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Research Paper

The Field Geology And Petrography of the Saiya-Shokobo Younger Granite Complex, Central Nigeria

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The Saiya-Shokobo Younger Granite Complex is one of the several anorogenic alkaline Younger Granite Complexes that is located approximately 48 kilometres north of Jos, Nigeria. The complex is found to comprise of felsic rocks like; rhyolite, biotite-granites, biotite microgranites, hornblende biotite granites and syenite. They are also found to be associated with mafic rocks like gabbros and diorites which, at some portions have formed hybrid rocks. Aegirine - arfvedsonite-, rebeckite- and quartz- feldspar- granites are the porphyritic rocks that form the ring complex. The complex intrude the basement rocks of central Nigeria. Structural trends on these rocks suggest that they were controlled by some deep seated structures of the basement. Mineral suite identified include; fayalite, pyroxene, amphibole, k-feldspar, biotite, quartz, iron- oxide and accessory minerals like zircon, apatite, and allanite. Generally, the petrography of these rock samples reveal the presence of a mafic magma which has two pulses (a mafic and felsic pulse) of injection.

Keywords: Saiya-Shokobo, Granite, Geology, Petrography, Structures

Introduction

The Younger Granites Ring Complexes are located in the southern part of a 200 km wide zone, along the 9th meridian and extending 1250 km from Andrar Bous in northern Niger to Afu in the margin of the Benue Trough in Nigeria (Figure 1). The form and general pattern of the ring centres may have been controlled by pre-existing lines of weakness in the Pan African basement (Kinnaird et al, 1985).

The Saiya-Shokobo Younger Granite Complex is one of the several anorogenic alkaline Younger Granite Complexes in the Nigerian Pan African Basement Complex (Macleod et al, 1971)

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(Figures 1 and 2). The complex is found associated with gabbroic and doleritic/dioritic enclaves, peralkaline and peraluminous igneous rocks (Plates 1).

In the study of the Nigerian Younger Granites, the Saiya-Shokobo Complex constitute a significant window to the detailed understanding of the magmatic evolutionary trends and metallogenic characteristics of the Nigerian Younger Granites as a whole. This is because of the prominent occurrence of mafic rocks which may represent the more primitive magma in the Younger Granite Province. At present, the origin of these anorogenic granites in Nigeria is still very intriguing due to inadequate data. This paper attempts to describe the various lithological units within the suite and the petrographic analysis.

Study Area

The area investigated is the Saiya-Shokobo Younger Granite complex which can be accessed through Rishi town in the northern part. Rishi lies approximately 48 kilometres north of Jos, Plateau State. The Complex is situated between latitudes 10°17’30"N and 10°28’30"N and longitudes 8°48’30"E and 9°00’00"E which belong to part of Lere sheet 147 NE. This suite occupies an area of approximately 385.19 square kilometres that forms a northerly trending ellipse which is about 17.6 X 14.4 kilometres (Figure. 2). It is one of the very few complexes in Nigeria and Niger Republic in which the early volcanic rocks are well preserved. Both the volcanic and intrusive rocks are confined to a roughly circular or elliptical area bounded by ring dykes or ring faults (Figure.1).

Figure 1: Top = Geological Map of Nigeria Showing the Location of the Younger Granite Ring Complexes (After Obaje, 2009); Left = Map of Younger Granites Ring Complexes of Nigeria (Modified After Kinnard et al, 1985); Centre = Geological Map of Saiya-Shokobo Younger Granite Complex

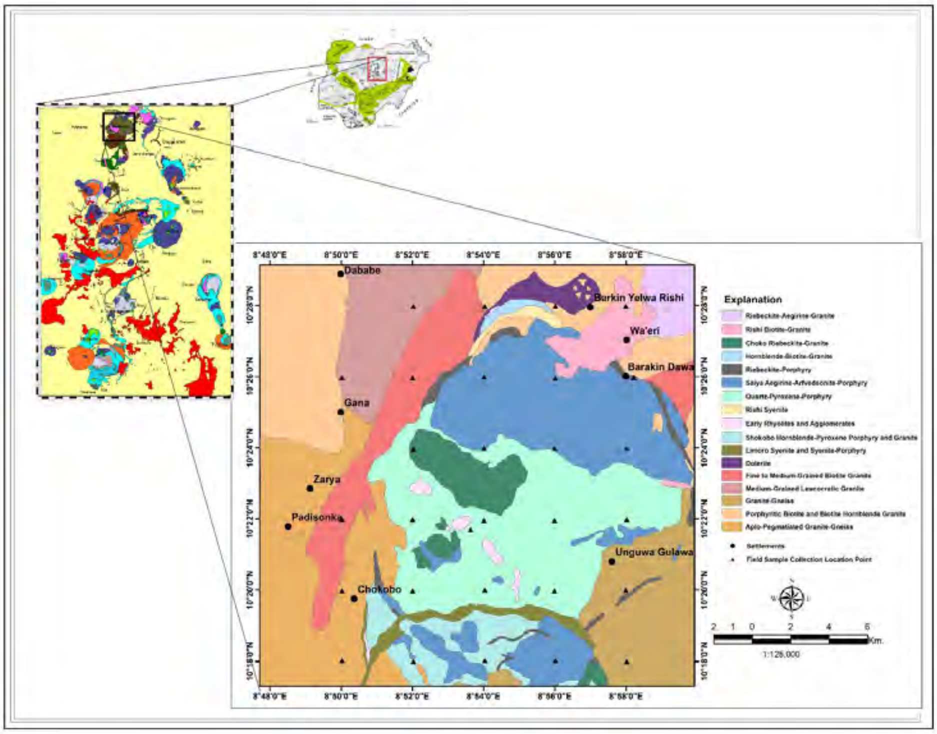
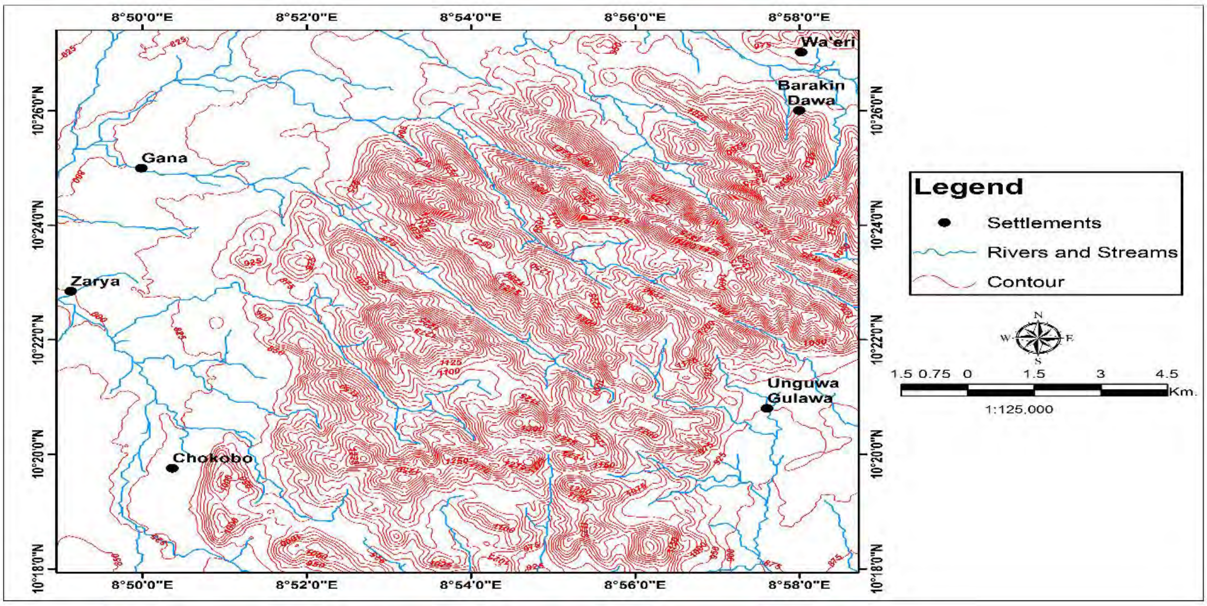


Figure 2: Physiographic Map of the Saiya-Shokobo Younger Granite Complex



The study area is marked by the south western part of the Waeri hills which trend in approximately N-S direction attaining the height of 1586 metres above sea level. This hill is visible in the southern and eastern part of the study area. There appears to be a sharp drop in height towards the northern and western parts to about 7776 metres above sea level. Rivers Waeri, Maraku and Yargi and their tributaries drain the area. They all flow in the NW direction. All the rivers in the study areas are seasonal, display a dendritic drainage pattern and are morphologically controlled. (Figures 2 and 3). Generally, the lowlands constitute the basement rocks while the Younger Granite rocks exhibit high relief due to its resistance to weathering.

Petrology

The major composition of twenty eight (28) selected rock samples is given in Table 1 above. The results were plotted on the petrological classification plot developed after Middlemost, 1985. The felsic comprising of various peralkaline and peraluminous granites and rhyolites fell in the granite section (Figure 4) and are quart-rich granitoids (Figure 5). The mafics which are made up of diorites and gabbroic diorites plotted in their appropriate polygons (Figure 4) and the QAPF diagram suggest that they are rich in akali feldspars.

