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Evaluation of Major and Trace Elements Geochemistry of Basement Complex Rocks in South -Eastern Part of Ado-Ekiti, Southwestern Nigeria

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ABSTRACT

Ten fresh rock samples (3 migmatite gneisses, 3 banded gneisses and 4 granites gneisses) were geochemically analyzed for major oxides and trace elements at Activation Laboratories Limited Ancaster, Ontario, Canada employing Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) technique with a view to unravel their petrogenesis. The geochemical composition of the country rocks revealed that they are felsic rocks with average SiO_2 content of 67.23%. Other oxides with average chemical compositions include Al_2O_3 (14.934), FeO (4.223), MnO (0.0646), MgO (0.986), CaO (4.668), Na_2O (3.382), K_2O (3.179), TiO_2 (0.4401) and P_2O_5 (0.397). Compositional features revealed a descending trend in the oxides of the basement rocks as shown; SiO2 > Al_2O_3 > CaO > Fe_2O_3 > Na_2O >K_2O > MgO >MnO> TiO_2 > P_2O_5. The compositional trend of the rocks suggests geologic setting of continental crust origin possibly formed during orogenic activity. Discriminant plots revealed strong negative correlation of all the oxides with SiO2 except Na2O that has positive correlation indicating pyroxene – hornblende and plagioclase fractionations respectively. Evaluation of the alumina variation of the rocks indicates met aluminous rocks produced from the partial melting of meta-igneous source at low pressure. The rocks are not corundum normative as aluminum saturated index (ASI)<1, typical of type I magmatic rocks. There are great variations among the trace elements compare to the average granite and crust values. The concentrations of Zr and Ba are exceptionally high indicating felsic source of derivation. Also, the low average ratio of Rb/Sr (0.284) for the rocks in the study area signifies possible depletion of Rb and/or enrichment of Sr in the gneisses. The rocks display a great range of rare earth element (REE) concentrations with Ce and Nd enrichment. The migmatite gneiss is more enrich in the REE compare to the banded gneiss and granite gneiss. The chondrite normalized diagram displayed a high degree of fractionation with steep pattern which was confirmed by the high values of normalized ratio of La to Yb, Ce to Yb and La to Sm. The negative Eu anomalies in the gneissic rocks show that high amount of plagioclase was removed from the magma during fractional crystallization while similarities in the rare earth elements (REE) pattern suggest they have similar origin. The rocks in the area are felsic and met aluminous with igneous origin.

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Introduction

The Basement Complex of Nigeria is an agglomerate of many rocks including; the migmatite – gneiss-quartzite complex, the schist belts and the granitoids. The study area is an integral part of the southwestern basement complex situated on a mapped sheet Ado-Ekiti SE sheets no 244. The migmatite-gneiss-quartzite complex constitutes the country rocks into which other groups of rocks have been emplaced mostly during the Pan-African orogeny [1].

Igonor and Abimbola, believed that the origin of the emplaced rocks mostly the granitoids is controversial as the protoliths could be igneous or sedimentary. According to, migmatite-gneiss complex rocks have undergone three major geological events with the earliest; Liberian dated 2700±200ma which involved the initiation of crust forming processes (e.g. the banded Ibadan grey gneiss of mantle origin) and of crustal growth by sedimentation and orogeny [2]. Eburnean, 2000±200ma was the second event which was typified by Ibadan type granite gneisses and the last of the events is the Pan African event dated 600±150ma. These three orogenic cycles were characterized by intense deformation and isoclinals folding accompanied by regional metamorphism, and then followed by extensive migmatization. The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses [3]. Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the late stages of this last deformation. The end of the orogeny was marked by faulting and fracturing [4,5].

