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Research Article

Geology and Geochemical Characterization of Basement Rocks Around Burumburum Area North Central Basement Complex Nigeria

Lawal Mohammed Lukman*, Tavershima Najime, Paul Olusegun Ogunleye, Shehu Magaji, Nyajon Kubuza Caleb

Department of Geology, Ahmadu Bello University, Zaria, Nigeria

Abstract

The geology and the geochemical characterization of rocks around Burumburum area north central basement complex of Nigeria was studied. Twelve (12) rocks samples were prepared for petrographic studies through a standard procedure while thirty (30) whole rocks samples were analyzed using X-ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry(ICP-MS). The result of the field investigation revealed that the study area is underlain by migmatites, gneisses, biotite microgranites, fine grained biotite granites, medium grained biotite granites, porphyritic biotite-hornblende granites, granodiorites, syenites, diorites, dolerites, quartzite, pegmatites and aplites. The geochemical characterizations of the granites, granodiorites, syenites based on Na_2O/K_2O versus SiO_2 showed acidic compositions while diorites and dolerites are intermediate to basic compositions. The granites, granodiorites, syenites, diorites and dolerites are generally peraluminous (ASI>1.1) to metaluminous (ASI≤1). The granitic rocks, diorites, dolerites and syenites plotted mainly in shoshonite series while the granodiorites occur in High-K calc-alkaline fields. The granitic rocks, syenites, diorite and dolerites based on A/CNK versus SiO_2 are of I-type while granodiorites are of S-type. The multi-elements discrimination trends for granites, granodiorites, syenites, diorites and dolerites revealed relative enrichment in Large Ion Lithophile Elements (LILE: Ba, La, Rb, and Th and depletion in High Field Strength Elements (HFSE: Nb, P, Ti and Sr) which indicates crustal contamination of magma. The enrichment in the light rare earth element (LREE) relative to heavy rare earth element (HREE) for granodiorites, fine grained biotite granites, medium grained biotite granites (except medium grained biotite granites S12 and S14 with positive Eu), porphyritic biotite-hornblende granites and syenites with negative Eu anomaly suggest moderate to high degree of fractionation. The enrichment in light rare earth element (LREE) for diorites and dolerites relative to moderate to flat HREE with weak negative Eu anomaly indicates low degree of fractionation. The Y+Nb vs Rb, Y vs Nb, Ta + Yb vs Rb and Yb vs Ta tectonic discrimination diagram revealed that granites and syenites plotted mainly within volcanic arc granite, syn-collisional granite and in the within plate granites fields, the granodiorites clearly plotted in the within the plate granites field. The tectonic ternary molecular proportions MgO – FeOt – Al_2O_3 revealed that dolerites and diorites plotted mainly in the spreading center island field.

Keywords

Geochemical Characterization, High Field Strength Elements, Large Ion Lithophile Elements, Precambrian Basement Complex, Tectonic Setting, Younger Granites, Clarke and Washington Value, Tailor Value

*Corresponding author: lawallukman4real@yahoo.com (Lawal Mohammed Lukman)

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1. Introduction

The Burumburum area is located in the northcentral basement complex of Nigeria and lies between latitudes 11° 00′ to 11° 30′ N and longitudes 8° 30′ to 9° 00′ E which cover an area of 3080 km^2 (Figure 1). The major settlements in the area include Garko, Dal, Gani, Sitti, Tiga, Rimi, Sumaila, Buruburum, Sayasaya and Burra. These areas are interconnected by well-constructed roads linking major settlements and villages. However, most of the sampling sites were accessed through uncleared bush and foot tracts. The study area is underlain by migmatites, gneisses, fine grained biotite granites, medium grained biotite granites, porphyritic biotite-hornblende granites, syenites, diorites and dolerites of the Precambrian basement complex and biotite microgranites of the anorogenic mesozoic granites. The Nigerian Basement Complex form part of the Pan-African mobile belt that lies between the West African and Congo Cratons, and south of the Tuareg Shield [5] and it is divided into eastern and western provinces. The eastern province comprises of a migmatite-gneiss complex intruded by Pan-African granites and the Mesozoic Ring Complexes of central Nigeria while the western province is characterized by narrow N-S trending sediment-dominated, low-grade schist belts separated from each other by migmatite-gneiss complex and intruded by Pan-African granitic plutons [3]. The Precambrian basement complex rocks and the Phanerozoic rocks occur in the eastern region and in the northcentral part of Nigeria. Available geochronological evidence indicates that four major tectonic thermal events have affected the Nigerian Basement Complex which includes (i) Liberian Orogenic cycle 2800 ± 200 Ma -Middle to Late Archean (ii) Eburnean Orogenic cycle (2000 ± 200 Ma - Paleoproterozoic (iii) Kibaran Orogenic cycle (1100 ± 200 Ma - Neo Proterozoic) and (iv) Pan-African Orogenic cycle (600 Ma ±150 - Late Proterozoic) [10, 12, 6, 17]. The Pan-African Orogeny being the most widespread event in Nigeria manifests in the emplacement of large volumes of granitoids and the reworking of all rock types in the basement complex [31, 3, 37, 12]. Wright, J. B and McCurry P (1970) [47] suggested there was collision between Pan-African region and the West African craton where a subduction zone dipped eastward beneath the Pan-African region. Deformation and metamorphism followed the continental collision around 660 Ma ago with consequent crustal thickening in the Nigerian region.

The other biotite microgranites in the study area, belong to the Ningi-Burra Ring Complex which are part of the so called "Younger Granites" [18] with several emplacement centres within the northcentral Nigeria Basement Complex [7]. The biotite microgranites however, is not the focus of this paper.

The chemical compositions of the rocks are useful to model their evolution and tectonic discrimination of geochemical processes. The geochemical characterizations of the rocks have been documented by varieties of authors [11, 41, 36]. Chappell and White (1974) [8] classified granitic rocks into metaluminous to weakly peraluminous, relatively sodic with a wide range of silica content formed from a mafic metaigneous rocks (I-type) and strongly metaluminous, relatively potassic with higher silica composition formed from melting of metasedimentary rocks(S-type). Frost *et al.*, (2001) [22] classified granitic rocks based on chemical composition of (FeO_2/FeO+MgO=Fe), modify alkali-lime index (MALI) and aluminium saturation index (ASI) that incorporate composition and abundances of feldspars, differentiation history and source of magma to determine their origin and tectonic evolution.

This paper is an attempt to determining the geology and geochemical characterization of the basement complex rocks within the area of study.

2. Methodology

The field mapping exercise of Burumburum (Sheet 104) was carried out on a scale of 1:50,000. The mapping commenced with a carefully planned traverses using field map where various rock types were identified and studied. Rocks samples were collected using sledge and geological hammers. The global Position system was used to record the coordinates of the locations of the major geological features and where rock samples were collected. The remote sensing data interpretation and the field map were carefully interpreted for identification of lineaments which were subsequently verified in the field. Field description and lithologies encountered were documented. Twelve (12) rocks samples were prepared by cementing thin slices of rock to glass and carefully grinding them using carborundum grit to produce a thin layer of rock to a standard thickness of 30 microns at the Department of Geology Petrographic Laboratory, Ahmadu Bello University, Zaria. The modal analysis of the rocks thin section was carried out by point counting with Jmicrovision 1.2.7 software. Thirty (30) rock samples were pulverized at the Department of Geology Geochemical Laboratory, Ahmadu Bello University, Zaria for whole rock analysis at the ICP-MS laboratory, Stellenbosch University, South Africa using XRF and ICP-MS methods.

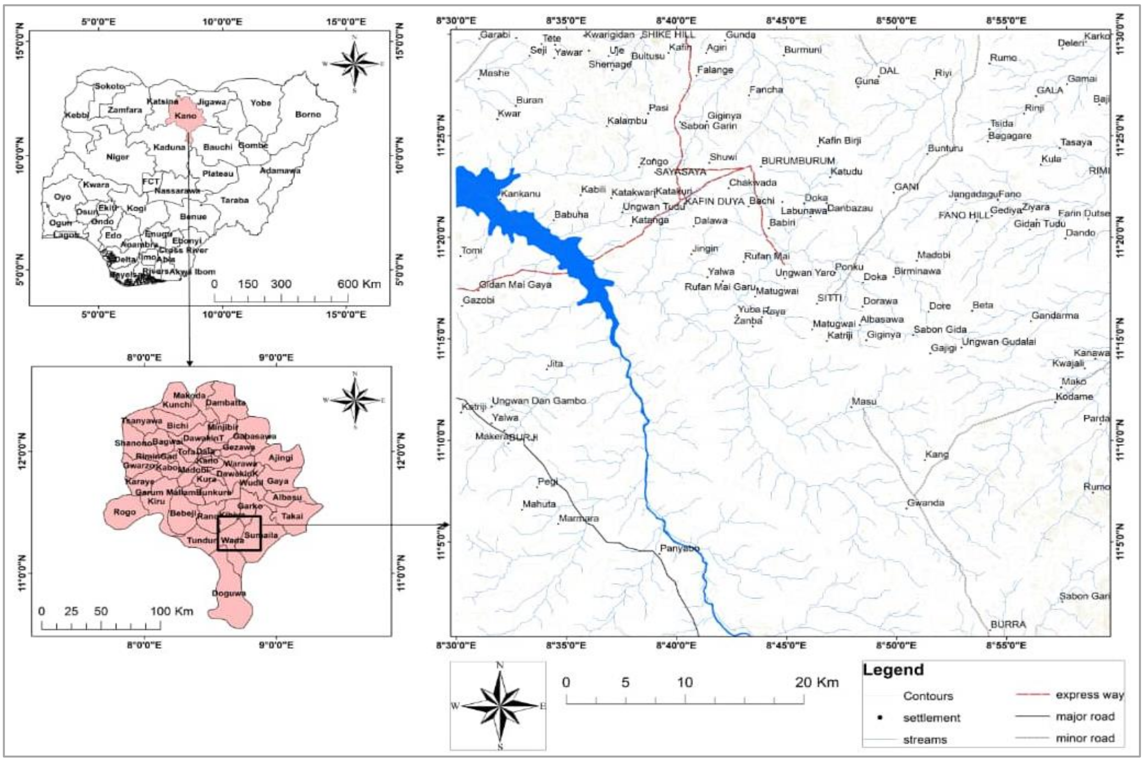

Figure 1. *Location and accessibility map of the study area (Burumburum Sheet 104).*

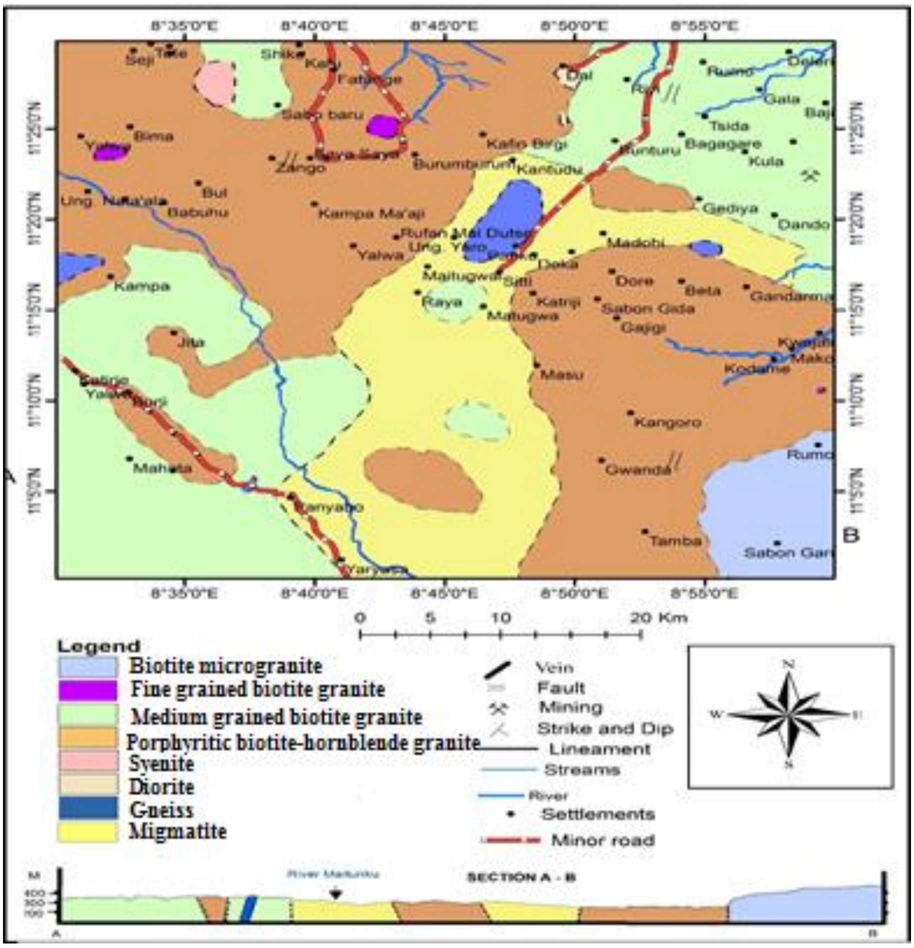

Figure 2. *Geological map of the study area (Burumburum Sheet 104).*

3. Result

The various lithological units encountered during the field mapping are presented in the geological map of the study area (Figure 2).

Migmatites occur as low lying outcrops in the central and north-eastern parts of the study area around Dando, Dore, Dogara, Beta Gidan Gizo, Sabo Matugwai and Tsoho Matugwai. They are banded and often display alternating bands of felsic and mafic minerals. Migmatite exhibit two distinct units consisting of paleosome that may be gneiss or amphibolites and the neosome made of granites, aplite or pegmatitic rock. The two types of migmatite identified in the field are lit-per lit migmatites and porphyroblastic migmatites. The texture of the rock is porphyroblastic and are intruded by quartz veins, pegmatitic veins and aplite dykes which are concordant with the host rock. The rocks grade in to gneisses and represent the host into which other rocks are emplaced.

