and crosshatched twinning. Plagioclase occurs as colorless grains, one directional cleavage observed in some grains, sub-hedral to anhedral, low relief under PPL; under XPL interference colour appears as alternation of grey and white lines and 1st order birefringence and depicting a simple twinning, usually altered sericite. Biotite occurs as platy grains, sub-hedral in shape, brown to dark-brown in color, non-pleochroic; under the XPL, the biotite interference color is light to dark green while birefringence is of 2nd order. The accessory minerals are sphene, zircon and allanite, occupying less than 3 vol. % (Table 1 and Figure 4).

Basalt

The minerals observed in basalts are plagioclase (40 %), olivine (20 %), augite (10%) and iron oxides (35 %). Plagioclase is colorless under PPL and non pleochroism having lath-like feature. Under PPL extinction is oblique and exhibit albite twining (Figure 5a-b). Olivine is colorless, euhedral to subhedral and has moderate relief under PPL, displaying pale green pleochroism with no distinct cleavage; under XPL show 2nd order interference color. Augite is pale-brown under PPL and non pleochroic; under XPL display simple twinning. Opaque minerals, which are likely iron oxides, appear dark colored under both PPL and XPL.

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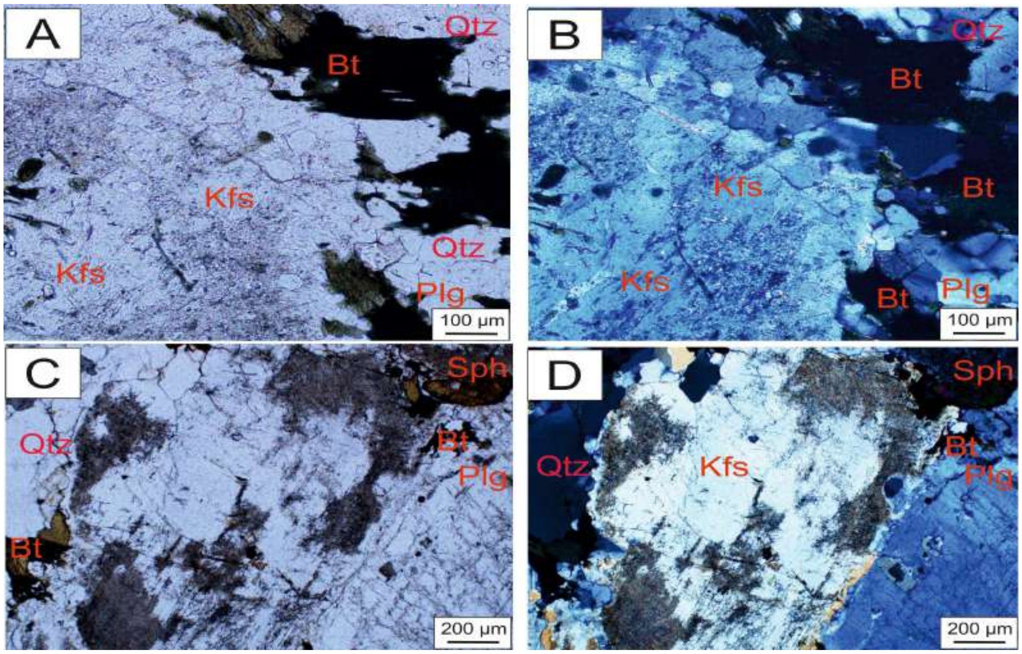

Figure 4: Photomicrograph of porphyritic biotite granite under PPL (a) and XPL (b) depicting the phenocryst of microcline; Photomicrograph of equigranular granite under PPL (a) and XPL (b) showing the nearly equal crystal size with sphene (titanite) grains as accessory. Qtz: Quartz; Bt: Biotite; Plg: Plagioclase; Kfs: K-feldspar; Sph: Sphene.