Some authors have worked on migmatite-gneiss-quartzite complex of the basement rocks of Nigeria with the aim to decipher its origin. Some school of thought attributing its origin to sedimentary while others believed, it is an igneous or heterogeneous source. Grant supported an igneous origin for Ibadan granite gneiss with his conclusions being inferred from the 87Sr/86Sr studies, while Burke et al. negated the submission as he concluded that the granite gneiss was derived from isochemical metamorphism of shale greywacke sequence (a sedimentary source) [6,7]. Elueze, worked on the petrochemistry of Precambrian gneisses and migmatites in the western part of Nigeria, and concluded that the varied petrochemical features of the rocks were considered to be related to the pregenetic affinity of the rocks, implying that the units were derived from heterogeneous progenitors [8].

Ademeso and Adeyeye, suggested a preference for igneous fields by the granite gneiss of Arigidi area, Southwestern, Nigeria [9]. Oyinloye, in his research on "Geology and Geotectonic Setting of the Basement Complex Rocks in South Western Nigeria: Implications on Provenance and Evolution" discovered that a mineral monazite was present in the basement rocks (amphibolite and granite gneisses) from Ilesha area, southwestern, Nigeria [10]. The implication of the presence of monazite in the amphibolite which is supposed to be purely igneous is that the initial magma from which the precursor rocks were formed had input from a crustal or sedimentary source. However, Elueze and Bolarinwa also concluded that Abeokuta granite gneiss was largely of igneous origin with a sedimentary input and this conclusion was based on the wide range concentration of Ba and Zr [11].

Based on field and geochemical evaluations, Onyeagocha researched on the granite gneiss of north central Nigeria, and proposed an igneous origin due to the partial melting of crustal rocks [12]. Also, Imaseun and Onyeobi proposed an igneous origin for migmatite rocks around Ganaja, Kogi based on geochemical studies and Alaku et al. suggested igneous origin for Tandama migmatite gneiss rocks [13,14]. Obiora on the basis of geochemistry researched on the basement gneisses around Ogoja and suggested a sedimentary source for the rock unit [15].

However, literature reveals that several works of different interest and extent by different authors have also been reported around Ekiti [16-18]. Variable composition of gneissic rocks from different locations has made it difficult to propose a single mode of origin for the rocks. Petrological and geochemical studies of rocks are reliable means of rocks classification. Proposing a single mode of origin for gneissic rocks generally is difficult as its variable compositions from different locations determine their origins. Hence, the research tends to describe the rock unit of the area with the aim of using the geochemical and petrographic study to determine the geochemical characteristics and petrogenesis of the rock unit.

Location of Study

The study area lies within latitudes 70 36′ – 70 43′ N and longitudes 50 15′ – 50 25′ E of sheet 244 SE (Ado Ekiti) (Figure 1) and comprise of five localities (Iworoko, Are, Afao, Igbemo and Ijan) in Ekiti, Southwestern Nigeria. The study area is generally accessible and motorable with tarred roads that links these towns and villages together. Some of the outcrops are located in the forest with some along the road side. The major towns around the study area include Ilokun, Ire, Iluomoba etc. The settlement pattern in the study area is nucleated types and major occupation of the inhabitants are farming and trading.

The area is generally an undulated terrain. The highest elevation within the area is granite gneiss outcrop at Aba Igbira community, Iworoko with the elevation of about 456.3m above sea level. Some outcrops have gently sloping surfaces ranging from 412m to 442m above sea level and the lowland area has elevation of 374m to 407m above sea level. The common river in the study area is River Ogbese with many tributaries which may dry off during drying season. The drainage pattern is dendritic (Figure 1) and its often develops in regions underlain by homogeneous materials, that is, the surface geology has a similar resistance to weathering, thus, no apparent control over the direction the tributaries take. These tributaries join the larger stream at acute angle [19]. The climate of the area consists of two main seasons in a year which are the rainy (April to part of November) and the drying season (November to March). The temperature ranges between 21^0 and 28^0 C with high humidity.