Gneisses are closely associated with the migmatites which occur as low lying outcrop in the north eastern and central parts of the study area around Beka, Gandarma and Jangadagu Villages. They are fine- medium grained texture and light to dark grey in colour due to variation in felsic and mafic minerals composition. Gneisses comprise of quartz, feldspar and biotite with occasional occurrence of poorly formed phenocryst of feldspar. They are strongly foliated and characterized by small, concordant, lensoid or fairly large angular or rotated xenolith of amphibolites and small occurrence of mica schist. The contact between migmatites and gneisses is gradational (Figure 3).

The porphyritic biotite-hornblende granites outcrop at the southeastern and northwestern part of the study area along Buruburum-Sumaila road, Gacha, Unguwa Lato Dal, Kankanu, Chambi, Itifan-Fancha, Makayya and Kwajala Villages. They are crystalline igneous rocks with porphyritic texture and are usually cross-cutting into migmatite-gneisses. They are composed of interlocked crystals of quartz, feldspar, biotite and muscovite minerals. They are weathered in most of the study area and are cut in places by quartz veins, pegmatites and felsic dykes. The size of the granitic rocks ranges from small low lying outcrop to massive rocks which are part of the Older Granites formed during the Pan-African Orogeny. The contact relationship between the porphyritic biotite- hornblende granites and the migmatites and gneisses is difficult to establish because of soil over burden. The petrographic studies of the porphyritic biotite-hornblende granites revealed quartz occurs as small to medium grained subhedral crystals, it is colourless with moderate relief and constitute about 20% of the entire rock by volume. Plagioclase depicts a dark to grey colour, displayed albite twinning with subhedral crystal habit. The presence of striation on cleavages surfaces distinguishes the plagioclase from K-feldspar and constitute 25% of the rock by volume. Microcline appears as subhedral crystals with high relief and no pleochroism. It is clearly identified by cross hatch twinning. Microcline appears as subhedral crystals with high relief and no pleochroism. It is clearly identified by cross hatch twinning. Microcline is white to grey coloured with an inclusion of quartz within it and comprise 15% of the rock by volume. Biotite has dark brown colour, displays strongly pleochroic and exhibits prismatic crystal habit with moderate relief and account for about 25% of the rock by volume. Hornblende is pale brown and forms roughly prismatic individual with cleavage in two intersecting sets of planes parallel to the direction of elongation. Some exhibits twinning with low relief, high birefringence with inclined extinction and account for 10% of the rock by volume. Magnetite occur as accessory mineral; it has moderate relief with subhedral crystal forms and constitutes 3% of the rock by volume while the remaining 2% is made up of apatite (Figure 4).

The medium grained biotite granites occur as low lying outcrops in the northeastern and southwestern part of the study area. The rock has equigranular texture and comprise of quartz, feldspar and biotite. The rock is pink due to high abundance of alkali feldspar. The contact between the medium grained biotite granites and porphyritic biotite-hornblende granites is difficult to established because of soil overburden. The petrographic study of the medium grained biotite granites outcropping around Kula, Jejin Kudu, Gala, Marena, Bunture, Rumo, Riyi, Dudan, Dal and Rimi revealed that the quartz is light coloured with low relief and makes up about 27% of the rock by volume. The orthoclase showed grey colour, low relief with anhedral crystals and constitutes about 25% of the rock by volume. Microcline is grey coloured with cross hatching subhedral crystals and account for about 15% of the rock by volume. Biotite display brown colour with anhedral crystals. It has straight extinction with moderate relief and constitute about 30% of the rock by volume. Opaque occur as accessory and account for 3% of the rock by volume (Figure 5).

The fine grained biotite granites commonly occur as low lying outcrop in few places in the northwestern part of the study area such as Gediya, Jangam and Ita-Fancha Villages. The rock is composed of equigranular or heterogranular of quartz, feldspars and biotite. The pink colour of the rock is due to high amount of alkali feldspar composition. The contact relationships between the fine grained biotite granites and the porphyritic biotite-hornblende granites is difficult to established due to soil overburden. The fine grained biotite granites under petrographic microscope revealed that quartz occur as colourless crystals, it displays large to medium mineral crystals with subhedral habit. Quartz shows moderate relief, exhibits undulose extinction and constitutes about 36% of the rock by volume. Orthoclase appear grey, it has anhedral crystal with low birefringence forming about 34% of the rock by volume. Plagioclase feldspar exhibit moderate relief with grey colour of subhedral crystals habit. It displays striation on cleavage surfaces with an intergrowth of biotite and contain about 10% of the rock by volume. Biotite appears dark brown, it exhibits subhedral habit with moderate relief forming about 20% of the rock by volume (Figure 6).

Granodiorites occur as low lying outcrops around Dal village. It is a medium to coarse grained. The petrography study of the granodiorite shows that quartz occur as subhedral crystals, it is colourless with moderate relief and comprise about 25% of the rock by volume. The orthoclase showed grey colour, low relief with anhedral crystals, it has simple twinning and constitutes about 32% of the rock by volume. Biotite is brown with inclusion of quartz, it has anhedral crystals habit with moderate relief and account for 35% of the rock by volume. Sphene, magnetite, apatite and zircon occur as accessory minerals and account for 8% of the rock by volume (Figure 7).

Syenites occur as massive outcrop in the northwestern part of the study around Kalambu Village. The rock varies from grey to dark green colour and composed of feldspar and a ferromagnesian mineral with little amount of quartz. The contact relationship with the porphyritic biotite-hornblende granites is gradational. The Petrographic study of the syenites revealed that quartz occur as medium sized anhedral crystal, it is milky with brown interference colour. It also displays strong pleochroism, moderate relief and constitutes about 4% of the rock by volume. Orthoclase is grey, it displayed moderate relief and exhibit subhedral crystal forms with interference colour and make up about 55% of the rock by volume. Biotite depict brown colour, occur as prismatic crystal with high relief and comprise 35 % of the rock volume. Opaque mineral occur as accessory mineral identified and contain 6% of the rock by volume (Figure 8).

The diorites occur as poorly exposed low lying outcrops around Bakin Laraba Village. It is a coarse grained intrusive igneous rocks and consist of dark coloured mafic minerals and large interlocking, randomly oriented crystals of plagioclase feldspar. The contact relationship with the porphyritic biotite-hornblende granites is sharp. The petrographic study of the diorites indicates that quartz crystal are colourless, it has small sized crystals with anhedral habit. The mineral has low relief, it exhibits undulose extinction and contain about 10% of the rock by volume. Plagioclase shows phenocryst crystals in subhedral shape with high relief and is diagnosed with good cleavages that intersect each other. It has an inclusion of magnetite crystals and constitutes about 23% of the rock by volume. Biotite occur as fibrous crystal with moderate relief and comprise about 25% of the rock by volume. Hornblende depicts yellow to dark grey colour, displays high relief with irregular crystals habit. It revealed two excellent cleavages that intersect and comprise about 34% of the rock by volume. Magnetite occur as accessory mineral identified which show dark crystals and constitute about 10% of the rock by volume (Figure 9).

The dolerites (dibasic dykes) occur as a dark coloured in the northern part of the study area around Burumburum settlements. They are fine grained igneous rock and composed mainly of plagioclase and pyroxene minerals. It is not prominent in the study area and only occurred as dyke intruding into porphyritic biotite-hornblende granites. The rock is poorly exposed because of soil overburden and the length of the dyke is not more than 5m. The contact relationship of dolerites with other rock could not be ascertain because of soil overburden. The petrographic study of dolerites revealed that plagioclase occurs as lath of needle-like crystal grain, it has high relief, colourless and constitutes about 35% of the rock by volume. Pyroxene displays green colour and subhedral crystals habit with good cleavages and constitutes about 10% of the rock by volume. Olivine display pale pink to brown colour with an inclusion of iron ore in some of its grains and constitutes about 33% of the rock by volume. Magnetite mineral have dark colour and constitutes about 22% by volume (Figure 10).

Figure 3. *Migmatite showing paleosome and neosome around Ungwan Kuka (Lat:11˚16 15.2 Long: 008˚ 53′07.8″) (C) Gneiss around Beta (Lat.11˚17'37.2", Long. 008˚54'38.1").*

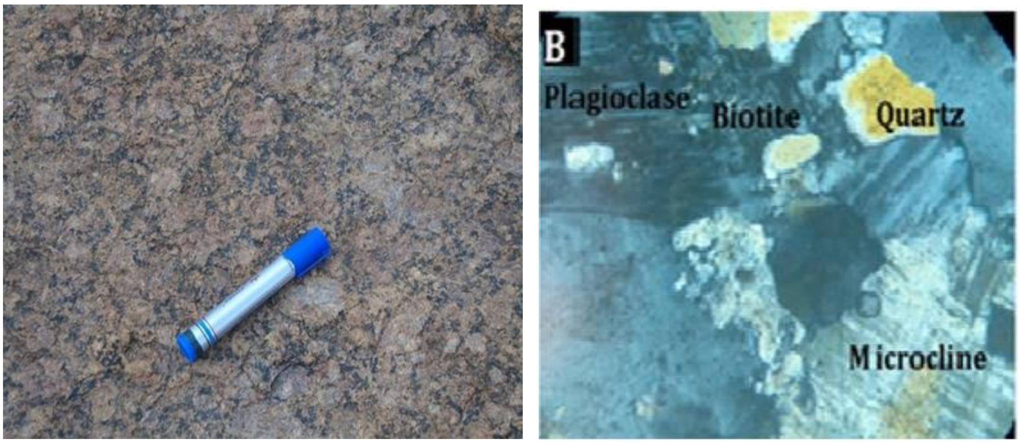

Figure 4. *Hand specimen of porphyritic biotite-hornblende granite around Ita fanchan area (QTZ)=Quartz, (M) =microcline and (PL) =plagioclase (BIO)=Biotite, Mag.=X100 (Lat: 11˚ 28′49.3″Long:008˚ 44′23.1″).*

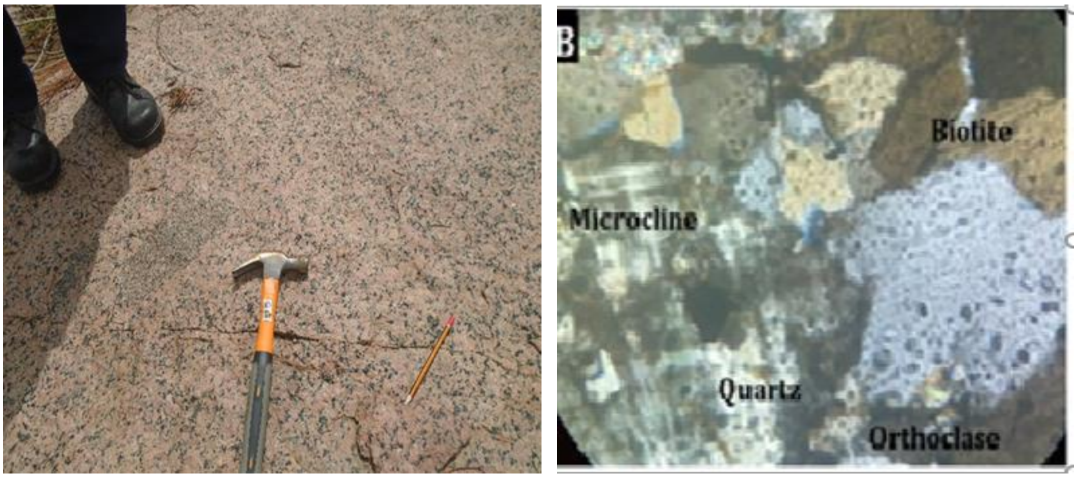

Figure 5. *Medium grained biotite granite around Burumburum area (QTZ)=Quartz, (ORTH) =Orthoclase (BIO)=Biotite and (OP) =Opaque Mag.=X100 (Lat: 11 °24′18.9″Long: 008 45′19.5″).*

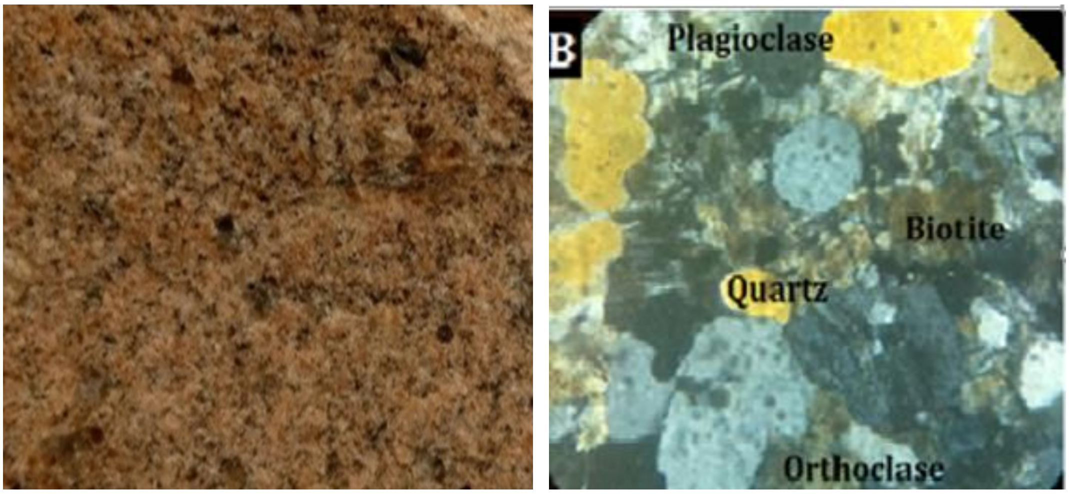

Figure 6. *Fine grained biotite granite around Gediya area (QTZ)=Quartz, (ORTH)=Orthoclase, (PL) =Plagioclase and (BIO) =Biotite. Mag.=X100 (Lat: 11˚ 25′32.4″Long:008˚ 37′25.5″).*