Field Description

The description given are generated from field observation during the one month field work in the study area. Attention is paid to the colour, texture of the mafics and felsic rocks in the Saiya-Shokobo Complex.

Diorite

Diorite occurs as a large arcuate dyke at the extreme northern end of the Saiya hills, and this broadens out in the vicinity of Rishi. This represent less than 5% of the study area on the outer side of the arc, contact between the gabbroic diorite and the porphyritic Pan African Granite becomes

Figure 3: Digital Elevation Modem (DEM) of the Saiya-Shokobo Younger Granite Complex

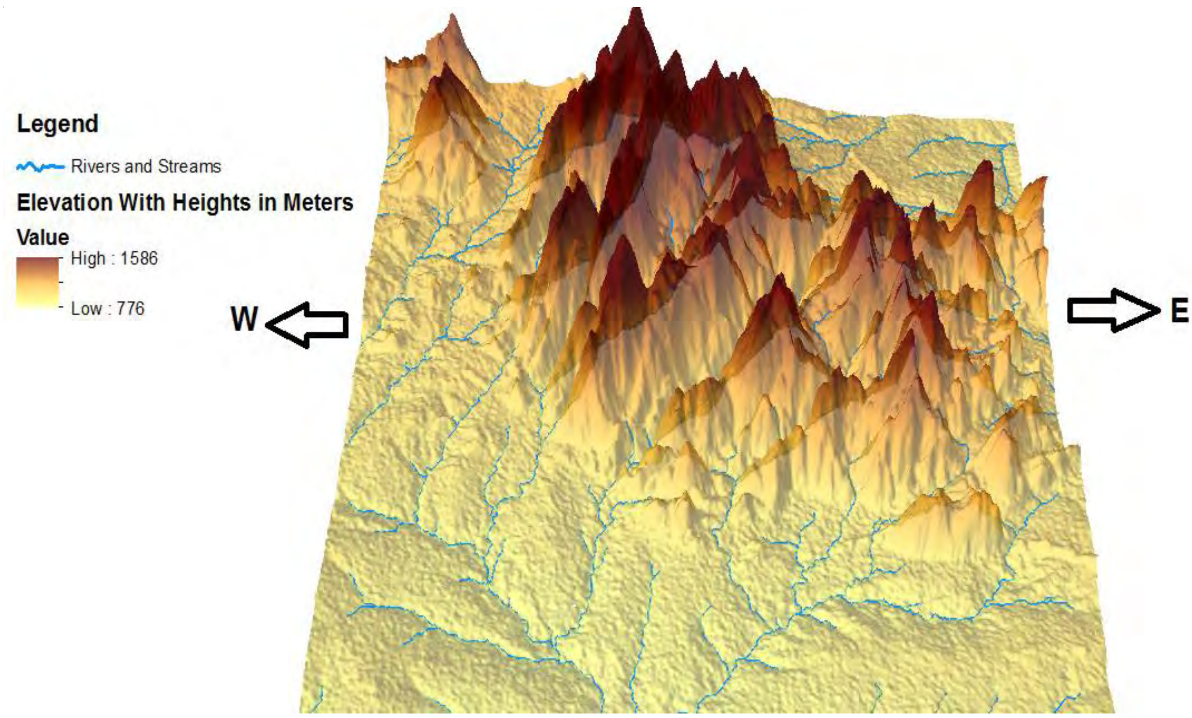


Table 1: Chemical Composition of the Rocks of the Saiya-Shokobo Younger Granite Complex

Sample ID	Location	Petrology	SiO_2	CaO	MgO	SO_3	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Fe_2O_3	Al_2O_3	H_2O^+
AT 1	Saiya - Shokobo	Gabbroic Diorite	50	8	4.5	0.28	0.87	0.28	2.1	0.2	0	4.9	19	8.08
AT8	Saiya - Shokobo	Granite	73.81	0.34	0.003	0	5.5	0.88	0.36	0.064	0	3.89	12.63	1.6
AT10	Saiya - Shokobo	Granite	72.96	0.82	0.04	0	5.5	1.01	0.43	0.16	0	2.85	12.67	2.08
AT11	Saiya - Shokobo	Gabbroic Diorite	52.24	3.32	5.6	0	1.83	0.6	5.06	0.25	0	14.4	13.42	3.14
AT12	Saiya - Shokobo	Diorite	58.3	3.46	6.2	0	2	0.43	3.14	0.21	0	11.72	10.46	2
AT13	Saiya - Shokobo	Granodiorite	59.9	7.3	0.43	0.36	4.11	0.73	1.71	0.31	0.004	9.8	10.04	3.86
AT16	Saiya - Shokobo	Granite	72.06	0.72	0.03	0	7	1.43	0.97	0.25	0.02	4.46	12.21	1.1
AT21	Saiya - Shokobo	Granite	74.43	0.02	0	0.63	4.01	0.89	0.21	0.062	0	2.51	13.86	1.84
AT25	Saiya - Shokobo	Granite	73.2	2.07	0.63	0.006	1.4	1.02	1.93	0.19	0	2.81	13.06	1.01
AT27	Saiya - Shokobo	Rhyolite	74.2	1.73	0.18	0.43	5.2	0.67	0.22	0.032	0	2.34	13.81	1.64
AT28	Saiya - Shokobo	Granite	72.46	1	0.34	0.032	7.4	2.54	0.23	0.06	0	2.34	12.21	1.2
AT38	Saiya - Shokobo	Granite	73.89	1.4	0.08	0.06	5.1	0.69	1.09	0.24	0	3.08	13.01	1.4
AT32	Saiya - Shokobo	Granite	68	1.12	0.008	0.068	10.3	0.14	1.48	0.092	0	2.94	11.48	2.94
AT33	Saiya - Shokobo	Diorite	53	6.5	2.23	0	0.4	1.86	3.16	0.36	0	18.42	1.06	2.06
AT35	Saiya - Shokobo	Rhyolite	70	0	0	0	9.18	1.02	1.11	0.039	0	4.28	10.08	3.42
AT45	Saiya - Shokobo	Diorite	57.1	2.33	8.84	0.13	1.08	0.33	3.24	0.27	0	8.24	12.34	5.6
AT49	Saiya - Shokobo	Diorite	58	6.1	3.81	0.7	1.7	0.16	2.81	0.22	0.04	10.46	10.6	4.08
AT53	Saiya - Shokobo	Rhyolite	73.74	1.68	0.2	0.23	5.14	0.43	0.506	0.09	0	0.96	13.66	1.72
AT54	Saiya - Shokobo	Granite	74.02	0.29	0.002	0.23	4.18	0.07	0.62	0.13	0.08	4.59	13	1.44
AT59	Saiya - Shokobo	Granite	74.6	1.03	0.04	0.02	5.12	0.93	0.69	0.12	0.13	2.64	13.46	1.16
AT61	Saiya - Shokobo	Diorite	58.6	9.7	0.82	0.56	1.34	0.63	3.52	0.25	0.03	10.06	10.71	2.24
AT66	Saiya - Shokobo	Granite	73.02	0.96	0.13	0.42	8.14	2.06	0.15	0.053	0	0.42	12.76	1.4
AT67	Saiya - Shokobo	Granite	72.8	1.46	0.1	0.06	3.4	0.43	2.18	0.075	0.01	4.1	13.4	1.51
AT70	Saiya - Shokobo	Granite	75.6	0.98	0.28	0.62	4.5	1.04	0.27	0.066	0	1.45	13.02	1.06
AT75	Saiya - Shokobo	Granite	73.9	0.38	0.03	0.43	4.02	0.76	0.55	0.23	0	3.64	13.86	2.08
AT78	Saiya - Shokobo	Granite	73.3	0.76	0.02	0.4	6.02	0.78	0.3	0.061	0	0.78	13.98	2.71
AT83	Saiya - Shokobo	Granite	72.96	1.9	0.73	0.06	3.69	0.67	0.98	0.032	0	2.02	13.06	2.86
AT3	Saiya - Shokobo	Granite	73	0.98	0.03	0.39	8.03	0.71	0.3	0.042	0	2.42	12.98	1.43

Figure 4: Rock Classification (After Middlemost, 1985)