Methodology

This section covers the methodology adopted in the present research. Reconnaissance survey was undertaken to establish the general overview of the study area. Subsequently, representative rock samples for geochemical analysis were collected from outcrops employing sledge hammer and chisel. Geographic co-ordinates were measured and recorded at each location using etrex 12 Channel GPS. The samples were labeled from M31 to M40. Samples numbered M32, M35 and M38 are representatives of Migmatite gneiss (MGn), M33, M36, and M39 are representatives of banded gneiss (BGn), while M31, M34, M37, and M40 are granite gneiss (GGn).

Ten fresh rock samples were selected for whole rock analysis. The samples were then broken into smaller chips by a jaw crusher and thereafter pulverized with a pulverizing machine. The pulverized samples were kept in sterilized bottles awaiting geochemical analyses. The samples were digested and subjected to major oxide and trace elements determination by Inductively Coupled Plasma -Mass Spectrometry (ICP-MS) at Activation Laboratories Limited Ancaster, Ontario, Canada employing standard analytical procedures named '4Litho 'a combination of packages Code 4B (lithium metaborate/tetraborate fusion ICP whole rock) and Code 4B2 (trace element ICP/MS) by Activation Laboratories Limited (ACTLABS), Canada.

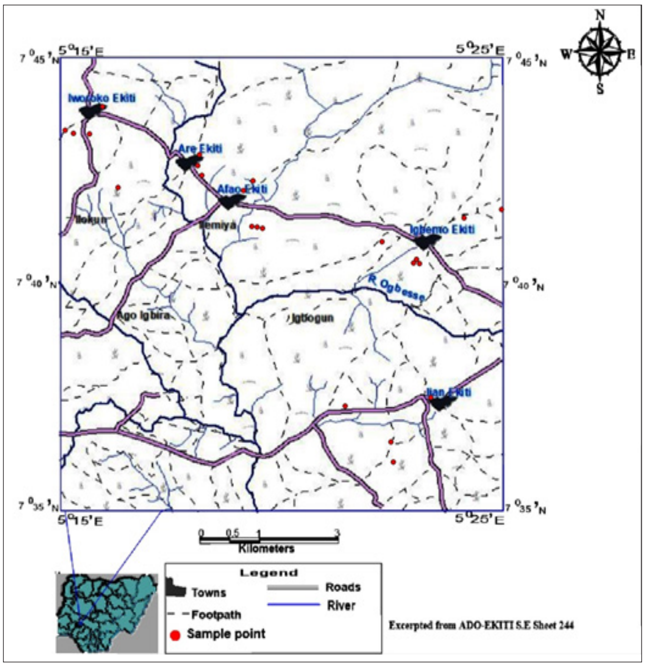

Figure 1: Location Study

The 4 Litho analyses used $LiBO_2$/Tetraborate fusion ICP for major oxides plus minor elements. Code 4B2 analyses of trace element used ICP-MS. Fused sample was diluted and analyzed by Perkin Elmer Scitex ELAN 6000. In order to sustain maximum accuracy, three blanks and five controls (three before sample group and two after) were analyzed per group of samples. Duplicates were fused and analyzed for every 2 samples. Instrument is recalibrated after every 5 samples using geochemical standards SPL-29. The REE data were normalized to the chondrite values of Taylor and McLennan [20]. The post-Archean Australian shale (PAAS) values were used for comparison while the normalized Eu anomaly (Eu/Eu*) calculated by using the following equation Eu/Eu*= 2 x Eun/Σ(Smn+Gdn) where n, the subscript represents the chondrite normalized values Taylor and McLennan [20].

Data Evaluation
This involved the plotting of the data obtained from the field. The geochemical data were subjected to statistical evaluation employing the software called GcDkits, which was used to draw various discrimination and variation diagrams to interpret the data.

Result and Discussions
Field observations revealed the following outcrops; banded gneiss, granite gneiss and migmatite gneiss (Figure 2). These rocks suffered alterations during the Pan-African orogeny.