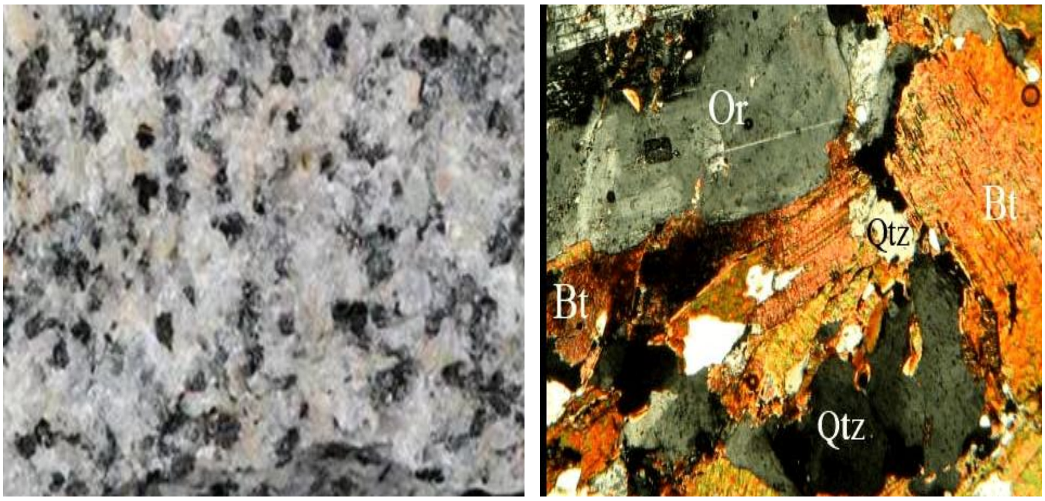

Figure 7. *Granodiorite around Dal area (QTZ)=Quartz, (ORTH)=orthoclase and (BIO) =Biotite. Mag.=X100. (Lat:11°25'32.1" Long: 008°37'25.4").*

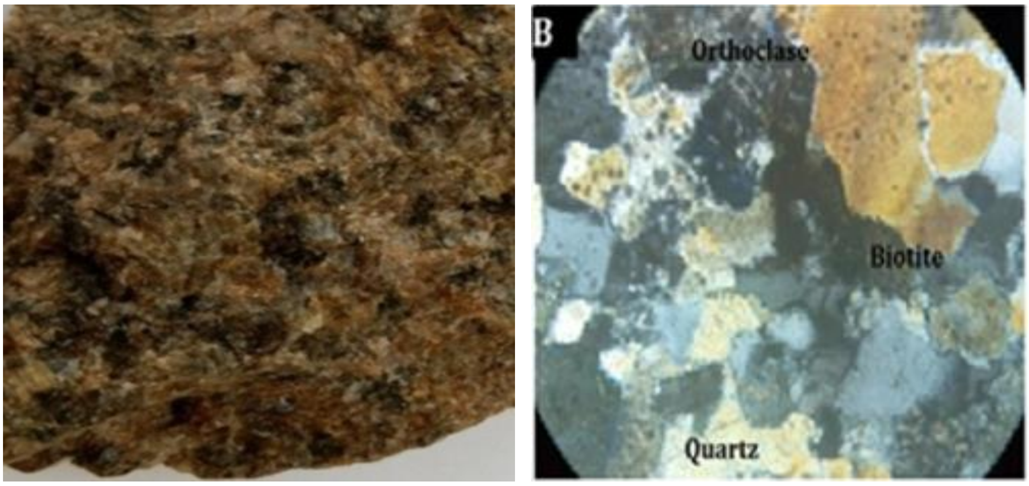

Figure 8. *Syenite around Kalambu area (QTZ)=Quartz, and (ORTH) =Orthoclase (BIO)=Biotite, Mag.=X100 (Lat: 11˚ 25ʹ50.6ʺLong: 008˚ 37ʹ10.7ʺ).*

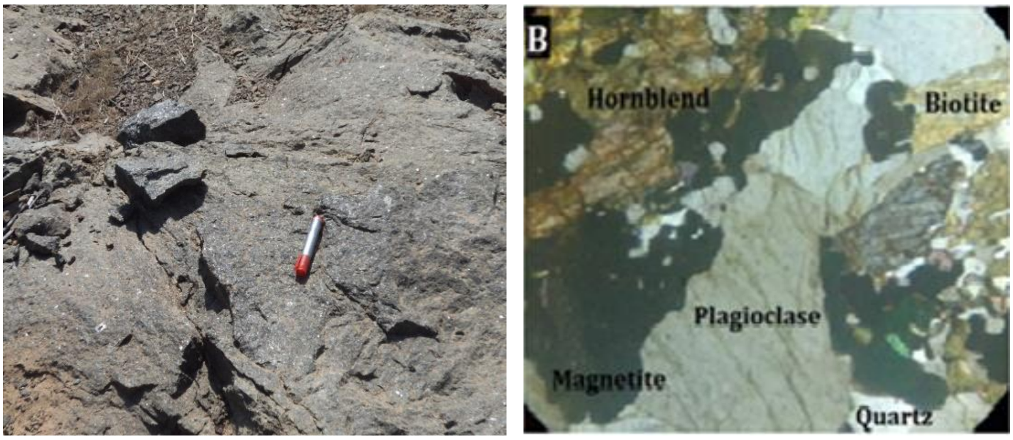

Figure 9. *Diorite (QTZ)=Quartz, (PL) =Plagioclase, (MGNT) Magnetite and (BIO) =Biotite. Mag. =X100 (Lat:11°20'30.8" Long:008°51'11.6").*

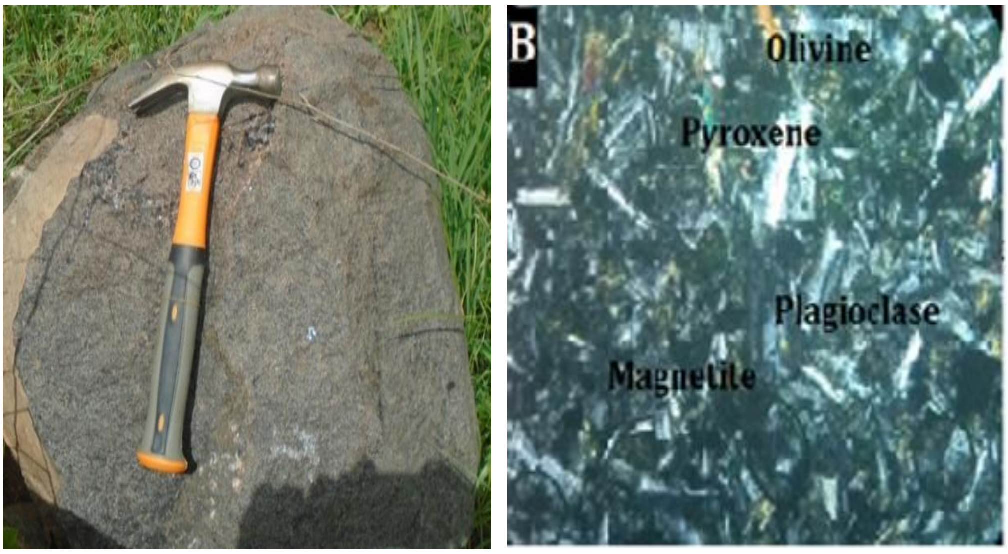

Figure 10. *Dolerites (OL)=Olivine, (PRX)=Pyroxene, and (MGNT) =Magnetite. Mag.=X100 (Lat: 11 °00 ′53.5 ″Long: 008 °59 ′29.3 ″).*

3.1. Major Elements Geochemistry

The major oxides contents are presented in (Table 1). The concentration of SiO_2 in fine grained biotite granites, medium grained biotite granites and porphyritic biotite-hornblende granites are in the range of 66.1-83.21 wt%. The increasing SiO_2 contents, high K_2O/ Na_2O ratio between 1.33-2.09, K_2O and Na_2O values greater than 3 wt % with decreasing Fe_2O_3 (t) contents of 0.44-4.27 wt %, MgO contents of 0.02-0.5 wt %, CaO contents of 0.52-1.97 wt% and P_2O_5 contents of 0.03-0.22 wt% in all the granites are consistent with the characteristics of igneous rocks trends. The granodiorite contained SiO_2 contents of 68.26wt%, high K_2O/ Na_2O ratio of 1.12, high K_2O and Na_2O values greater than 3 wt%, high Al_2O_3 contents of 15.21 wt%, Fe_2O_3 (t) contents of 4.91 wt%, MgO contents of 1.01 wt% and CaO contents of 2.43 wt% with low TiO_2 contents of 0.59 wt% and P_2O_5 contents of 0.12 wt%. The syenites has SiO_2 contents of 61.24-66.51 wt%, K_2O/ Na_2O ratio of 0.55-1.68, high K_2O contents of 4.18-6.64 wt%, Na_2O contents of 3.38-7.61 wt %, Al_2O_3 contents of 14.35-17.98 wt%, Fe_2O_3 (t) contents of 1.2-8.86 wt%, MgO contents of 0.18-0.98 wt% with low P_2O_5 contents of 0.14-0.6 wt%. The diorites contained SiO_2contents of 54.23-62.97 wt%, low K_2O/ Na_2O ratio of 0.93-1.35, high K_2O and Na_2O greater than 3 wt% with high P_2O_5 contents of 0.2-1.05 wt%. The dolerites contained SiO_2 contents of 46.82 wt%, K_2O low contents of 2.5 wt%, low K_2O/ Na_2O ratio of 0.7, and increased in Fe_2O_3 (t) contents of 15.43 wt%, MgO contents of 2.52% and P_2O_5 contents of 2.67 wt%.

The major element composition of granites, granodiorites, syenites and diorites as well as dolerites plotted on Harker diagram using SiO_2 as an index of diff8rentiation showed a pronounced inversed correlation with Al_2O_3, CaO, MnO, TiO_2, P_2O_5, Na_2O, Fe_2O_3 and a positive correlation with K_2O (Figure 11). The total alkali versus silica (TAS) of [11] based on the chemical variation revealed that syenites, granodiorites and granites are acidic rocks, diorites are intermediate rocks while dolerites are basic rocks (Figure 12). The A/NK versus A/CNK discrimination diagram of [41] revealed that granites, granodiorites, syenites, diorite and dolerites are generally peraluminous (ASI>1.1) to metaluminous (ASI≤1) (Figure 13). The Peccerillo and Taylor (1976) [36] used to determine the degree of evolution indicate that granites, syenites, diorites and dolerites plotted mainly in shoshonite series while granodiorites occur in High-K calc-alkaline field (Figure 14). The A/CNK versus SiO_2 diagram plot of [8] classify the granitic rocks, diorites, syenites and dolerites in the study area as I-type granite field while granodiorite is S-type granite field (Figure 15).

Table 1. *Major Oxides (wt %) of rocks in the study area.*

Major oxides	Granodiorite	Fine grained biotite granite	Biotite microgranite			
	S1	S 2	S3	S 4	S5	S 6
SiO_2	68.26	72.67	83.21	76.12	78.5	79.3
Al_2O_3	15.21	14.9	10.63	13.44	12.2	12.73

Major oxides	Granodiorite	Fine grained biotite granite	Biotite microgranite			
	S1	S 2	S3	S 4	S5	S 6
Fe_2O_3(T)	4.91	1.29	1.13	0.79	3.58	1.97
MnO	0.1	0.02	0.02	0.03	0	0
MgO	1.01	Bdl	0.09	Bdl	0.01	0.02
CaO	2.43	0.52	0.04	0.8	0.02	0.02
Na_2O	3.06	3.55	0.02	3.05	0.07	0.09
K_2O	3.43	6.11	3.23	5.54	3.47	3.63
TiO_2	0.59	0.12	0.12	0.08	0.19	0.23
P_2O_5	0.12	0.03	0.01	0	0.03	0.02
L.O.I.	0.9	1.03	1.69	0.39	2.03	2.85
Sum Of Conc.	100.02	100.24	100.19	100.24	100.1	100.86

Major oxides	Porphyritic biotite-hornblende granite					Medium grained biotite granite						
	S7	S 8	S 9	S10	S11	S12	S13	S14	S15	S16	S17	S18
SiO_2	70.99	82.44	69.13	74.2	66.1	68.94	69.89	70.42	70.6	71.15	69.43	70.45
Al_2O_3	15.38	10.87	14.85	14.75	15.57	15.31	15.07	14.78	14.07	14.58	14.19	15.29
Fe_2O_3(T)	1.68	1.35	3.07	0.44	4.27	3.64	3.38	3.17	3.45	2.82	4.1	1.71
MnO	0.04	0.02	0.04	0.03	0.07	0.06	0.06	0.05	0.07	0.05	0.06	0.03
MgO	0.26	0.09	0.15	bdl	0.5	0.02	0.09	0.13	0.4	0.41	0.35	0.19
CaO	1.34	0.04	1.64	0.52	1.97	1.09	1.45	1.4	1.2	1.32	1.5	1.2
Na_2O	4.06	0.02	3.15	3.76	3.36	3.55	3.9	3.46	2.82	3.57	3.14	3.26
K_2O	5.39	3.27	6.32	6.16	6.42	6.46	5.26	6	5.91	4.89	5.94	6.59
TiO_2	0.26	0.12	0.46	0.04	0.54	0.32	0.37	0.26	0.52	0.39	0.6	0.27
P_2O_5	0.09	0.01	0.08	0.04	0.22	0.1	0.12	0.07	0.14	0.1	0.22	0.11
L.O.I.	1	1.77	1.82	0.34	0.55	0.54	0.6	0.51	1.29	0.6	0.45	1
Sum Of Conc.	100.49	100	100.71	100.28	99.57	100.03	100.19	100.25	100.47	99.88	99.98	100.1