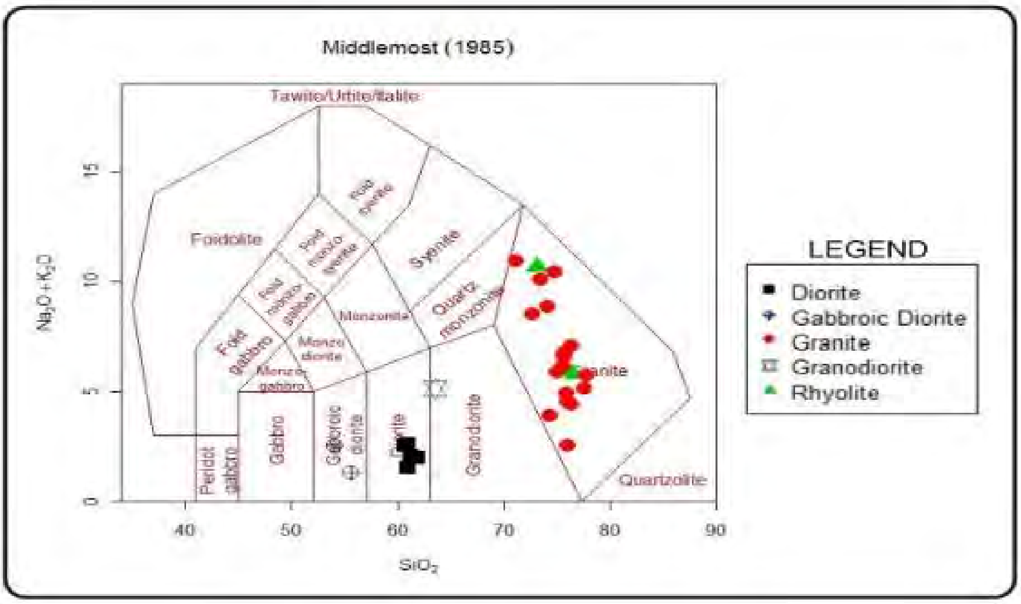
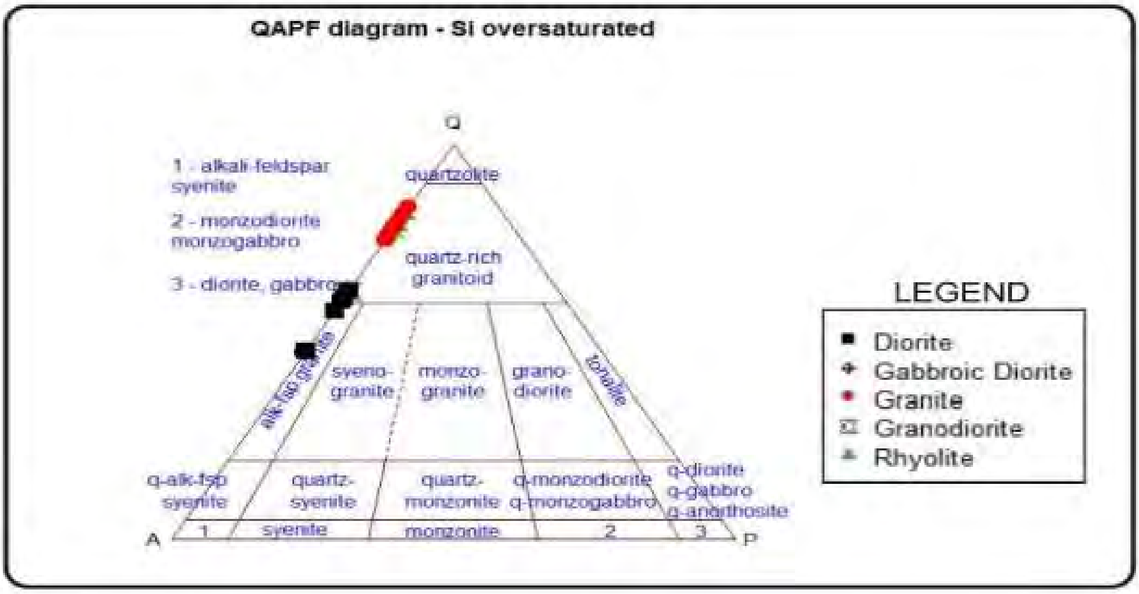


Figure 5: QAPF - Si Oversaturated Diagram



rather indefinite, because both the diorites and the adjacent porphyritic Pan African Granite have been shattered and partly assimilated by a later acid phase. These resulted in the production of a hybrid dolerite with a wide range of composition.

The hybrid diorite is characterized by its distinct and irregular net-veining by the acid phase, which is well displaced on some flat slabs to the north of the road outside Rishi (Figure. 6).

Rhyolites

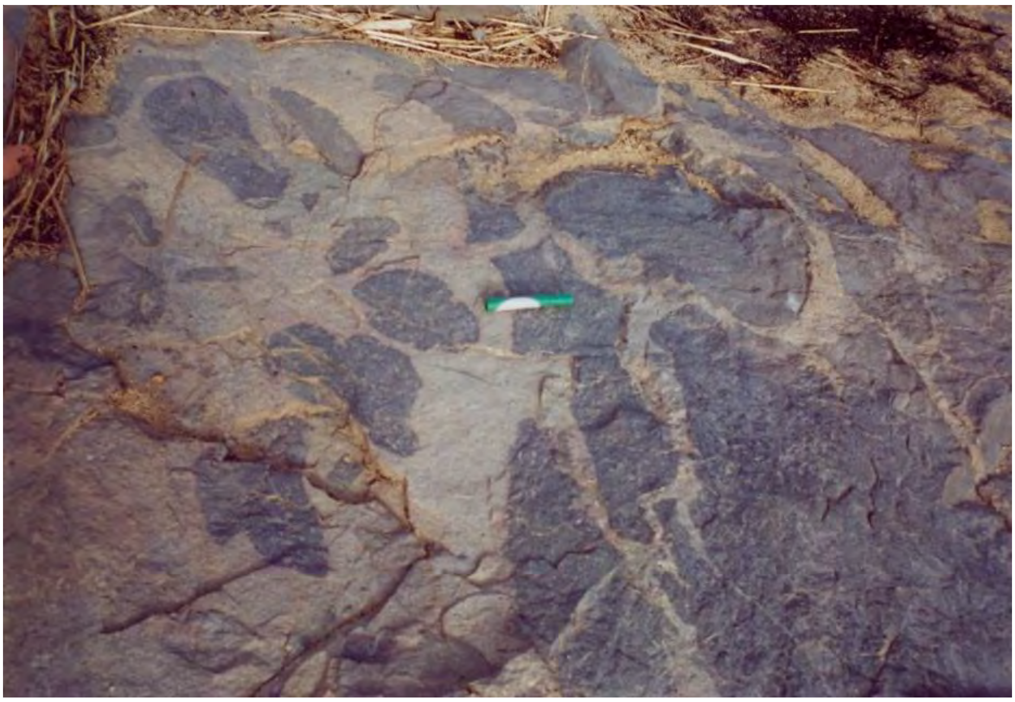
The early rhyolites dominate in the south western part of the study area, around Yargi village. It covers only a very small part of the area (approximately 5%) because most of them have been obliterated by later intrusion or removed by erosion. The early rhyolites in the projects area have undergone subsidence and persist only as marginal screes along the main ring-fracture. They have varying texture and composition, and represent a succession of individual flows with interbedded pyroclastic.

A portion of the early rhyolites in the southwestern part show batches of comenditic composition. The boundary between them is not clearly defined. They contain fiamme, lenticular inclusions with ragged flame-like ends which are more coarsely recrystallized than the matrix, showing axiolitic structures. Presence of commendite is an indication that the early ryholite was in part peralkaline

Aegirine - Arfvedsonite Granite Porphyry

This porphyry forms a semi-circular outcrop in the southern sector of the project area. It occupies approximately 10% of the study area. The form of the porphyry appears to have been controlled by a circular fracture, within which the central block of the early rhyolites suffered segmentation and differential subsidence. As a result, the

Figure 6: Gabbroic Enclaves at Rishi Area



porphyry shows a wide range of texture consistent with emplacement in a surface caldera.

In the marginal zones, the rock has a dark blue near glassy matrix, with scattered phenocrysts of euhedral to subhedral feldspars and clear quartz. The phenocrysts constitute about 30% of the rock and vary in size from 1 to 2mm. The matrix consist of a mozaic of quartz, feldspar and arfvedsonite.

Syenite

The Rishi syenite forms a small arcuate intrusion in the study area, and this gives rise to a low ridge. The syenite occupies approximately about 15% of the project area. The rock is pinkish grey when fresh, speckled with abundant dark clusters and patches of fine grained hornblende. It also has a porphyritic texture with phenocrysts of feldspars between 2 and 4mm in length distributed in a matric of perthite, quartz and hornblende.

Quartz Pyroxene Porphyry

The quartz pyroxene porphyry is dark greenish to dark grey or dark bluish in colour due to the presence of pyroxene. The porphyry constitute over 10% of the study area. The rock is porphyritic in texture with fragmental phenocrysts of alkali feldspar, quartz and pyroxene set in a microcrystalline groundmass. The K feldspar phonocryst is a microperthite while the quartz phenocryst show wavy extinction.

Hornblende Biotite Granite

The hornblende biotite granite is one of the minor intrusions which have occupied part of the principal ring-fracture zone. The main outcrop occupies about 5% of the study area and forms a narrow curve between the Rishi syenite and the diorite at the north-central region of the project area (Figure. 7).

Figure 7: Hornblende Biotite Granite

Riebeckite Granite Porphyry

The riebeckite porphyry occupies approximately 5% of the study area. It is thought to have been the original fracture controlling the emplacement of the early rhyolites, and it has probably occupied the former position of the earlier minor phases which have been intruded along the same ring fault. It outcrops as a persistent ring dyke in the study area. The porphyry weathers easily and hardly forms any obvious feature.

Biotite Granite/Microgranite

The Rishi biotite granite occupies approximately 25% of the study area and is well known for tin mineralization. Fresh samples collected at Barkin French indicate that they are medium grained in texture and pink in colour. Only the roof zones of the granite is exposed. Biotite microgranite is commonly developed at the contacts with the overlying rocks, and zones of greisenization up to 0.6 or 1.0 metres are abundant.