The major element oxides compositions of the rocks are presented in Table 1. The major elements composition shows that the rocks (Migmatite gneiss, banded gneiss and granite gneiss) are characterized by high SiO_2 in the range of 64.4 – 70.76wt% with an average of 67.23wt%. All the rocks in the study area fell into felsic class with average SiO_2value>65% (Table 1). The rocks show moderate Al_2O_3 (14.33 – 15. 89wt %), low TiO_2 (0.19 – 0.96wt %), MgO (0.42 – 2.25wt %), MnO (0.034 – 0.11wt %) and high K_2O (2.67 – 4.12wt%), Na_2O (3.00 – 3.63wt%) and CaO (3.05 - 6.46wt%). These compositional trends of the rocks suggest geologic setting of continental crust origin possibly formed during orogenic activity. Compositional features revealed a descending trend in the oxides of the basement rocks as shown; $SiO_2 > Al_2O_3 > CaO > Fe_2O_3 > Na_2O > K_2O > MgO > MnO > TiO_2 > P_2O_5$ (Figure 3).

Discriminant Plots
Discriminant plots were employed to model the difference between distinctive classes of data based on the correlation coefficients. The Harker plot (Figure 4) shows that most of the major oxides correlate with SiO_2. MnO, Fe_2O_3, MgO, CaO, TiO_2, and P_2O_3 have a negative strong correlation (inverse relationship) against SiO_2, K_2O correlated positively with SiO_2 and according to Okobi et al., the trend suggested fractionation in the protoliths of the rocks [21]. Negative correlation of CaO, Al_2O_3 and a positive correlation with Na_2O indicates plagioclase fractionation, and a very strong negative correlation with Fe_2O_3 and MgO also suggests pyroxene and hornblende fractionation [22].

Alumina Variation in the Rocks of the Study Area
These rocks contain >2.0 high K_2O content in the range of 2.67 to 4.12wt% (av. 3.179wt%). The total alkalis A/NK [molar ($Al2O_3$/$Na_2O + K_2O$)] and A/CNK [molar (Al_2O_3/CaO + $Na_2O + K_2O$)] contents ranges from 1.44 -1.9 and 0.73 – 0.95 respectively (Table 3). According to Ackerson et al. (Figure 5), the rocks are met aluminous [23]. Aluminum saturated index (ASI) = molar [Al/Ca + Na + K] content range from 0.75 – 0.97 which means in the rocks, there is likely to be excess Ca after aluminum has been accommodated in the feldspars. These rocks are not corundum-normative as the ASI < 1.0 [24]. According to Chappell and White, ASI less than 1 is typical of I type rocks and it is an indication that the rocks are products of partial melting of meta-igneous source at low pressure [25]. In addition, the plot of A/CNK versus A/NK, a powerful tool for characterizing the aluminum saturation of rocks indicate that all samples from the migmatite gneiss, granite gneiss and banded gneiss plotted in the metalumminous field (Figure 5). This plotting (Figure 5) indicates aluminum saturation with a predominance of minerals like biotite, amphibole and garnet [25,26].