Sample ID	Syenite									Diorite		Dolerite
	S19	S20	S21	S22	S 23	S24	S25	S26	S27	S28	S29	30
SiO_2	61.24	63.75	65.49	63.58	66.51	63.24	63.45	65	62.04	62.97	54.23	46.82
Al_2O_3	14.35	17.98	15.65	15.74	17.74	17.67	15.73	16.87	15.5	16.16	13.48	14.24
Fe_2O_3(T)	8.86	2.77	5.01	5.96	1.2	2.38	5.91	4.18	8.43	6.2	14.2	15.43
MnO	0.14	0.07	0.09	0.08	0.02	0.03	0.1	0.08	0.13	0.09	0.19	0.19
MgO	0.98	0.46	0.42	0.58	0.41	0.53	0.6	0.26	0.18	0.38	1.4	2.52
CaO	4.15	1.58	3.04	3.04	1.35	2.27	2.72	2.55	2.65	2.59	5.06	8.42

Sample ID	Syenite									Diorite		Dolerite
	S19	S20	S21	S22	S 23	S24	S25	S26	S27	S28	S29	30
Na_2O	3.38	5.39	3.75	3.64	7.61	5.76	3.59	4.22	3.87	4.13	3.11	3.27
K_2O	4.18	6.64	5.04	5.6	4.2	5.94	6.03	5.66	5.27	5.63	2.9	2.31
TiO_2	1.11	0.6	0.63	0.78	0.4	0.38	0.69	0.48	0.86	0.76	1.75	3.46
P_2O_5	0.64	0.14	0.28	0.38	0.21	0.17	0.26	0.16	0.26	0.2	1.05	2.67
L.O.I.	0.81	0.57	0.67	0.35	0.48	1.44	95.02	0.34	0.3	0.38	2.55	0
Sum Of Conc.	99.84	99.95	100.07	99.73	100.13	99.81	194.1	99.8	99.49	99.49	99.92	99.33

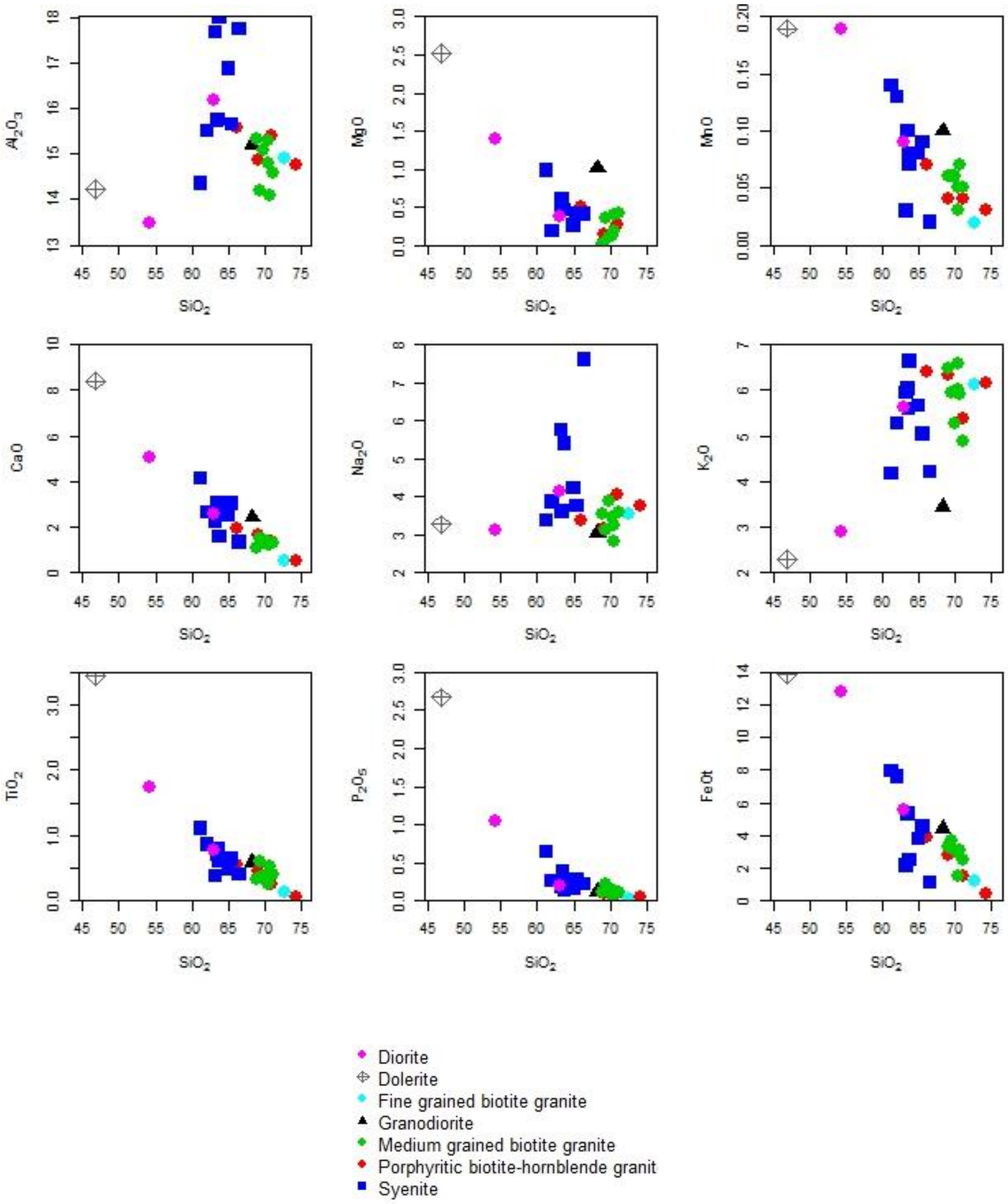

***Figure 11**. Harker's variation diagrams for major oxides against SiO_2 of the igneous rocks of the study area.*

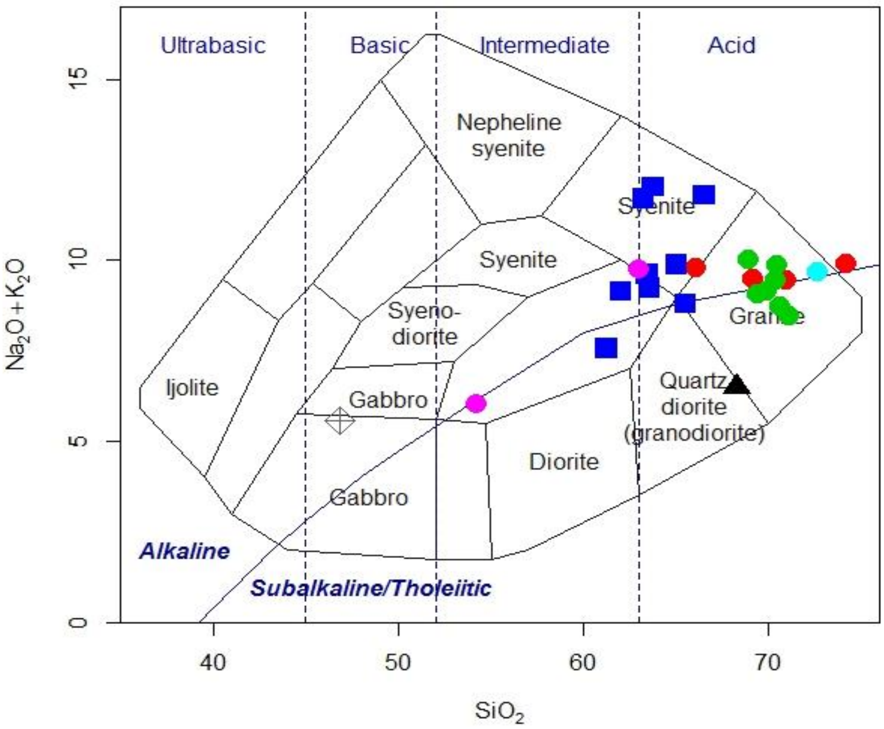

Figure 12. *Total Alkali versus Silica classification diagram of the granitic rocks of the study area using Cox et al, 1979) discrimination diagram. Symbols and colour of rocks are the same as in Figure 11.*

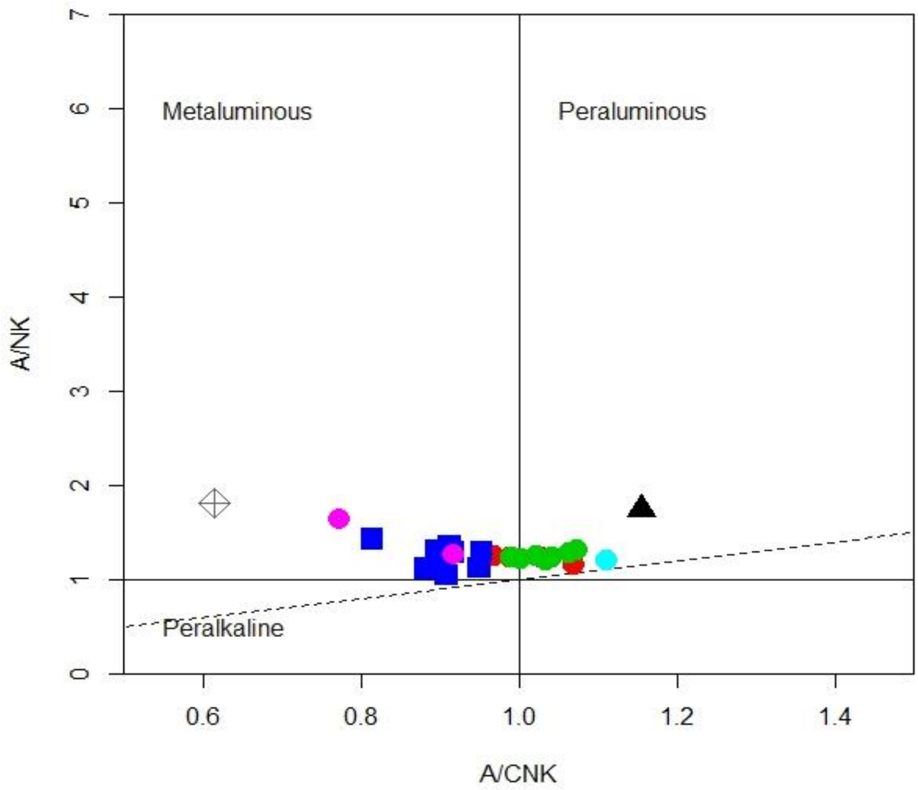

Figure 13. *A/NK versus A/CNK diagram of rocks in the study area, (using Shand, 1943 discrimination diagram). Symbols and colour of rocks are the same as in Figure 11.*

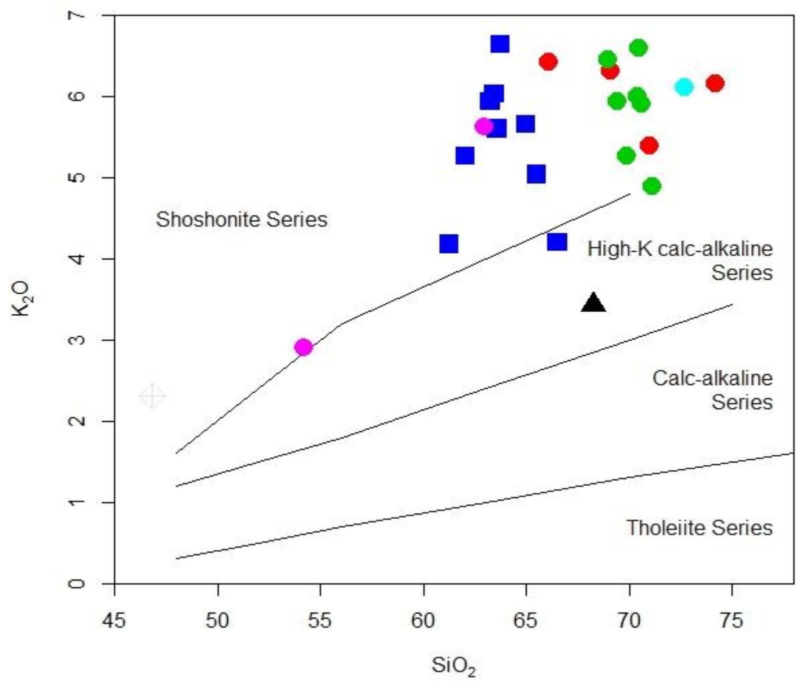

Figure 14. *K_2O versus SiO_2 diagram of the rocks in the study area (using Peccerillo and Taylor, 1976). Symbols and colour of rocks are the same as in Figure 11.*

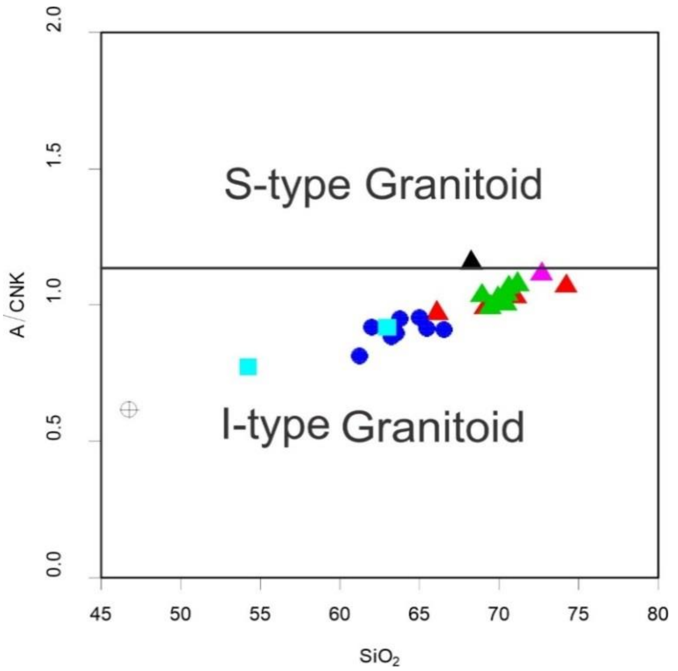

Figure 15. *Classification plot of the granitic rocks in the study area, of A/CNK vs SiO_2 (using Chappel and White, 1974 diagrams). Symbols and colour of rocks are the same as in Figure 11.*

3.2. Trace Elements Geochemistry

The result obtained from the analysis of trace elements of the rocks in the study area are presented in (Table 2). The multi-element discrimination plot for fine grained biotite granites, medium grained biotite granites and porphyritic biotite-hornblende granites and granodiorites normalized based on [44] revealed relative enrichment in Large Ion Lithophile Elements (LILE: Ba, La, Rb, and Th and depletion in High Field Strength Elements (HFSE: Nb, P, Ti and Sr) (Figure 16). The discrimination diagram for syenites, diorites and dolerites shows an enrichment in (LILE: Ba, Th, La and depletion of (HFSE: Nb, P, Ti and Sr) (Figure 17).