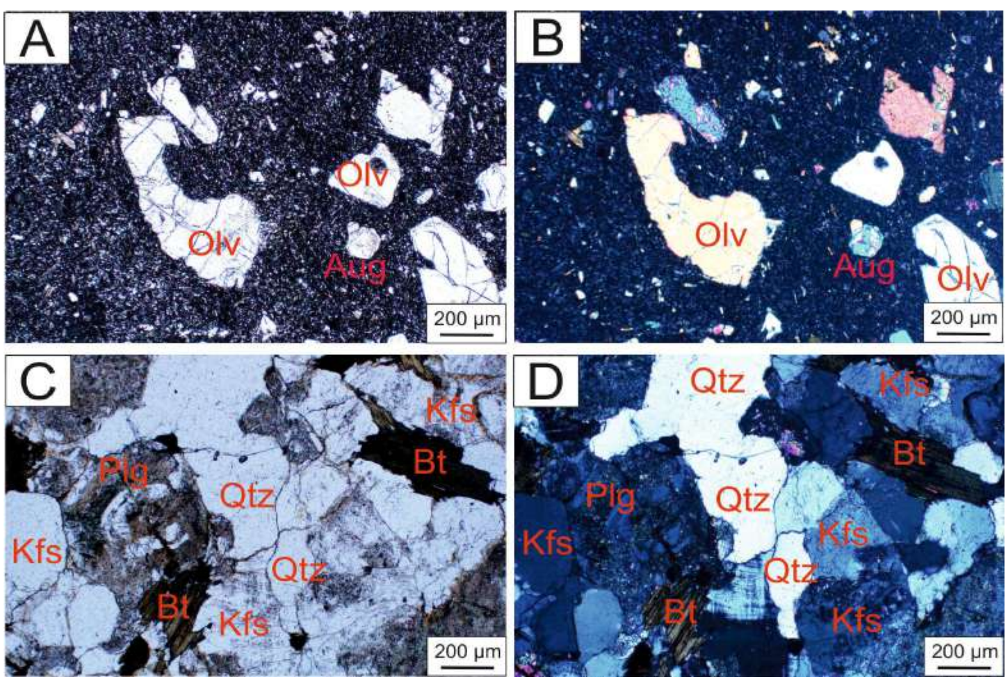

Figure 5: Photomicrograph of basalt under PPL (a) and XPL (b) showing phenocryst of olivine and matrix made up of plagioclase laths and iron oxide; photomicrograph of trachyte under PPL (a) and XPL (b) showing zoned plagioclase and flakes of biotite. Plg: Plagioclase, Olv: Olivine, Aug: Augite, Opq: Opaque; Kfs: K-feldspar

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Trachyte

This rock is composed of orthoclase (70%), biotite (10), plagioclase (10) and quartz (10%). Quartz occurs as subhedral grains, colorless; under the XPL, the interference color is grey to white. Microcline occurs as colorless to cloudy, sub-hedral to anhedral in shape with low relief; under the XPL, the microcline interference color is grey to white and birefringence is of 1st order, crosshatched twinning. Plagioclase occurs as colorless grains, subhedral to euhedral, and low relief under PPL; under XPL interference colour appears as alternation of grey and white lines and 1st order birefringence and depicting a simple twinning, usually altered sericite; zonning is also observed in some plagioclase grains (Figure 5c). Biotite occurs as platy grains, sub-hedral in shape, brown to dark-brown in color, non-pleochroic; under the XPL, the biotite interference color is light to dark brown (Figure 5c-d).

Structures

Structures identified in the studied area are mainly joints and quartzo-felsdpathic veins. Joints and quartzo-feldspathic veins are very common in porphyritic biotite granite and equigranular granite (Figure 6). Although the intermediate rocks occupy small portion of the study but they also contain quartzo-feldspathic veins (Figure 6). The quartzo-feldspathic veins in both porhyritic biotite granite and equigranular granite show a dominant trend of NE-SW, few show trend of NW-SE and E-W direction. The joints in both porphyritic biotite granite and equigranular granite show a dominant trend of NW-SE while few joints show a trend of NE-SW and E-W (Figure 7).