Structural Geology

The structural features observed in the field of study include joints, dykes, flow structures and veins. Measurement carried out on them reveal that they display variable trends.

Joints

Fractures that are oriented systematically, with no evidence of relative movement, are called joints. Most of the joints in the Rishi study area show a general, NE-SW and NW - SE direction. Joints observed on these Younger Granite complexes are not structurally controlled hence are cooling joints formed as a result of contraction and cooling of the emplaced magma. Also, the uniformity in the trends of the joints suggest that they are syngenetic.

Veins

Veins are joints that have been filled. In the study area, these joints have been filled by quartz and hence are referred to as quartz veins. The quartz veins are thin, raging in thickness from 0.4 to 0.7cm and their lengths vary between 4 and 25 metres. They are relatively few and trend in the NE - SE direction and have steep vertical dips. The quartz veins are mineralized with minerals suspected to be cassiterite or some low quality gems in place.

Dykes

A dyke is a sheet-like discordant body within the country rock in which they occur. The dykes in the Rishi study area are mostly granite porphyries and some dolerite dykes. These dykes could be grouped into two viz large and small scale dykes. The large scale dykes form what is left of the original ring- dykes that have intruded the basement. The original pattern of these ring dykes have been altered by tectonism and subsequent intrusions. The small scale dykes are not usually extensive and basic in composition. They have a general NE-SW and NW - SE trend.

Net - Veins

These are network of veins of felsic intrusions injected under high considerable pressure and penetrating a marginal zone of the mafic rocks thus forming a meshwork. Reacting between the veining materials and the mafic host rock is common, giving rise to hybrid rocks.

Felsic magmatic intrusion formed the veining material within the mafic rocks of the Saiya-Shokobo Complex. They are linked at intervals points by cross-connecting veins, the contact of the veins with the mafic rocks are sometimes highly irregular. This is evidence of flow of felsic material marked by preferred trend of feldspar and hornblende. The evidence of the flow indicate that the veins did not form metasomatically and the highly irregular contacts are not such as would be expected if the host rock had been solid when the felsic material was intruded.

The ring-like and elliptical configuration of these net veins is common in the Rishi area. The thickness of the veins vary between 0.2 and 1.0 metres (Figure. 8). The average dimension of the smaller elliptical vein is 0.15 metres on the minor axis by 0.35 metres on the major axis.

Xenoliths

A xenolith is a pre-existing rock embedded in a newer (igneous rock). Xenoliths are formed when a rising magma incorporates the pre-existing rock. If the pre-existing rock does not melt, it will not be assimilated into the magma and will therefore remain distinct from the new igneous rock that surrounds it. Xenoliths observed in the study areas are mostly mafic in composition and of varying sizes, some up to 1.5 by 2.6 metres. A larger percentage of the xenoliths are formed in the area of net veinings of mafic rocks by felsic materials.

Flow Structures

Flow structures are formed in a rock due to directional movement of its lava, causing the crystals contained in the lava to take up a parallel to sub- parallel orientation. Flow structures occur in the rhyolites with comenditic structures in the Rishi study area.

Micro-Faults

Micro-faults are faults that occur in a very small scale and they are usually observed as faulting occurring in veins and joints. In the Rishi study area, they were observed on the diorite.

Structural Interpretation

In Nigeria, the major structural directions are oriented N-S, NE-SW, NW- SE, NNE-SSE and ENE - WSW, corresponding to the major structural trends in the Basement Complex and direction of alignment of the Younger Granite ring complexes (Rahaman et al, 1988; Turner 1989).

The form and general distribution pattern of the ring centres may have been controlled by these pre-existing lines of weakness in the Pan-African Basement into which the Younger Granite Complexes were intruded.

In the study area, the following joint directions were mapped, N-S, NE- SW, NW-SE, NNE-SSW and E-W which correspond with the structural trend of the underlying basement. The general structural trend in the study area is shown in Figure. 9. This suggest that these joint direction are outward prolongation of deep seated fracture zones that initiate and guided the location of the Younger Granite eruption centres. They followed these weak zones during eruption in the Jurassic (165 ±25ma).

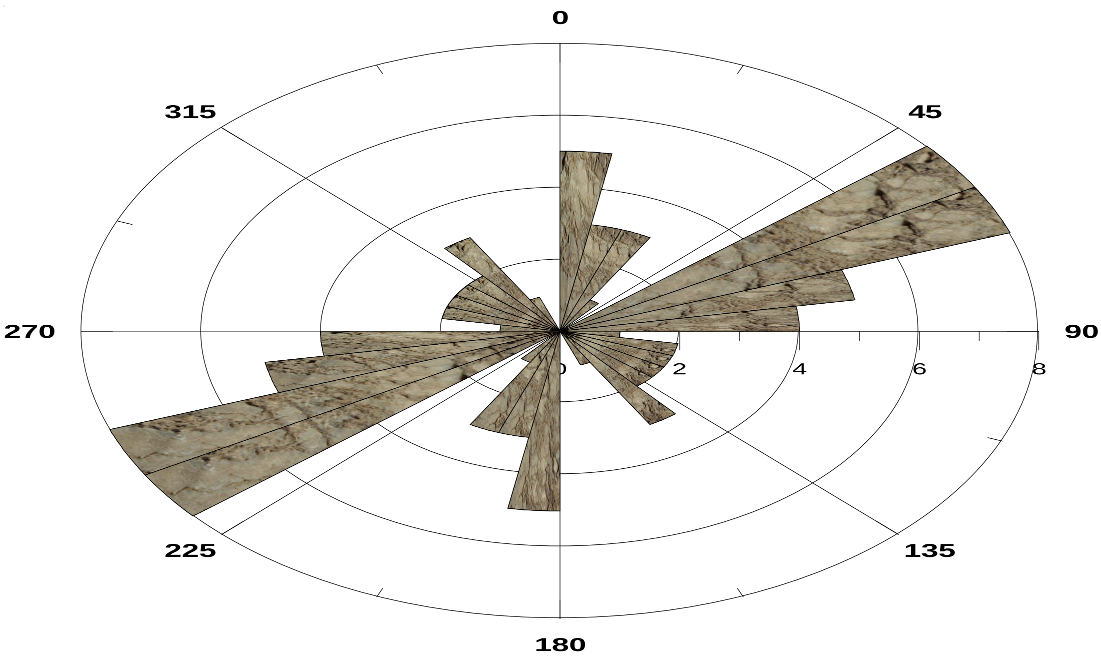
Petrography

Out of the sixty six [66] samples collected from the field, twenty five [25] representative samples were presented for thin section. The slides were prepared at the laboratory of the Department of Geology at the University of Jos, Nigeria. These thin sections which represent the lithological units in the study area were studied under the transmitted light microscope. Particular attention was given to descriptive features such as mineral composition, grain size and inclusions.

The report that follow groups these slides into four viz mafic, felsic, porphyries and contact rocks respectively. Particular attention was given to descriptive features as mineral composition, grain size and inclusions

Figure 8: Net-veinings around the Rishi area

Figure 9: General Structural Trend



Mafic Rocks

The mafic rocks comprise of three slides comprising of two diorites and one gabbroic diorite. The estimated modal composition of these rocks are given in in form of pie charts.

Diorite/Gabbroic Diorite

The diorite and gabbroic diorite look similar in hand specimen. The rock is dense, melanocratic and dark green in colour. It is fine grained and doleritic in texture. The crystals are allotroimorphic, compact and aphanitic which implies that the constituent minerals cannot be distinguished by the unaided eye. The essential minerals are plagioclase, clinopyroxene and biotite.

Under the microscope, the rocks consist mainly of plagioclase groundmass and displays typical doleritic texture. The modal compositions of the diorite and gabbroic diorite are shown in Figure. 12. The rocks are characterised by an ophitic or sub ophitic groundmass in which intersecting laths of labradorite are enclosed by allotroimorphic pyroxenes (Figures 10A and 10B).

Augite crystals are colourless to yellowish brown in colour. Although they exhibit nice, bright interference colours of the second and third order. They are subhedral in form and show high relief. Most of the crystals have been altered. The plagioclase are subhedral in form, the crystals are colourless and the well-twinned laths are abundantly sericitized and zoned.

Biotite crystals are subhedral in form. Two types of biotite were observed the first, primary biotite is pleochroic from yellowish brown to reddish brown and show high interference colours. The other, secondary biotite is pleochroic from light to dark green and has high interference colours. The secondary biotite is an alteration product. Quartz crystals are colourless and are distinguished by their wavy extinction from light to dark. The crystals are subhedral in form and occur as small interstitial crystals within the groundmass.

Iron oxide occur as dark mineral grains which remain unchanged. They have variable shapes and do not have any definite orientation. Apatite and zircon constitute the accessory minerals present. The former is euhedral to subhedral while the later is subhedral in shape both are colourless

Felsic Rocks

The felsic rocks comprise of the study area are described below with modal compositions represented in pie charts.

Rhyolite

In hand specimen, the rock is reddish brown to grey. Some parts show porphyritic texture with microphenocrysts of pink or cream feldspar and greasy quartz. Under the microscope, the groundmass has an interlocking matrix of feldspar and quartz in a texture which is microcrystalline. Within the groundmass are phenocryst of quartz and feldspar (Figure. 10C). The modal composition of the rhyolites is shown in Figure. 13a while Figure. 13b is a rhyolite with patches suspected to be comendite.