Table 2. *Trace Elements (ppm) of rocks in the study area.*

Elements	Granodiorite	Fine grained biotite granite	Biotite micrigranite			
	S1	S2	S3	S4	S5	S6
Sc	16.75	4.19	3.86	3.40	4.32	4.37
V	54.07	6.62	6.30	11.02	9.20	9.84
Ba	612.67	118.61	40.79	395.95	39.40	31.73
Sr	83.62	28.26	3.10	96.99	5.16	5.42
Y	39.06	30.81	51.40	5.70	60.90	59.38
Zr	319.48	199.36	416.89	47.87	525.40	439.42
Cr	29.23	6.52	5.92	8.20	9.60	8.55
Co	82.92	82.56	118.21	126.90	82.60	64.86
Ni	12.66	4.30	3.48	5.84	3.53	4.16
Cu	65.61	28.21	60.49	4.14	62.13	43.12
Zn	70.10	25.47	16.14	26.10	10.26	8.32
Rb	139.31	312.25	186.32	198.27	155.62	159.87
Nb	13.73	21.51	167.88	8.54	111.63	108.45
Mo	4.84	4.17	1.34	1.63	2.31	3.05
Cs	7.72	2.70	0.36	1.18	0.46	0.46
Hf	9.16	7.07	17.13	2.55	17.76	14.32
Ta	1.60	2.16	11.07	1.27	7.83	6.86
Pb	21.77	44.34	50.68	37.80	24.46	26.43
Th	16.04	17.18	25.81	26.06	22.41	17.42
U	2.29	4.37	6.94	4.08	4.15	4.15
Rb/Sr	1.67	11.05	60.10	2.04	30.16	29.50
Th/U	7.00	3.93	3.72	6.39	5.4	4.20

Ele-ments	Porphyritic biotite-hornblende granite					Medium grained biotite granite						
	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18
Sc	4.88	4.04	7.06	4.46	12.37	9.30	10.44	10.78	8.26	6.26	8.80	5.26
V	19.53	6.30	11.73	6.72	26.60	7.72	13.06	12.57	30.45	23.45	23.98	16.46
Ba	356.78	39.92	1103.51	156.74	1108.61	1346.05	989.18	1044.45	996.05	747.30	928.33	599.08
Sr	116.47	3.56	167.32	39.17	176.97	106.48	109.96	111.89	154.35	152.69	181.31	101.66
Y	37.02	59.13	24.70	9.39	65.95	23.04	24.82	25.74	43.46	24.87	56.28	16.58
Zr	154.51	458.07	854.17	21.41	586.47	679.05	380.30	312.54	444.68	294.16	636.11	245.31
Cr	9.56	7.66	7.45	8.44	6.42	7.23	10.95	13.14	8.80	11.78	4.88	9.32
Co	88.97	97.60	85.19	97.51	71.25	78.01	76.28	78.81	91.73	115.77	82.48	83.93
Ni	5.59	3.98	4.58	4.43	4.11	5.14	4.21	5.24	9.11	7.40	3.74	4.52

Ele-ments	Porphyritic biotite-hornblende granite					Medium grained biotite granite						
	S7	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**
Cu	30.57	48.00	21.92	10.71	27.74	16.33	11.54	64.18	33.88	14.00	43.24	14.72
Zn	46.22	16.66	60.38	32.09	75.68	86.58	100.63	98.81	65.29	68.35	84.39	51.09
Rb	222.09	190.74	135.23	284.76	171.83	144.66	135.75	161.38	189.76	187.30	205.38	261.38
Nb	15.37	186.04	12.39	5.39	29.43	16.00	16.35	14.47	17.51	19.50	30.86	18.37
Mo	1.12	1.16	3.66	0.90	3.91	2.35	2.20	2.06	3.35	3.17	2.80	1.70
Cs	3.24	0.41	2.00	1.52	1.41	1.66	1.89	1.95	0.74	2.12	1.95	5.06
Hf	5.34	18.59	21.42	0.84	15.30	15.38	9.67	8.41	11.78	8.11	16.44	7.64
Ta	1.97	11.66	1.42	1.15	2.04	1.43	1.77	1.92	1.27	1.54	2.35	1.40
Pb	45.98	60.65	23.41	36.08	24.33	22.49	24.87	29.26	24.26	28.72	31.69	55.44
Th	50.59	26.89	9.51	7.40	41.26	7.22	13.83	16.14	44.45	35.28	30.99	84.81
U	11.56	8.20	3.10	2.00	3.50	1.66	3.91	4.60	1.62	4.68	2.27	7.39
Rb/Sr	1.91	53.58	0.81	7.27	0.97	1.36	1.23	1.44	1.30	1.22	1.13	2.57
Th/U	4.38	3.28	3.06	3.7	11.79	4.35	3.54	3.51	27.78	7.54	2.27	11.48

Elements	Petrology	Syenite							Diorite		Dolerite
	S19	**S20**	**S21**	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**
Sc	18.31	9.11	12.10	12.97	5.18	5.56	12.96	9.82	16.70	17.22	13.21	20.99
V	47.88	20.18	17.87	30.95	22.06	35.47	28.27	13.46	10.63	50.47	17.00	250.38
Ba	1076.81	1154.45	1422.61	1527.26	847.46	1485.18	1248.61	1619.12	1326.64	1639.05	979.98	1174.84
Sr	274.13	190.09	331.78	295.25	184.23	531.94	205.60	288.04	123.47	324.00	283.53	517.04
Y	85.97	81.63	43.49	69.25	10.60	34.65	64.08	32.83	59.86	71.77	34.39	87.18
Zr	953.21	653.00	510.94	556.28	77.21	192.63	852.22	712.33	1595.77	550.92	1011.75	685.07
Cr	8.00	6.75	5.90	6.62	11.04	10.43	8.93	7.64	7.09	5.98	8.63	5.82
Co	70.84	51.89	76.14	79.86	51.37	42.94	54.42	73.65	66.74	43.59	62.71	72.87
Ni	5.77	3.84	3.20	4.75	7.85	7.00	4.29	4.43	4.41	3.04	4.96	11.06
Cu	34.69	49.83	30.53	16.31	38.15	54.61	32.74	28.91	37.62	48.13	34.64	48.71
Zn	159.95	77.39	103.53	103.62	31.09	40.94	112.63	84.21	195.30	210.40	102.49	164.30
Rb	116.74	101.90	105.01	136.38	106.85	102.49	173.52	126.68	114.75	46.84	106.48	34.01
Nb	50.39	24.64	26.89	38.92	13.99	10.20	38.97	28.00	36.57	35.75	54.94	37.43
Mo	2.57	1.37	3.84	3.13	0.89	0.82	4.20	1.72	3.94	4.15	4.07	3.71
Cs	2.27	0.57	1.10	4.68	1.54	0.93	3.01	2.92	1.76	1.89	0.69	0.52
Hf	22.81	16.62	12.22	14.12	2.84	5.70	20.68	16.58	34.96	23.87	13.86	16.18
Ta	2.96	2.05	2.06	2.76	1.57	1.03	2.61	2.22	2.29	2.46	3.18	2.42
Pb	23.95	41.46	24.54	28.56	17.33	20.87	24.32	28.45	22.84	22.97	7.02	10.61
Th	25.42	22.65	7.33	21.11	18.58	16.35	22.14	20.63	11.16	21.96	5.31	5.23
U	4.80	1.96	1.72	5.32	5.58	4.89	4.11	5.64	3.54	3.99	1.35	1.66

Elements	Petrology	Syenite								Diorite		Dolerite
	S19	**S20**	**S21**	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**
Rb/Sr	0,43	0.54	0.32	0.46	0.58	0.19	0.84	0.44	0.93	0.14	0.38	0.07
Th/U	5.29	11.56	4.26	3.97	3.33	3.34	5.39	3.66	3.15	5.50	3.93	3.15

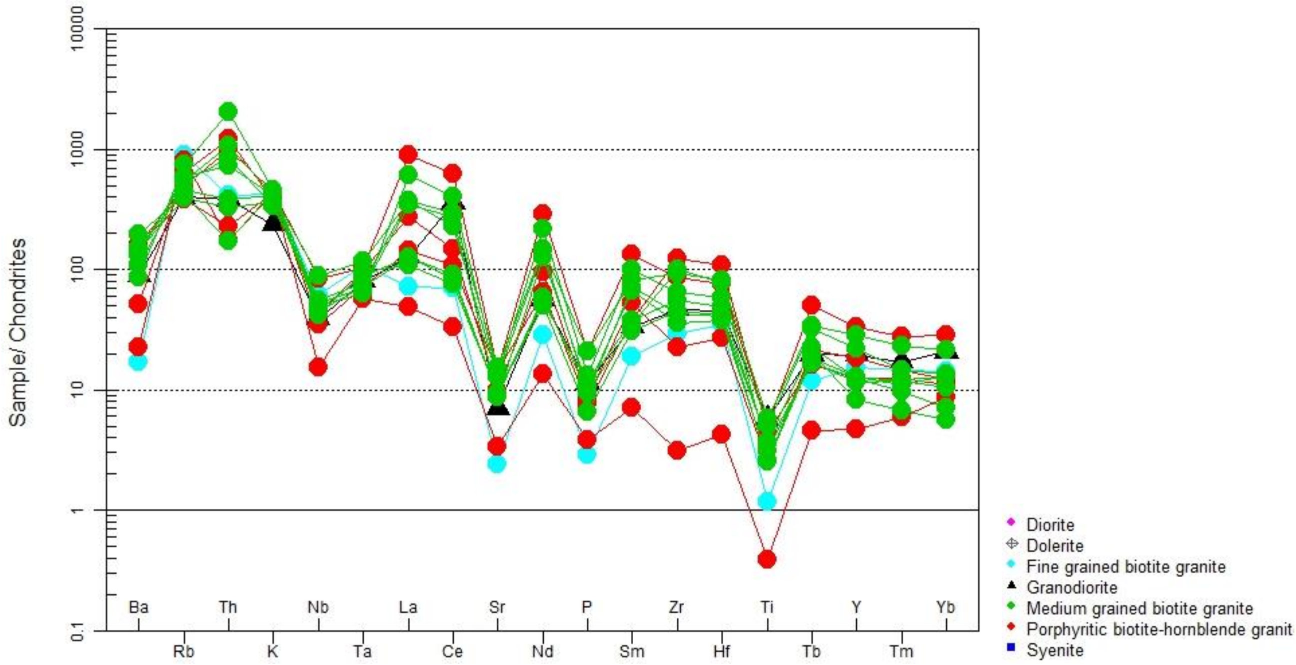

Figure 16. *Multi-element Spider diagram of trace elements for fine grained biotite granites, medium grained biotite granites, porphyritic biotite-hornblende granites and granodiorite normalized after Thompson (1982).*