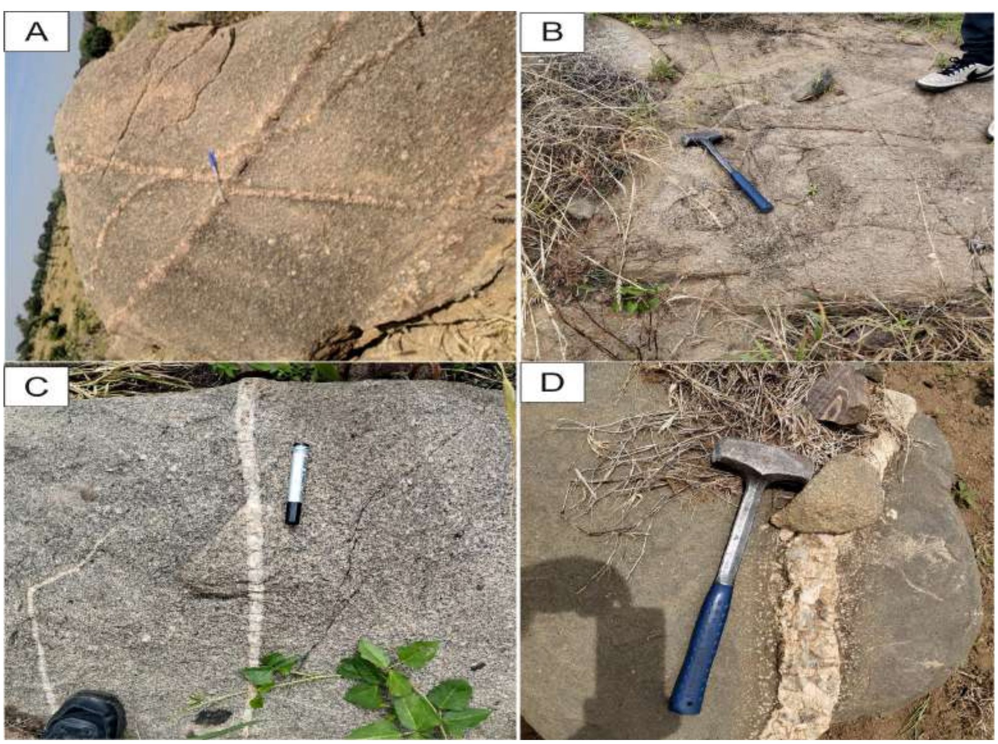

Figure 6: Quartzo-feldspathic veins (a) and numerous joints (b) in porphyritic biotite granite; (c) quartz veins in the equigranular granite; (d) Quartzo-feldspathic veins in the intermediate rock (monzodiorite).

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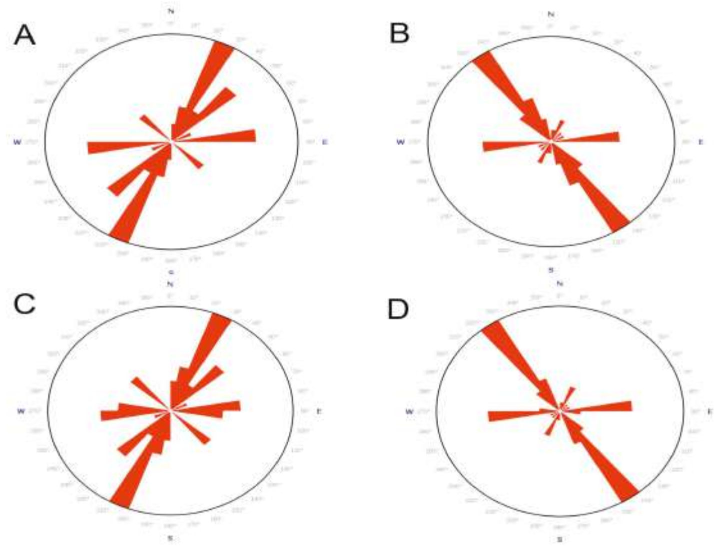

Figure 7. Rose Plot for veins (a) and joints (b) for porphyritic biotite granite; rose plot of veins (c) and joints (d) for equigranular granite. Showing NE-SW as the dominant trend for the veins; and NW-SE as the major trend for the joints.