Aegirine occurs as pale yellow to green crystals and is non pleochroic. The crystal show high birefringence. It occurs in an interlocking matrix of hornblende, possessing a cryptocyrstaline groundmass. Hornblende is pleochroic from greenish brown to dark blue and show high birefringence. The crystals occur in an interlocking matrix of aegirine and hornblende in a cryptocrystalline material, and are subhedral in

Figure 10: Photomicrographs of Thin Sections of Rocks in the Study Area

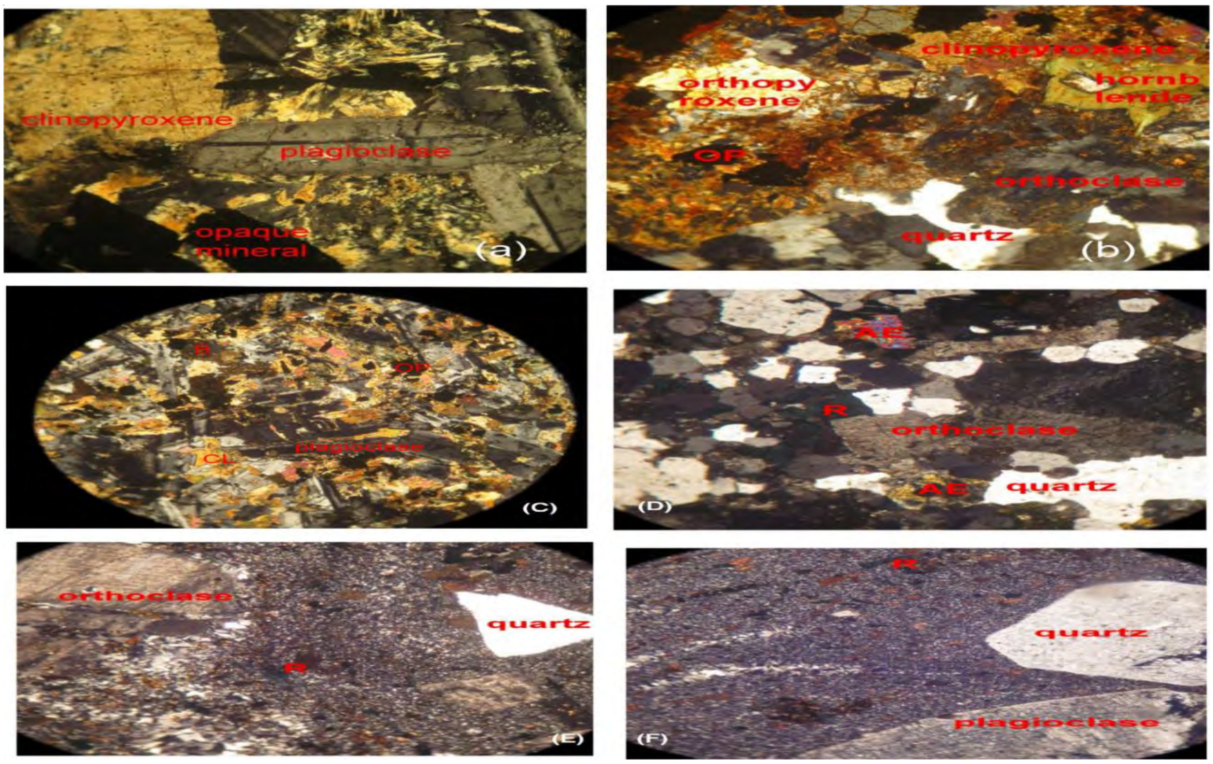


Figure 11: Photomicrographs of Thin Sections of Rocks in the Study Area

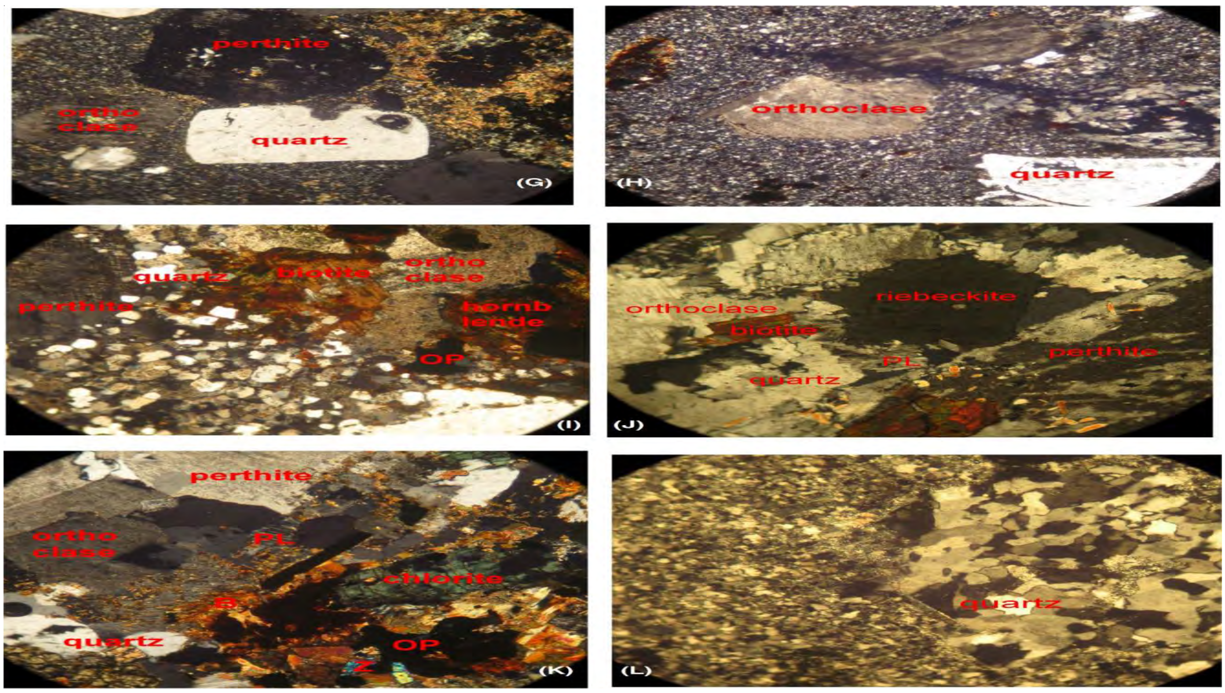
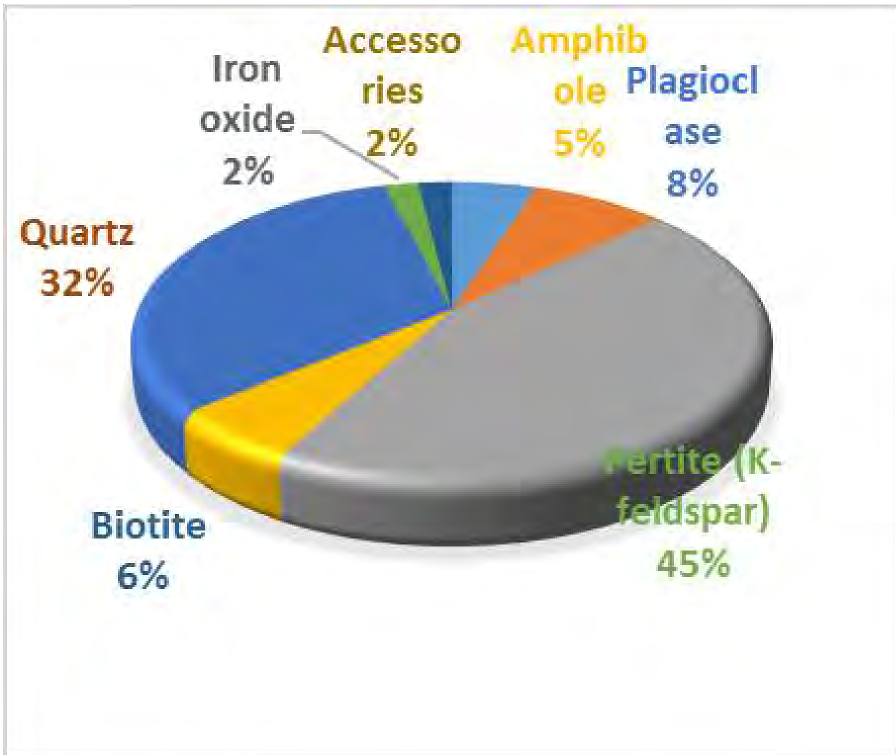
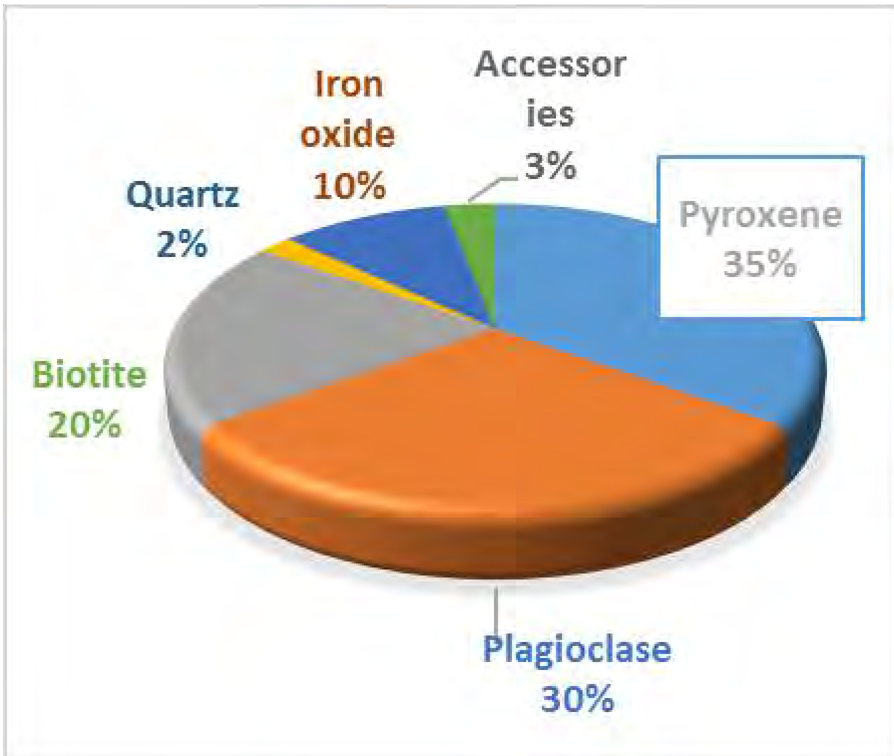