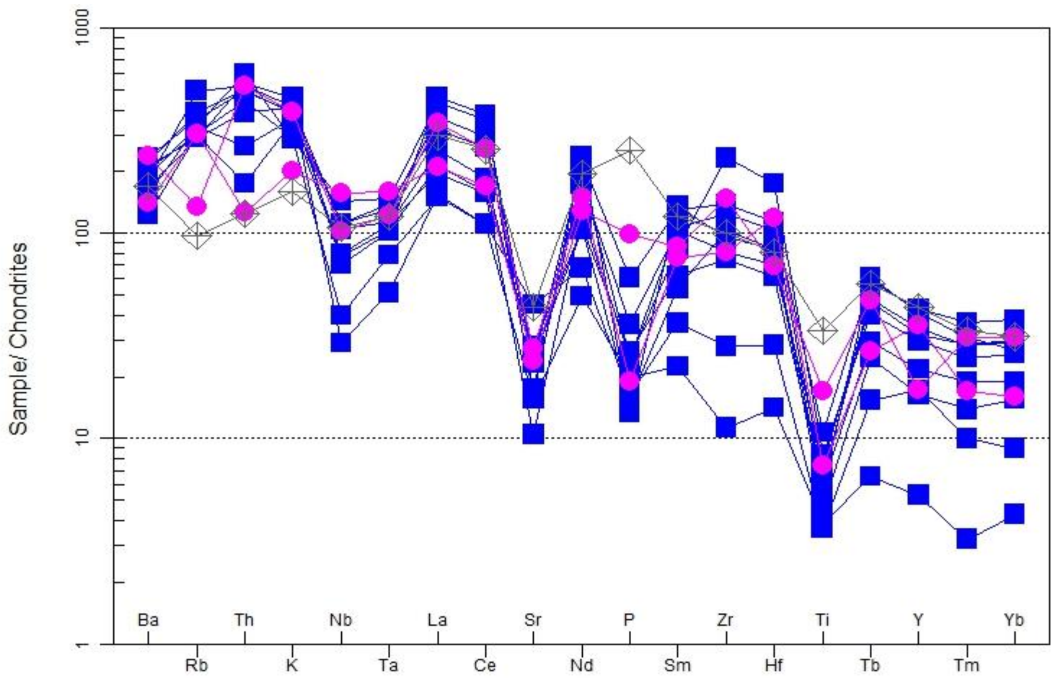

Figure 17. *Multi-element Spider diagram of trace elements for syenites, diorites and dolerites normalized after Thompson (1982). Symbols and colour of rocks are the same as in Figure 16.*

3.3. Rare Earth Elements Geochemistry

The REE distributions pattern are presented (Table 3). The chondrite normalized values are based on [27] are La (.329), Ce (.865), Nd (.63), Sm (.203), Eu (.077), Gd (.276), Dy (.343) Er (.225), Yb (.22), Lu (.0339). The REE patterns for granodiorites and fine grained biotite granites showed enrichment in LREE and flat HREE with negative Eu anomaly (Figure 18). The REE distribution pattern for the medium grained biotite granites revealed high enrichment in LREE and moderate to flat HREE with negative Eu anomaly except one of the medium grained biotite granites with (sample ID 12 and 14) that shows positive Eu anomaly (Figure 19). The porphyritic biotite-hornblende granites REE pattern revealed relative enrichment in the LREE and low enrichment in HREE with negative Eu anomaly (Figure 20). The REE distribution pattern of the syenites revealed moderately inclined slope with enrichment of the LREEs relative to fairly flat fractionated HREEs and negative Eu anomaly (Figure 21). The REE distribution patterns for the diorite and dolerites revealed high enrichment in LREE and moderate to flat HREE with weak negative Eu anomaly (Figure 22).

Table 3. Rare Earth Elements (ppm) of rocks in the study area.

Elements	Granodiorite	Fine grained biotite granite	Biotite microgranite			
	S1	S2	S3	S4	S5	S6
La	42.15	23.46	7.52	17.09	33.64	32.08
Ce	86.50	61.27	19.00	43.89	71.10	79.63
Pr	36.20	39.97	16.49	28.11	9.40	11.28
Nd	35.91	17.80	8.26	11.88	31.14	30.10
Sm	6.79	3.87	3.19	1.85	7.73	7.65
Eu	1.22	0.31	0.20	0.90	0.49	0.34
Gd	6.21	3.31	4.31	1.56	7.62	7.59
Tb	1.02	0.61	1.18	0.20	1.32	1.43
Dy	6.54	4.70	8.84	1.18	9.53	9.78
Ho	1.47	1.10	2.03	0.21	2.24	2.09
Er	4.09	3.21	6.97	0.58	6.88	6.41
Tm	0.58	0.50	1.16	0.10	1.02	0.94
Yb	4.57	3.14	8.33	0.59	7.29	6.28
Lu	0.67	0.48	1.11	0.10	1.03	0.95
ΣREE	428.68	128.93				
(La/Yb)N	6.15	4.98				
(Ce/Yb)N	17.13	4.96				
(La/Sm)N	3.82	3.73				
(Ce/Sm)N	10.64	4.96				
(Eu /Yb) N	0.76	0.28				
Eu/Eu*	0.58	0.27				

Elements	Porphyritic biotite-hornblende granite					Medium grained biotite granite						
	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18
La	89.96	7.20	47.95	16.01	294.95	41.50	41.87	35.99	198.87	123.89	124.03	112.46

Elements	Porphyritic biotite-hornblende granite					Medium grained biotite granite						
	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18
Ce	127.93	18.19	94.62	28.60	538.46	78.42	73.01	64.80	346.89	200.03	255.20	240.05
Pr	30.78	17.76	17.59	24.99	18.69	28.63						
Nd	59.43	7.66	40.77	8.48	180.24	36.56	34.03	31.79	136.50	90.65	92.43	79.51
Sm	10.69	3.15	7.69	1.45	26.94	7.08	7.68	6.22	20.17	14.59	16.49	13.65
Eu	1.15	0.28	3.18	0.40	2.88	3.82	2.76	2.98	2.22	1.42	2.81	1.17
Gd	8.80	4.52	6.08	1.17	18.29	6.27	5.93	5.97	13.25	9.80	13.04	8.24
Tb	1.12	1.28	0.85	0.24	2.58	0.89	0.86	0.96	1.69	1.18	1.78	1.02
Dy	6.73	10.08	4.77	1.36	13.73	4.69	5.19	5.68	8.91	5.63	10.48	4.22
Ho	1.32	2.40	0.91	0.38	2.69	0.94	0.95	0.90	1.70	0.97	2.06	0.67
Er	3.41	8.14	2.64	1.14	7.12	2.52	2.69	2.75	4.17	2.56	5.52	1.43
Tm	0.50	1.33	0.42	0.20	0.95	0.40	0.41	0.37	0.50	0.33	0.78	0.23
Yb	2.69	9.55	2.40	1.93	6.21	2.31	2.82	2.88	2.99	1.56	4.72	1.24
Lu	0.44	1.26	0.37	0.28	0.80	0.38	0.42	0.43	0.47	0.30	0.71	0.19
ΣREE	332.11		223.38	64.42	1149.69	194.92	187.33	169.69	77.55	478.81	556.58	488.17
(La/Yb)N	22.29		3.79	0.59	1.33	11.98	9.90	8.33	44.34	52.94	17.52	60.46
(Ce/Yb)N	12.10		2.89	4.63	4.69	8.63	6.58	5.72	29.51	32.61	13.75	49.24
(La/Sm)N	5.18		10.03	3.77	22.05	3.61	3.35	3.56	6.07	5.22	4.63	5.07
(Ce/Sm)N	2.81		3.84	6.79	6.73	2.60	2.23	2.44	4.04	3.22	3.63	4.13
(Eu /Yb) N	1.22		13.32	5.53	31.66	4.72	2.80	2.96	2.12	2.60	1.70	2.70
Eu/Eu*	0.36		1.43	0.94	0.40	1.76	1.26	1.50	0.42	0.37	0.59	0.34

Elements	Syenite									Diorite		Dolerite
	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30
La	143.04	152.59	70.65	104.81	49.38	50.69	121.68	83.30	63.86	113.88	69.21	98.30
Ce	307.82	328.21	137.93	226.82	95.91	95.99	258.21	161.02	136.67	222.87	148.08	221.79
Pr	36.20	39.97	16.49	28.11	9.40	11.28	30.78	17.76	17.59	24.99	18.69	28.63
Nd	140.55	149.37	67.19	108.54	31.09	42.60	116.31	65.91	76.90	94.21	81.33	122.40
Sm	26.62	27.55	12.59	21.11	4.56	7.44	21.66	10.92	17.13	15.47	17.58	24.46
Eu	4.08	3.07	3.68	4.43	0.82	1.26	3.43	3.11	4.65	3.24	4.61	5.47
Gd	21.46	21.76	10.95	16.56	2.95	6.61	16.71	9.20	14.69	11.02	16.08	21.90
Tb	3.06	3.17	1.55	2.48	0.34	0.80	2.40	1.29	2.09	1.39	2.46	2.93
Dy	17.12	17.64	8.97	13.84	2.21	4.25	12.98	7.10	12.31	7.70	14.20	16.95
Ho	3.28	3.35	1.59	2.61	0.30	0.96	2.47	1.33	2.46	1.42	2.82	3.32
Er	8.90	8.56	4.73	7.33	0.78	2.19	7.08	3.34	6.23	3.78	7.68	8.37
Tm	1.25	1.06	0.64	0.97	0.11	0.34	0.98	0.47	0.84	0.58	1.05	1.14
Yb	8.39	5.95	4.16	6.52	0.94	1.97	6.67	3.41	5.69	3.52	6.81	6.91

Elements	Syenite									Diorite		Dolerite
	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30
Lu	1.23	0.76	0.56	0.99	0.12	0.26	0.93	0.48	0.82	0.63	0.99	0.94
ΣREE	723.00	763.01	341.68	545.12	198.91	226.64	602.29	368.64	361.93	504.70	391.59	563.51
(La/Yb)N	11.37	17.10	11.32	10.72	35.02	17.15	12.16	16.29	7.48	21.57	6.78	9.48
(Ce/Yb)N	9.33	14.03	8.43	8.85	25.95	12.39	9.85	12.01	6.11	16.10	5.53	8.16
(La/Sm)N	3.31	3.41	3.45	3.05	6.66	4.19	3.46	4.69	2.29	4.53	2.42	2.47
(Ce/Sm)N	2.71	2.80	2.57	2.52	4.94	3.03	2.80	3.46	1.87	3.38	1.98	2.13
Eu /Yb)N	1.39	1.47	2.53	1.94	2.49	1.83	1.47	2.61	2.33	2.63	1.93	2.26
Eu/Eu*	0.52	0.39	0.96	0.73	0.69	0.55	0.55	0.95	0.90	0.76	0.84	0.73

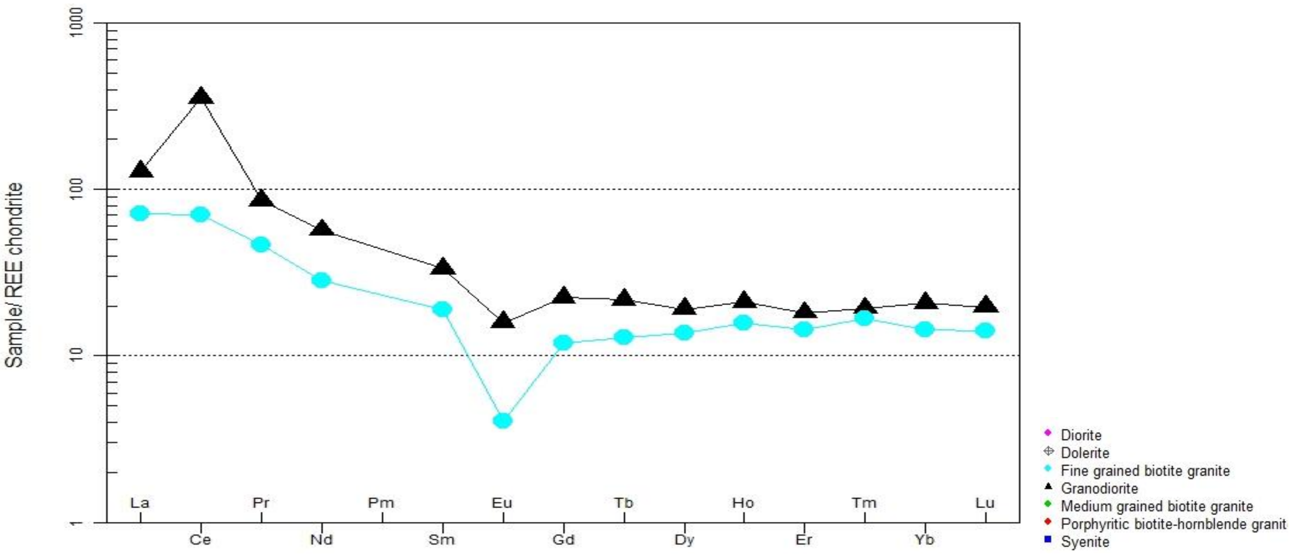

Figure 18. *Rare earth element pattern for fine grained biotite granite and Granodiorite after Nakamura (1974).*

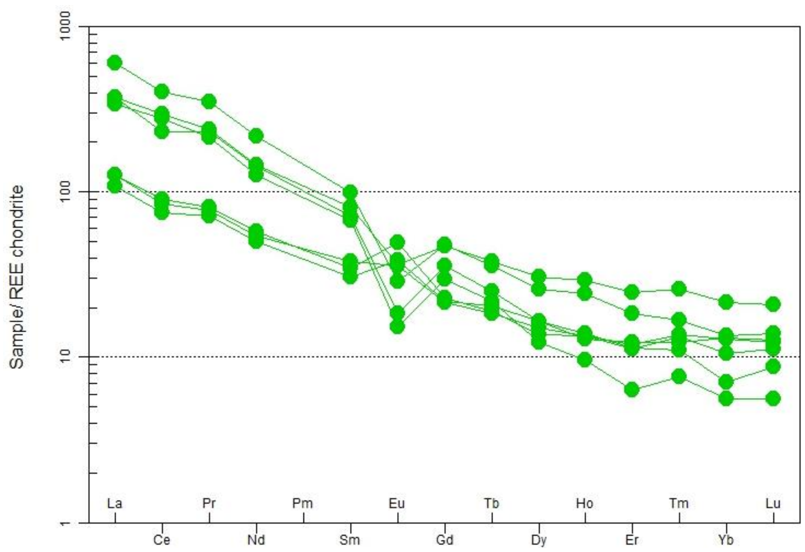

Figure 19. *Rare earth element pattern for medium grained biotite granite after Nakamura, (1974). Symbols and colour of rocks are the same as in Figure 18.*