DISCUSSION

The International Union of Geological Sciences (IUGS) classifications were employed for the classifications of igneous rock of Kufai and environs Kaltungo Inlier. The IUGS classification is based on the modal proportion of common rock forming minerals; this includes quartz (Q), alkali feldspar (A) and plagioclase (P). Based on the QAP triangular diagram for plutonic rocks, the porphyritic biotite granite plotted in the field of syenogranite while the equigranluar granite straddles both the fields of syenogranite and monzogranite (Figure 8a). This imply that the porphyritic granite is rich in alkali feldspar than the equigranular granite; while the equigranular granite is rich in plagioclase. Generally, the granites of the study area overlap the Gubrunde granites of Hawal Massif (Bute et al., 2020). The trachyte plotted in the field of quartz-trachyte due to moderate proportion of quartz (10%) while the basalts reside in the field of basalt/andesite (Figure 8b).

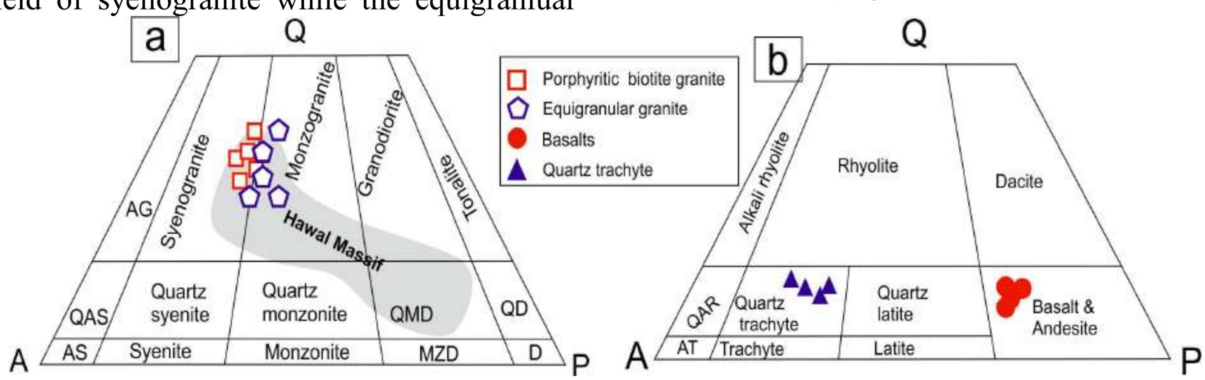

Figure 8: (a) IUGS classification of plutonic rocks based upon modal mineralogy After Le Bas and Streckeisen (1991); (b) IUGS classification of volcanic rock based on modal mineralogy (Le Bas and Streckeisen 1991)). A = alkali feldspar, P = plagioclase, Q = quartz.

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The gradational contact observed between the equigranular granite and the porphyritic biotite granite may suggest they have generated from the same magma. Generally the trend of the structural features is NE-SW, which is consistent with the major NE-SW lineaments of the Pan-African basement (Maurin et al., 1986; Suh and Dada, 1997). These NE-SW lineaments controlled the Mesozoic to Tertiary magmatic activities in the region.

CONCLUSION

The rock units in the study area comprised of granitic suites identified as porphyritic biotite granite and equigranular granite; while the volcanic rocks are basalt and quartz-trachyte. The modal compositions indicate that the porphyritic biotite granite is syenogranite while the equigranular granite is monzogranites. The granite suites are coeval which was later ruptured by the volcanic rocks. The structural data indicates trend of mainly NE-SW which consistent with Pan-African major lineaments, and subsequently controls the Mesozoic to Tertiary magmatic activities in the region.

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