Figure 12: Modal Composition of Diorite (Left) and Gabbroic Diorite (Right)





form. The hornblende occurs mainly in the groundmass and does not have any preferred orientation within the matrix.

K-feldspar crystals are euhedral to subhedral in form. They are colourless and show sharp extinction. The K-feldspar present is orthoclase. The crystals range from small interlocking crystals to large isolated phenocrysts. The quartz crystals are euhedral to subhedral in form. They are colourless and show wavy extinction. They occur as phenocryst within the groundmass, and some of the crystals have been highly cracked.

Iron oxide occurs as an abundant mineral. It has a rusty brown coloration or a dark colour which remains unchanged. The accessory mineral present is flourite, attached to aegirine. They form minute crystals that are light purple in colour and non pleochroic.

Rhyolite with Comenditic Patches

In hand specimen, the rock contain a few small phenocrysts of turbid alkali feldspar which are light in colour and are about 0.5cm in length. There are also small rounded quartz crystals which are less than 0.3cm in diametre. It exhibit a conspicuous feature referred to as flow banding.

Under the microscope, the rock contain fiamme, lenticular inclusions with ragged flame like ends which are more coarsely recrystallized than the matrix, often showing axiolitic structures. Presence of comendites is an indication that the early rhyolites was in part peralkaline.

Aegirine is greenish but pleochronic from yellowish brown to purple. They occur in the same habit as the amphiboles, but often being replaced by the amphiboles or biotite from the fringes. Extinction is oblique. Amphiboles are sodic varying between arfvedsonite and riebeckite Arfvedsonite is green and pleochroic from green through blue to brown while riebeckite is blue. Both exhibit two cleavage directions, one at an acute angle and the other obtuse with oblique extinction.

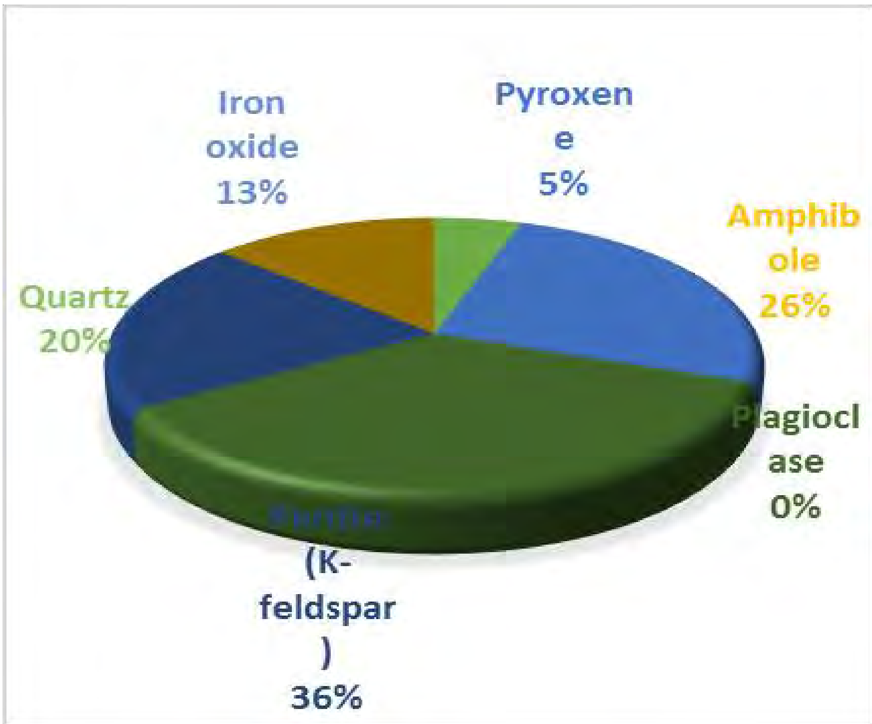
The feldspars are mostly k-feldspars, mainly perthites with some minor occurrences of plagioclase laths exhibiting albite twinning. Biotite occurs as tabular small to medium sized grain with one perfect cleavage direction. It is brown and pleochroic from brown to dark brown. They are characterized by straight extinction quartz occurs as small anhedral crystals. It is colourless to grey. Tiny opaque iron oxide grains are visible. They occur as small clusters in some part of the rock. Accessory minerals constitute about 1% of the slide.

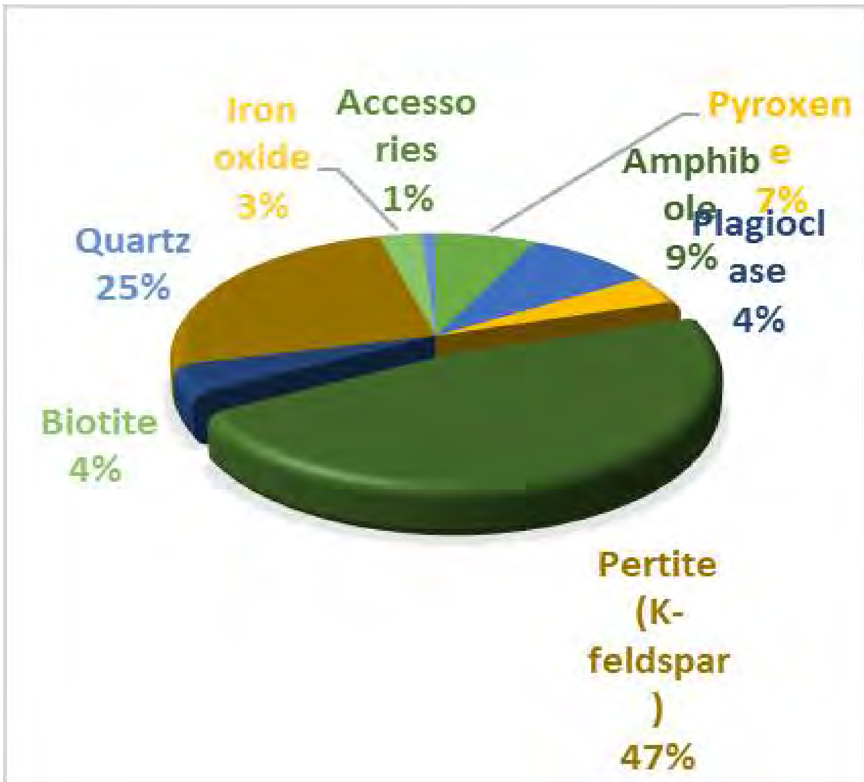
Syenite

In hand specimen, the rock is Pinkish grey when fresh, speckled with abundant dark clusters and patches of fine-grained hornblende. Under the microscope, it has a porphyritic texture with phenocrysts of feldspar distributed in a matrix of perthite, quartz and hornblende (Figure. 14a).

Hornblende is pleochroic from pale blue to pale green and it is anhedral in form. The crystals have high birefringence. The main K-feldspar is orthoclase and it occurs in a groundmass of microperthite. It is easily observed due to its sharp extinction from light to dark. Micropethite is partly covered by k-feldspar and does not exhibit pleochroism. It also has a muttled appearance. Biotite crystals are subhedral to anhedral in form and occur both as primary and secondary. The primary biotite is pleochroic from greenish brown to dark brown while the secondary biotite (alteration product) is pleochroic from green to light green.

Figure 13: Modal Composition of Rholite (Left) and Rhyolite with Comenditic Patches (Right)





Quartz grains are subhedral in form, and each crystal show a high degree of fragmentation. They exhibit wavy extinction and range is size between 0.5 and 1.0mm in length. Iron oxide is present and constitute approximately 2% of the slide Accessory minerals include zircon and apatite.