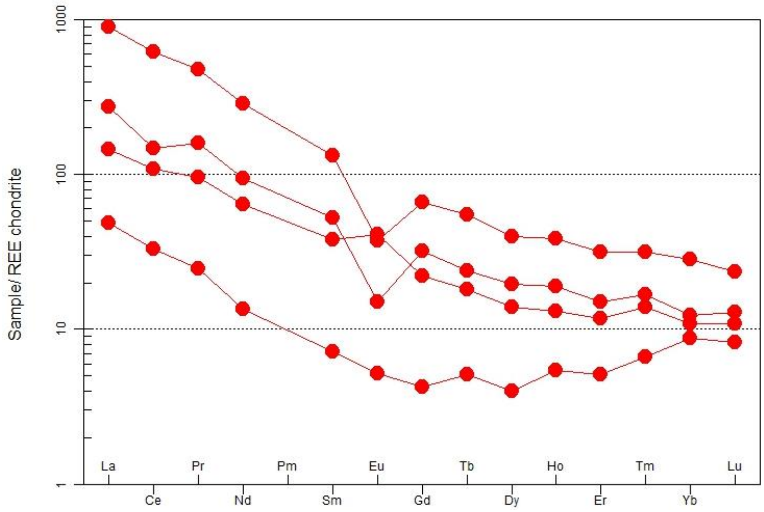

Figure 20. *Rare earth element pattern for porphyritic biotite-hornblende granites after Nakamura, (1974). Symbols and colour of rocks are the same as in Figure 18.*

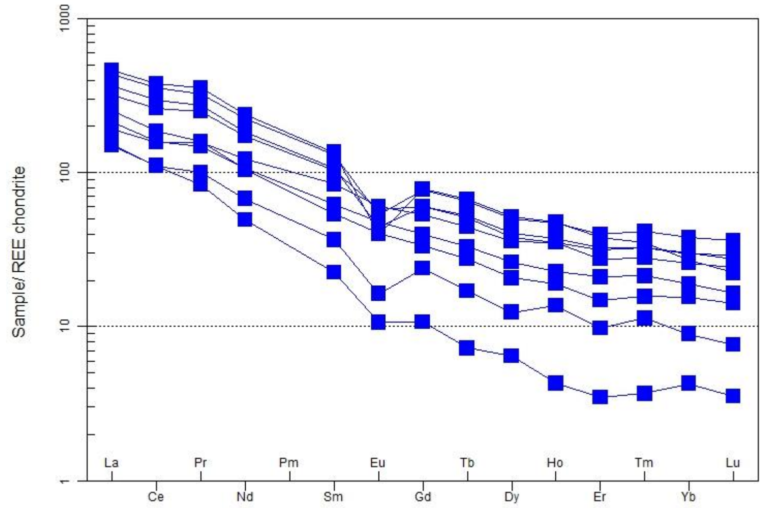

Figure 21. *Rare earth element pattern for syenites after Nakamura (1974). Symbols and colour of rocks are the same as in Figure 18.*

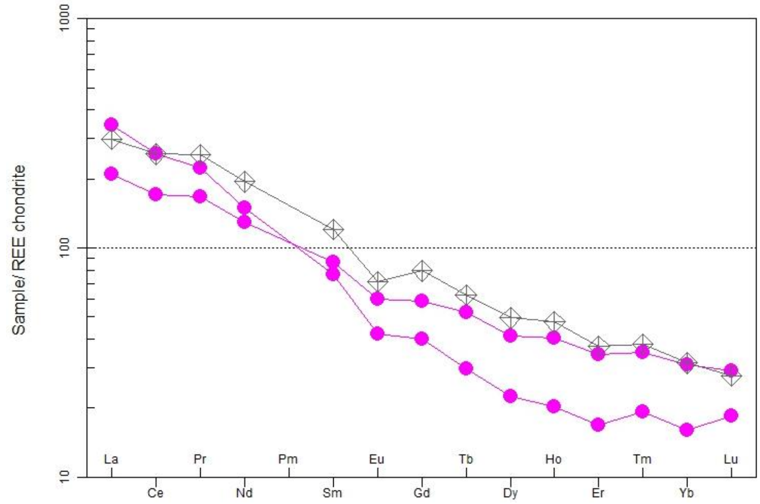

Figure 22. *Rare earth element pattern for diorite and dolerite after Nakamura (1974). Symbols and colour of rocks are the same as in Figure 18.*

3.4. Tectonic Setting

The Y+Nb vs Rb, Y vs Nb, Ta + Yb vs Rb and Yb vs Ta tectonic discrimination diagram based on [35] (Figure 23) showed that granites and syenites plotted mainly within volcanic arc granite, syn-collisional granite and in the within plate granites fields while the granodiorites clearly plotted in the within the plate granites field. The tectonic ternary molecular proportions MgO – FeOt – Al_2O_3 based on [34] diagram shows that diorite and the gabbro plotted mainly in spreading center island field (Figure 24).

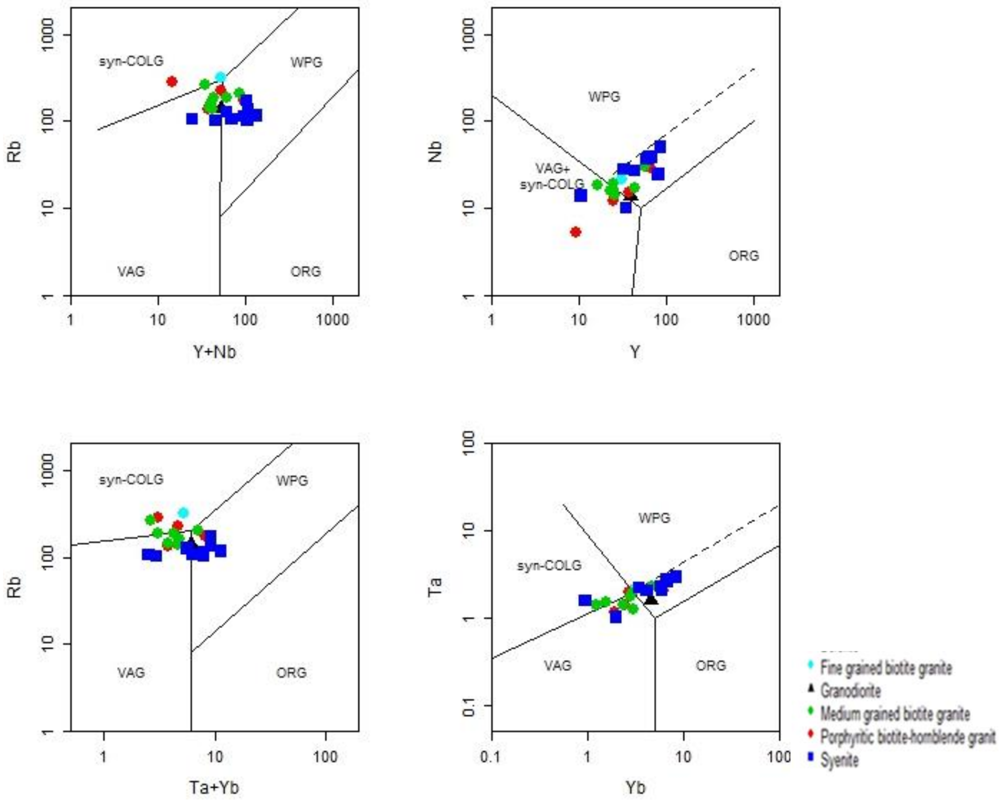

__Figure 23.__ Tectonic discrimination diagram of the granites, granodiorite and syenites of the study area (using Pearce et al, 1985 discrimination diagrams).

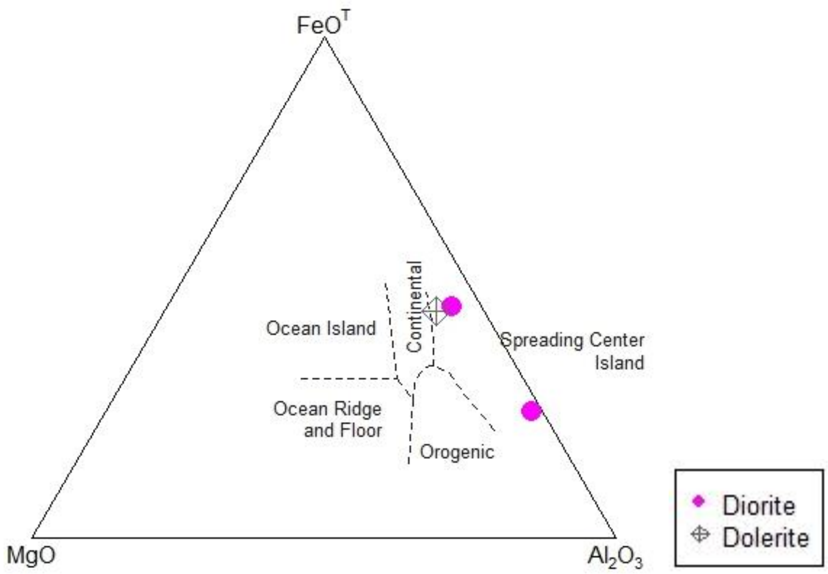

__Figure 24.__ Ternary plot of molecular proportions MgO – FeOt –Al_2O_3 of Diorite and Dolerite of the study area (using Pearce et al., (1977 discrimination diagram).

4. Discussion

The evolution of basement complex rocks in the study area is related to the thermotectonic orogenic events in Nigeria which resulted in the emplacement of several lithological units. Migmatites occur as low lying exposures in the study area and are characterized by the alternating bands of felsic and mafic minerals. They are product of anatexis corresponding to the partial melting of the rocks under specific temperature and pressure condition. The anatexis melting of the migmatites manifested in plastic deformation at the exposures of the rocks (ptygmatic folds) around Ungwan Kuka Village in the study area. Ajibade *et al.*, (2008) [4] described the migmatites, as formed by anatexis in medium to high grade terrain in the Kusheriki area. The migmatites are closely associated with gneisses in the study area whose geological features and field relationship are comparable to the migmatites described by [26] around malumfashi and funtua area. Dada (1999) [13] studied the age of the reworked archean migmatitic- gneiss around Kaduna area and documented the Archean age which may be comparable to the ages of migmatites in the study area. The migmatites represent the oldest lithological unit in the study area which was intruded by Older Granites suite. The late migmatites series observed in the study area are believed to be related to the emplacement of Older Granites as described by [26] in northern Nigeria.

The gneisses occur as low lying outcrop in the northeastern and central parts of the study area and are strongly believes to have sedimentary origin. They are strongly foliated and characterized by rotated zenolith of amphibolites and small xenolith parchment of mica schist. The gneisses may have evolved from sedimentary origin and it is believed that an ancient sedimentary sequence has been metamorphosed. According to [1], the Pan-African deformation was associated with regional metamorphism, migmatization, granitization and gneissification which produced syntectonic granites and homogeneous gneisses. The migmatites and gneisses occupied about 3 percent of the total study area.

The fine grained biotite granites, medium grained biotite granites, porphyritic biotite- hornblende granites are high level intrusion that occur as low lying or massive outcrop in the northwestern, southwestern and southeastern part of the study area and belong to the Pan-African Older Granites suite. McCurry (1976) [26] categorized granites into syn-tectonic to late-tectonic granites. The granites are considered to be the products of widespread mobilization and reactivation of older basement rocks during the Pan-African Orogeny. The granites intruded the migmatites and gneisses in the study area and occupied about 70 percent of the total study area.

Granodiorites occur as low lying outcrops with medium to coarse grained texture in the study area. They are also parts of an Older Granites suite emplaced in both the migmatite-gneiss complex and the metasedimentary and metavolcanic rocks schist. They are high-level intrusions emplaced by stoping and diapiric processes [20]. The granodiorites intruded the porphyritic biotite-hornblende granites in the study area with high mafic mineral contents compared to the granites. The granodiorites encountered in the study area are similar to the type described by [2] around Minna area. Apart from the granites and granodiorites, syenites occur as massive outcrop in the northwestern part of the study as a coarse grained rock and varies from grey to dark green colour. They belong to the Older Granites suite and intruded the porphyritic biotite-hornblende granites in the study area. Syenites contain less amount of quartz compared to granites and granodiorites and account for about 3% of the total study area. Another magmatic rock occurring in the study area are the diorites. The diorites occur as low lying exposure in the northeastern part of the study area and formed parts of the Older Granites suite. It consists of large interlocking, randomly oriented crystals of mafic minerals and appeared dark compared to granites, granodiorites and syenites in the study area. The dolerites occur as a dark coloured igneous rock with a fine grained texture around northern part of the study area and emplaced into porphyritic biotite-hornblende granites as dykes trending in NE-SW direction with about 2% coverage of the total study area. The rock is poorly exposed because of soil overburden and are generally regarded as the youngest units in the Nigerian Basement Complex with the lower age of ca. 500 Ma according to [24]. The average silica contents of 73.06 wt% in porphyritic biotite-hornblende granites is slightly higher than the contents of 72.67 wt% in fine grained biotite granites while the lowest value of 70.13 wt% was recorded in medium grained biotite granites in the study area. The silica values in the study area are high compared to 66.78-67.86 wt% reported for porphyritic biotite granites in Saminaka and Falgore areas [32], it is within the range for porphyritic biotite-hornblende granites, fine grained biotite granites and marginally lower for medium grained biotite granites than the range of values of 71.90-75.00 wt% reported for granites in Ekiti area [42], it is within the range for porphyritic biotite-hornblende granites with contents values of 74.25-76.52 wt% and medium grained biotite granites with contents values of 73.52-75.43 wt% from Ado-Ekiti area [33]. However, these values fall within the lower limits for ferro-potassic granites and quartz-monzonite plutons of eastern Nigeria with contents values of 63.84 to 75.09 wt% reported by [19]. The contents values of K_2O of 6.11 wt% for fine grained biotite granites is higher than porphyritic biotite-hornblende granites with value contents of 6.07 wt% but lower in the medium grained biotite granites with contents of 5.86 wt% obtained in the study area. The values are marginally higher than 5.72 wt% documented for porphyritic biotite-hornblende granites in Saminaka areas [32]. The SiO_2 composition of granodiorites in the study area are slightly higher than the silica values of 65.42 wt% reported for granitoids of the northern part of Adamawa Massif, northeastern Nigeria [25]. The syenites in the study area has a higher value of Fe_2O_3 but lower values of MgO compared to 5.01 wt% to 5.66 wt% of FeO and 3.62 wt% to 4.78 wt% of MgO reported for syenites around Igarra area, Southwestern Nigeria [46]. The High-K cal-alkaline, relatively presence of CaO and MgO as well as $K_2O > Na_2O$ shown by the syenites in the study area closely match the geochemical signatures typical of syenites associated with the Older Granites in Nigeria as earlier reported by [15]. Compared to the nepheline syenites around the Oyioba-Uganga area in southern Benue Trough as reported by [16], the syenites in the study area are enriched in Na_2O and Al_2O_3 but low in CaO and K_2O. However, the syenites in both areas are compositionally comparable in terms of TiO_2, MnO, Fe_2O_3 (t) and P_2O_5. The silica contents in syenites is lower than the values in granites and granodiorites in the study area but have high contents of Al_2O_3, Fe_2O_3 (t), MgO and low P_2O_5. The decreasing SiO_2, K_2O and Na_2O contents, with the increasing ferromagnesium minerals in diorites is consistent with the characteristic of intermediate igneous rocks composition. The magnesium contents of 0.14 wt% in the diorites is higher than the values in granites, granodiorites and syenites but lower compared to the average crustal abundance of 2.33 according to [43]. These are common characteristics of intermediate rocks and is found in mineral phases of olivine, pyroxene, amphibole and feldspars. The Fe_2O_3 (t) contents of 10.2 wt% in diorites are high compared to granites, granodiorites and syenites as well as the average crustal abundance of 5.63 according to [43] due to the presence of ilmenite and magnetite. The magnesium is high in dolerites with contents of 2.52 wt% compared to the values in granites, granodiorites, syenites and diorites as well as the crustal abundance value of 2.33 according to [43]. They are concentrated in the early crystals phases of olivine and pyroxene forming at high temperature. The highest Fe_2O_3 (t) content of 15.43 wt% in dolerites are high compared to granites, granodiorites, syenites and diorites in the study area. The manganese contents of 0.19 wt% in dolerite is high which reflects the characteristics of basic rock and is found in mineral phases of olivine, pyroxene, amphibole and feldspars.

Shand (1943) [41], classified granites based on the saturation in alumina in to metaluminium and peraluminium in order to understand the geochemical diversity. Frost *et al*., (2001) [22] distinguished geochemical characteristics of granitic rocks based on chemical parameters such as Modified Alkali Lime Index (MALI), Fe number and Aluminium Saturated index (ASI) which incorporate composition and abundances of feldspars, differentiation history and source of magma. In the study area, the fine grained biotite granites, medium grained biotite granites and porphyritic biotite-hornblende granites, granodiorites, syenites, diorites and dolerites are metaluminous to peraluminium which suggest the presence of muscovite, garnet, hornblende and augite in the mineral phase. The degree of depth, by measure of potassium contents indicates a shallow depth for dolerites followed by granodiorites and diorites with High K-calc-alkaline characteristic and a thicker crust for syenites and granites. Granites, syenites, diorites and dolerites are formed from mafic metaigneous rocks (I-type) while granodiorites are formed from metasedimentary rocks (S-type). The enrichment in Ba, La, Rb, Th and depletion in Nb, P, Ti and Sr in fine grained biotite granites and porphyritic biotite-hornblende granites indicates crustal contamination of magma [39]. They are characterized by high Rb contents of 135.23-312.25 ppm in comparison to the average crustal value of 90 according to [43]. high Ba concentration of 118.61-1346.05 ppm in comparison to the average crustal abundance of 425 according to [43]. low Sr contents of 28.26-181.31 ppm in comparison to the average crustal value of 375 according to [43] and low Nb except one of the fine grained biotite granites (S2) with contents values of 21.51 ppm, porphyritic biotite-hornblende granite (S7) with contents values of 29.43 ppm and medium grained biotite granite (S13) with contents values of 30.86 ppm when compared with the average crustal concentration values of 20 for Nb according to [43]. This trends reflects common characteristics of calc-alkaline igneous rock [19]. The variation in Th/U ratio of 2.27 to 27.78 for granites is an indication of contributions from crustal and mantle materials [38, 40]. The low-high Rb/Sr ratio of 0.81-53.58 indicate an increase in the formation of the feldspars in granitic rocks. The fine grained biotite granites, medium grained biotite granites and porphyritic biotite-hornblende granites revealed an enrichment in LREE and depletion in HREE. The value of La/Yb_N increases for granites from 0.59- 60.46 ppm which indicate high degree of fractionation with a negative Eu anomalies (Eu/Eu*= 0.27-0.94) except the porphyritic biotite-hornblende granites (S9) with contents of 1.43 ppm, medium grained biotite granites (S12) with values of 1.76 ppm, medium grained biotite granites (S13) with contents of 1.26 ppm and the medium grained biotite granites (S14) with contents of 1.50 ppm that showed positive Eu anomalies. The negative Eu anomaly of the granites, reflects the early crystallization of feldspars from the melt [39]. The porphyritic biotite-hornblende granites enrichment in the LREE relative to low enrichment in HREE could be caused by the presence of hornblende in the felsic melts [39]. Titanium contents values are low in medium grained biotite granites (0.39 wt%), porphyritic biotite-hornblende granites (0.325 wt%) and low in fine grained biotite granites (0.12 wt%) when compared against the average crustal value of 0.63 according to [9]. The titanium occur in the mineral phases of magnetite and ilmenite. Manganese is low in porphyritic biotite-hornblende granites (0.05 wt%), medium grained biotite granites (0.02 wt%) and fine grained biotite granites (0.02 w%) compared against the average crustal value of 0.10 according to [9]. The Ba contents is high in medium grained biotite granites (950.06 ppm) and porphyritic biotite-hornblende granites (553.11 ppm) but low in fine grained biotite granites (118.61 ppm) when compared against average crustal value of 500 according to [9]. This may be due to the replacement of K^+ by Ba in biotite and k-feldspar leading to higher degree of fractionation [28]. Wide range of Rb in granites in the study area is an indication of mantle contamination with crustal materials. Flagler and Spray, (1991) [21] has reported that subduction-related granites have a much wider range of Rb values. The ratio of La/Ta for fine grained biotite granites with values of 10.86 indicates an asthenospheric mantle source for fine grained biotite granites, La/Ta for medium grained biotite granites with values of 58.05 and porphyritic biotite-hornblende granites with values of 31.19 indicates crustal contamination. Leat *et al*., (1988) [29] suggested that rocks with La/Ta ratios of less than 22 are derived from an asthenospheric source, whereas [45] proposed that La/Ta ratios between 10 and 12 originate from an asthenospheric source while values of greater than 30 indicate crustal contamination.

The enrichment in La, Th and depletion of Nb and Ti in granodiorite indicate crustal contamination of magma [39]. The low Rb/Sr ratio of 1.67 in granodiorite is lower than the ratio in granites which indicate formation of the mafic minerals. The Th/U ratios of 7 indicates granodiorites is derived from crustal materials. The value of La/Yb_N of 6.15 for granodiorites indicates moderate degree of fractionation with a negative Eu anomalies of 0.58. La/Ta ratios of 26.34 for granodiorite indicate crustal source. The granodiorite has high titanium contents values of 0.59 wt% compared to the granitic rocks with the contents of 0.35 wt% in the study area but lower when compared against the average crustal value of 0.63 according to [9]. The syenites, shows an enrichment in Ba, Th, La and depletion of Nb, P, Ti and Sr. Syenites contained high Rb contents 101.9 t-173.52 ppm in comparison to the average crustal value of 90 according to [43], high Ba contents of 847.46-1619.12 ppm in comparison to the average crustal abundance of 425 according to [43], low-high Sr contents of 123.47-531.94 ppm in comparison to the average crustal value of 375 according to [43], high Nb contents of 24.64-50.39 ppm when compared against the average crustal concentration values of 20 according to [43] and high Th value of 0.4-20.6 ppm compared against the average crustal concentration values of 9.6 according to [43]. The Th/U ratios of 3.15-11.56 indicates syenites is derived from mantle materials. The low Rb/Sr ratio of 0.19-0.93 shows an increase in the formation of the mafic minerals. The syenites revealed enrichment in LREE and depletion in HREE. The value of La/Yb_N for syenites with values of 7.48- 35.02 indicates high level of fractionation with moderate negative Eu anomalies (Eu/Eu*= 0.39- 0.96). The Syenites occupied about 3 percent of the total study area.

Diorites shows an enrichment in Ba, Rb, Th, La and depletion of Nb, P, Ti and Sr. They contain low to high Rb contents of 46.84-106.48 ppm compared against the average crustal value of 90 according to [43], high Ba contents of 979.98-1639.05 ppm compared to the average crustal abundance of 425 according to [43], low Sr contents of 283.53-324 ppm compared to the average crustal abundance of 375 according to [43] and high Nb contents of 35.75-54.94 ppm compared to the average crustal abundance of 20 according to [43]. The low Rb/Sr ratio of 0.14- 0.38 reflect the presence of mafic minerals in diorites while the Th/U ratio of 3.93 to 5.50 is an indication of contributions from crustal and mantle materials. Diorites shows high enrichment in LREE and moderate to flat HREE with weak negative Eu anomaly. The La/Yb_N for diorites with value of 6.78-21.57 with a weak negative Eu/Eu*= 0.76- 0.84 indicate weak fractionation. The diorites occupied about 2 percent of the total study area.

The dolerites show an enrichment in Ba, Th, La and depletion of Nb, P, Ti and Sr. The low Rb/Sr ratio of 0.07 indicate formation of the mafic minerals in dolerites. The Th/U ratios of 0.07 indicate that the dolerites are derived from mantle sources [38, 40]. The dolerites show high enrichment in LREE and moderate to flat HREE with weak negative Eu anomaly. The La/Yb_N for dolerites with value of 9.48 with negative Eu/Eu* of 0.73 indicate weak fractionation.

5. Conclusion

Field, petrographic and geochemical studies revealed that the Precambrian basement rocks in the study area are of acid, intermediate and basic rocks compositions. The area present unique features of the magmatic cycles of events that have reactivated the study area. The ages of rocks in the study area are mostly related to the Pan-African thermotectonic events, with few imprints of older events such as the Liberian, Eburnean and Kibaran [30]. The fine grained biotite granites, medium grained biotite granites and porphyritic biotite-hornblende granites are of I- type, metaluminum to peraluminium tholeiitic, calc-alkaline and shoshonitic rocks. The granodiorites are of S-type, peraluminium tholeiitic, calc-alkaline, High-K calc-alkaline rocks. The syenites are of I-type, metaluminium, tholeiitic, calc-alkaline and shoshonitic rocks. The diorites revealed I-type, metaluminium, tholeiitic, calc-alkaline and shoshonitic rock. The dolerites are of I- type, tholeiitic, calc-alkaline and shoshonitic rocks. The Precambrian basement rocks in the study area are formed in the volcanic-arc granite, syn-collisional granite and in the within-plate granites fields as well as in the spreading center island field.

The high contents of Sr, and Ba indicate plagioclase fractionation in dolerites, diorites, syenites, granodiorites and granites. The diorite and dolerites show high content of Co and Ni (incompatible elements) indicating olivine fractionation derived from mantle source with limited fractionation or crystal accumulation. The low value of U, Th, K, and Nb and P in diorite and dolerites is a reflection of thin or attenuated crust crustal. The content of P and Ti in granodiorite and granites is low but moderately high in syenites and high in dolerites, diorites which may probably be due to lack of apatite crystals in the former compared to the latter with apatite in the accessory phase. The relative enrichment trend observed in TiO_2 in dolerites, diorite reflect higher content of pyroxene, hornblende, biotite and iron-oxide (magnetite and ilmenite). Lower TiO_2 content in the granite, granodiorite and syenites is probably due to the fractionation of biotite and iron-rich minerals.

The biotite microgranites in the study area evolved as anorogenic Younger Granites rocks emplaced into the Precambrian basement rocks. Geochemical characteristics of the biotite microgranites are of alkali, potassic, ferroan and is typical of post-collisional or within-plate granites. They are classified as A-type due to their alkalinity nature, anhydrous characteristics and anorogenic tectonic setting. The Younger Granites rocks in the area are formed in the within-plate granite field. The structures in the study are classified as brittles and ductiles structures such as fractures, joints, fold and faults. The structures play a pivotal role as conduits of mineralization which is generally related to Pan-African tectonic events.

The nature of the intrusive and extrusive rocks in the Burunburun area indicate evolution from a single magma source. In the Burumburun area the magmatic rocks evolved to diorites, dolerites, syenites, granodiorites, and granites. The mineralogical composition of various lithological units that underlain this area clearly reflect the overall effect of the tectonic activity. The rocks in the study area shows characteristic common with those found in the Pan-African mobile regions while those with sub-alkaline affinities are characteristic of continental margins.

Conflicts of Interest

The authors declare no Conflict of Interest.

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