Biotite Granite

In hand specimen, the rock varies in colour from pale grey and sometimes pale yellow. It is a granular, medium grained rock. Under the microscope, the rock is highly weathered and this has resulted in the breakdown of biotite to form chlorites. The chlorite occurs within the cracks present. The rock has medium to fine -grained texture (Figures 10E and 14b).

The feldspar present is actually an irregularly formed perthite. Patches of plagioclase feldspar could be observed on the surface on the K-feldspar. Biotite is pleochroic from pale green to brown and are subhedral in form. The chlorite has light green colouration and occur mainly along the cracks present within the mineral grains. The chlorite has an anhedral crystal form, and it occurs as an alteration product. Quartz occurs as euhedral to crystals. Some of the crystals have cracks in them which contain inclusions of a crypto-crystalline material. Iron oxide is less abundant in this sample. It only occurs as tiny black patches in some biotite crystals.

Biotite Microgranite

In hand specimen, the rock is fine to medium grained and even - texture. It varies a little in grain size and contains a few basic clots or larger diffuse xenoliths. Minerals present include quartz, k-feldspar (orthoclase), albite, hornblende and accessory minerals.

Under the microscope, it consist of irregular crystals of feldspar and quartz. These are distributed as small grains and granophyre intergrowths. Hornblende is present and occur as a primary mineral together with quartz and plagioclase. It is pleochroic from dark to light green and is fractured. It has been replaced by biotite in some places especially in the margins. Oligoclase occur as colourless, subhedral and anhedral crystals. The relief is low with extinction in most crystals parallel to cleavage traces. Others have oblique extinction. Carlsbad twinning is also common.

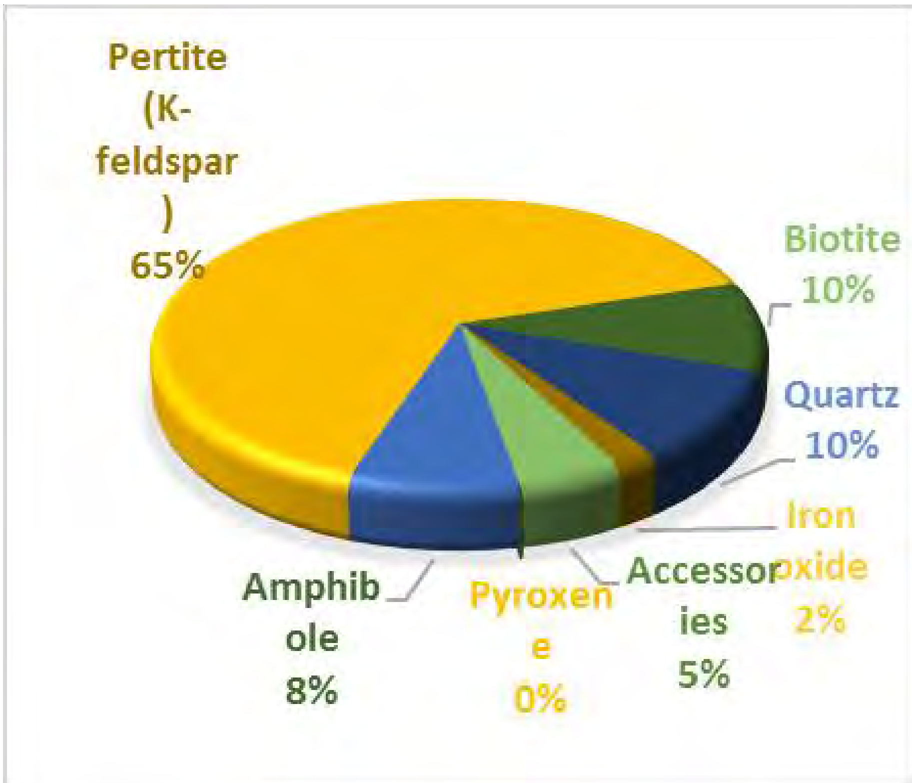
The k-feldspars are perthite. Plagioclase and microcline are intergrown with quartz. Biotite is pleochroic from light green to dark brown. It penetrates the fractures in plagioclase or associated with quartz aggregates. Quartz occurs as colourless, clear, anhedral and form clusters. It displays undulose extinction. Accessory minerals include allanite, zircon and calcite. Iron oxides is also present (Figure.11K).

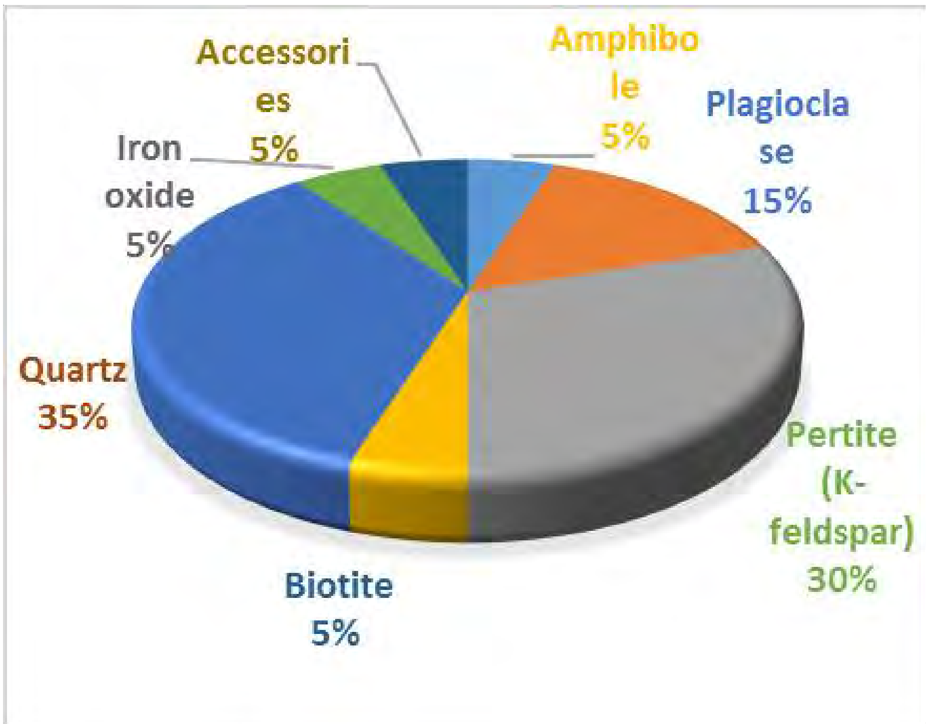
Hornblende-Biotite Granite

In hand specimen, the rock is dark grey and has equigranular grain size between 0.5 to 1.0mm. Under the microscope, quartz and perthite form an interlocking mosaic containing scattered flakes and clusters of mafic minerals, principally hornblende. The hornblende show greenish brown to blue- green pleochroism and is occasionally associated with sheds of biotite. The crystals are subhedral (Figure. 11I).

Both perthite and separate albite are present and in the former the potash component is cloudy and is veined by albite in a rather irregular way. Biotite which is pleochroic from dark green to straw yellow, also occur as net - like crystals replacing the plagioclase member of the perthite. Quartz forms clusters of anhedral grain set between large interlocking crystals of perthite. Iron

Figure 14: Modal Composition of Syenite (Left) and Biotite Granite (Right)





ore form clusters, with the green - brown hornblende as subedral crystals which are sometimes pseudomorphed by biotite. The accessory minerals include fluorite, apatite, zircon and ilmenite.

Porphyries

Two thin sections were examined for the porphyries in the study area. The modal composition of the aegirine-arfvedsonite and riebeckite granite porphyries are shown in Figureures 15a and 15b respectively.

Aegirine - Arfvedsonite Granite Porphyry

In hand ‘specimen, the rock is dark blue in colour and has phenocrysts of light euhedral to subhedral feldspars scattered all over. The modal composition is given in Figure. 15a. Under the microscope, the rock comprise of aegirine, arfvedsonite, k-feldspar, biotite, iron oxide and other accessory minerals (Figure. 10D). Aegirine crystals are pleochroic from green to brownish green. The crystals show wavy margins. It is less abundant in this slide. Arfvedsonite crystals occur either as minute rounded plates which form spongy, stellate clusters, or as elongated laths. It is pleochroic from light blue to yellowish green and show very low birefringence. K-feldspar crystals are subhedral in form and have cloudy margins. They appear colourless and show irregular extinction. The crystals have a cryptoperthitic texture and occur as phenocrysts within the groundmass.

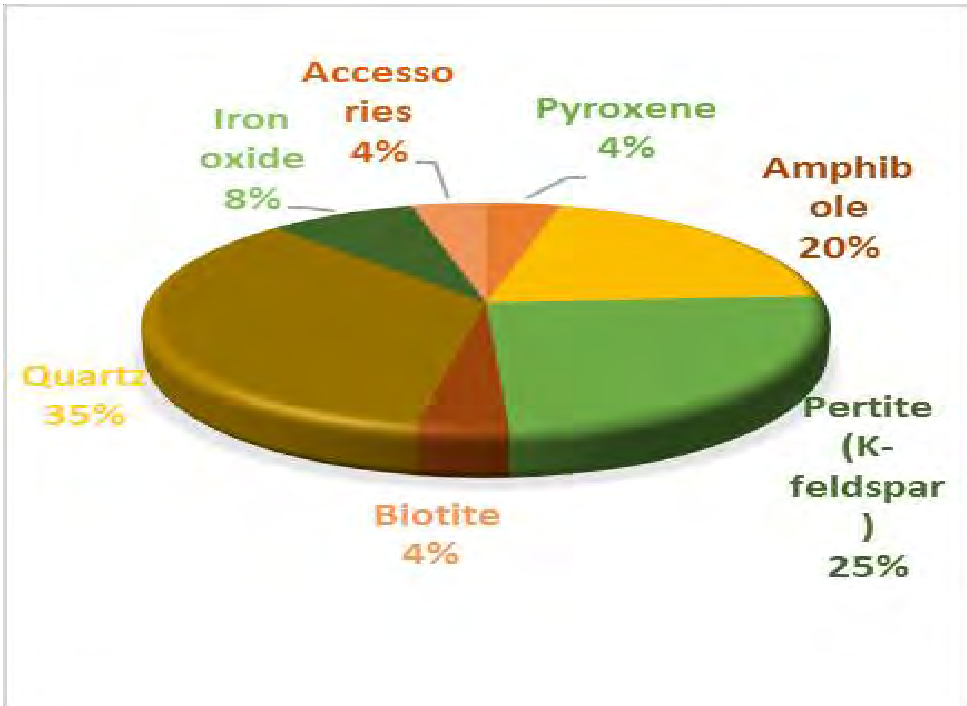
The biotite is anhedral in form and is pleochroic from green to brownish green. The quartz occurs as phenocrysts within the groundmass. The crystals are colourless and show wavy extinction. The quartz phenocrysts are subhedral in form, and some of the phenocrysts have been stretched to an elongated from showing flow banding. Iron oxide crystals occur as dark coloured crystals. The crystals are displayed all over the groundmass without any particular orientation. They sometimes contain inclusion of accessory minerals. Accessory minerals present include apatite and zircon.

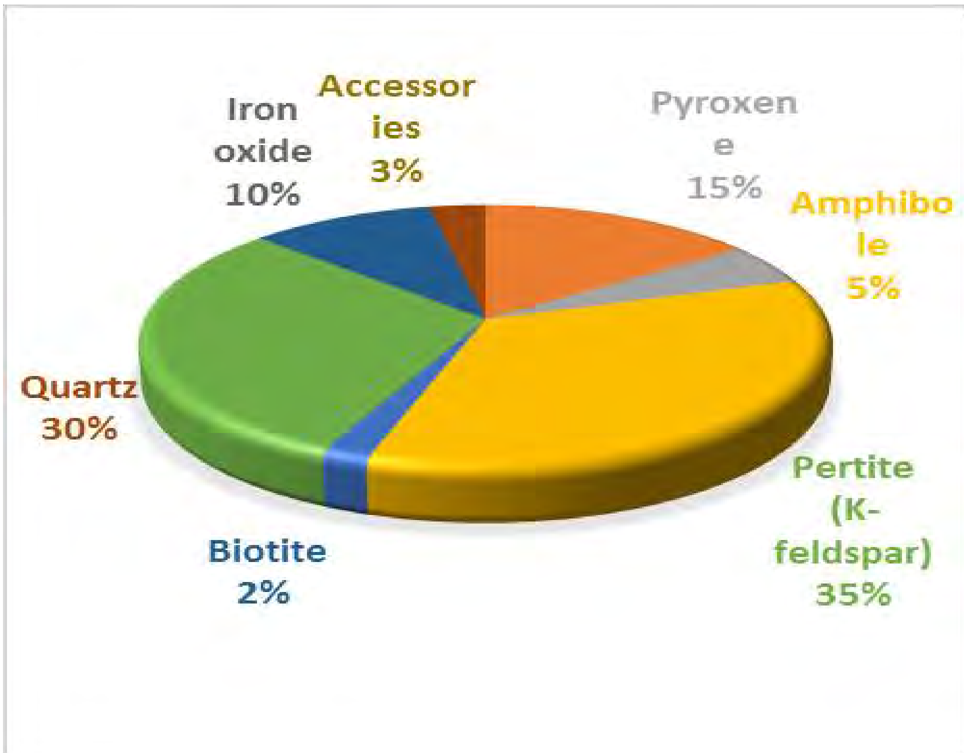
Riebeckite Granite Porphyry

In hand specimen, the rock is characterized by the presence of numerous pink or cream euhedral phenocryst of feldspar up to 1cm long. The modal composition is given in Figure. 15b. Under the microscope, the rock show a cryptocrystalline groundmass with granophyre texture. Phenocrysts of quartz and feldspar are observed within the groundmass, and the other mineral grains present have a medium to fine grained texture which merges with the groundmass. Aegirine crystals are subhedral in form. They occur as minute patches/clusters of pale yellow crystals within the groundmass. Riebeckite is the principal mafic mineral which occurs as wispy blades scattered through the matrix. It is pleochroic from greenish brown to deep blue and show anomalous interference colours. It is generally present in minor amounts and forms minute colourless prisms (Figure. 11J).

The main k-feldspar present is orthoclase. The crystals are euhedral to subhedral in form, and they occur as phenocrysts within the groundmass. Biotite crystals are subhedral in form. They are pleochroic from yellowish green to green. The biotite is basically an alteration product and occur mainly in cracks within the groundmass. Quartz crystals have deeply eroded boundaries with several internal cracks. Biotite is sometimes observed in between the cracks. The quartz crystals are subhedral in form. Iron oxide occur as anhedral mineral grains, and they

Figure 15: Modal Composition of Aegirine - Arfvedsonite Granite Porphyry (Left) and Riebeckite Granite Porphyry (Right)





occur in between patches/clusters of aegirine. Accessory minerals include zircon and ilmenite. Zircon occurs as subhedral crystals with high relief. Some of the zircon occurs crystals occur as inclusions in aegirine.

Quartz-Feldspar Granite Porphyry

In hand specimen, the rock is coarse grained and light to pink in colour. It has a pitted surface on account of differential surface weathering, making the feldspars to stand out profusely. Under the microscope, mineral recognized are quartz and feldspars while dark coloured minerals in the slide are biotite and hornblende. Hornblende is the chief mafic constituent and is generally greenish in colour. It is pleochroic from light to dark green. The plagioclase in this rock is albite. They are well twinned (albite twinning) and crystals are small, subhedral forming lath shapes. Orthoclase-microperthite occur as phenocrysts of up to 2mm long with a later generation of strongly cross hatched microcline perthite. The orthoclase occur as large anhedral and patch grains that appear cloudy due to alteration. Some of the microcline occur as interstitial grains or replacement rims around orthoclase. (Figure. 11G).

Biotite crystals are generally brownish or reddish in colour. They are generally cleaved in one direction and have parallel extinction. They are subhedral and pleochroic from light to dark brown. Quartz occur as smaller rounded phenocrysts. It is colourless, clear anhedral and occur in complete micrographic inter-growth with orthoclase and its interlocking pieces usually enclose feldspar, biotite and opaques. The iron oxide mineral present in this slide is magnetite. Accessory minerals include zircon, sphere and apatite (Figure. 11H).

Hybrid Rock

The contact rock comprise of a slide of gabbroic diorite/granite around Rishi. Even in hand-specimen, the contact between the mafic and felsic is very sharp.The granitic component is a hornblende - biotite - granite. Under the microscope, the contact is also very visible. The coarse- granite is to the right while the left half Figure. 11L is occupied by the gabbroic diorite. The major component minerals of these granites are microcline, oligoclase, biotite, hornblende and quartz. The accessories include apatite, zircon, allanite, iron ore, epidote, sphene, sericite, muscovite and chlorite.

Petrographic Interpretations

Slides of the mafic rocks which comprise of diorites and gabbroic diorites show that plates of plagioclase and hornblende enclose abundant pyroxene, biotite, olivine and iron oxide. This arrangement usually develop during the crystallization of magma formed from ultramafic rocks like peridotite where plates of hornblende surround grains of divine and pyroxenes forming ophitic texture. Most of the biotite and hornblende observed in slides of gabbroic diorites show some level of alteration to iron oxide. This is probably as a result of a subsolidus deuteritic alteration that was brought about by the felsic injection. A general lack of fayalite in the biotite rich granites may likely indicate a low $P0_2$in the parent magma. Even when the granite became alkaline, the development of aegirine was only sporadic. Within the felsic rocks, biotite microgranites show k-felspar occurring with inclusions of globular quartz. This probably occurred during crystallization or through replacement of one mineral by the other.

The thin section from the hybrid rock show that hornblende biotite and iron oxide occur close to each other. Reaction rims of biotite observed around iron oxide-was probably due to hydrothermal activity that followed the injection of the felsic (granitic) material into the mafic rocks. The heating up of the felsic magma must have resulted to a violent release of volatiles that fractured and brecciated the marginal zones of the mafic rocks leading to a metasomatic alteration. Although the mafic rocks have been altered and metasomatized by the granitic injection, and have in turn contaminated the felsic material the actual compositional changes have in each case been small and rocks of the truly intermediate composition are formed and are usually the product of mechanical mixing of the felsic and mafic material.

Generally, the petrography of these rock samples reveal the presence of a mafic magma which has two pulses (a mafic and felsic pulse) of injection.

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