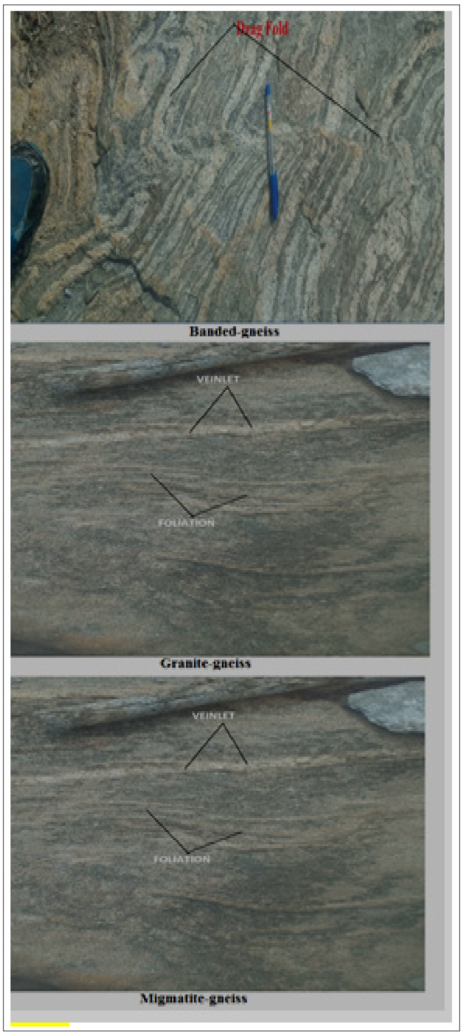

Figure 2: Few Outcrops from the Study Area

Table 1: Major Elements (wt%) Composition of Gneisses (Banded, Granite and Migmatite)

Rock names	MGn	MGn	MGn	BGn	BGn	BGn	GGn	GGn	GGn	GGn	AVR	RANGE
Samples	M32	M35	M38	M33	M36	M39	M31	M34	M37	M40		
SIO_2	67.14	66.17	67.57	66.68	68.66	66.04	70.76	65.53	69.35	64.4	67.23	64.4 - 70.76
Al_2O_3	15.16	14.94	14.79	15.89	14.55	15.78	14.35	15.17	14.33	14.38	14.934	14.33 - 15.89
Fe_2O_3(T)*	3.99	4.53	4.03	3.78	4.32	3.73	2.32	7.21	2.10	6.22	4.223	2.10 - 7.21
MnO	0.066	0.063	0.065	0.063	0.058	0.055	0.034	0.11	0.035	0.097	0.0646	0.034 - 0.11
MgO	0.74	0.79	0.69	0.83	0.85	0.7	0.42	2.16	0.43	2.25	0.986	0.42 - 2.25
CaO	4.11	4.18	3.94	5.02	4.40	5.49	3.05	6.20	3.83	6.46	4.668	3.05 - 6.46
Na_2O	3.52	3.41	3.34	3.46	3.43	3.63	3.38	3.33	3.32	3.00	3.382	3.00 - 3.63
K_2O	3.09	3.31	3.09	2.67	2.93	3.08	3.69	2.99	4.12	2.82	3.179	2.67 - 4.12
TiO_2	0.346	0.315	0.318	0.33	0.524	0.443	0.27	0.696	0.19	0.969	0.4401	0.19 - 0.969
P_2O_5	0.30	0.31	0.29	0.46	0.38	0.32	0.36	0.62	0.20	0.55	0.397	0.20 - 0.62
LOI	0.50	0.44	0.53	0.47	0.60	1.03	0.65	0.83	0.65	0.65	0.635	0.44 – 1.03
Total	98.97	98.45	98.64	99.65	100.7	100.3	99.28	99.87	98.54	99.81		
A/NK	1.66	1.63	1.67	1.90	1.61	1.70	1.50	1.74	1.44	1.80	1.665	1.44 – 1.9
A/CNK	0.91	0.89	0.92	0.89	0.86	0.82	0.95	0.76	0.85	0.73	0.858	0.73 – 0.95
K_2O/Na_2O	0.88	0.97	0.93	0.77	0.85	0.85	1.10	0.90	1.24	0.94	0.943	0.77 – 1.24
Na_2O_3/Al_2O_3	0.23	0.23	0.23	0.24	0.24	0.23	0.24	0.22	0.23	0.21	0.23	0.21 – 0.24
K_2O/Al_2O_3	0.20	0.22	0.21	0.17	0.20	0.20	0.26	0.22	0.29	0.20	0.217	0.17 – 0.29
FeOt / (FeO+MgO)	0.83	0.84	0.84	0.80	0.82	0.83	0.83	0.76	0.81	0.71	0.807	0.71 – 0.84
Na_2O+K_2O-CaO	2.50	2.54	2.49	1.11	2.54	1.22	4.02	0.12	3.61	-0.64	1.951	-0.64 – 4.02

N.B: MG: Migmatite gneiss, BGn: Banded gneiss, GGn: Granite gneiss

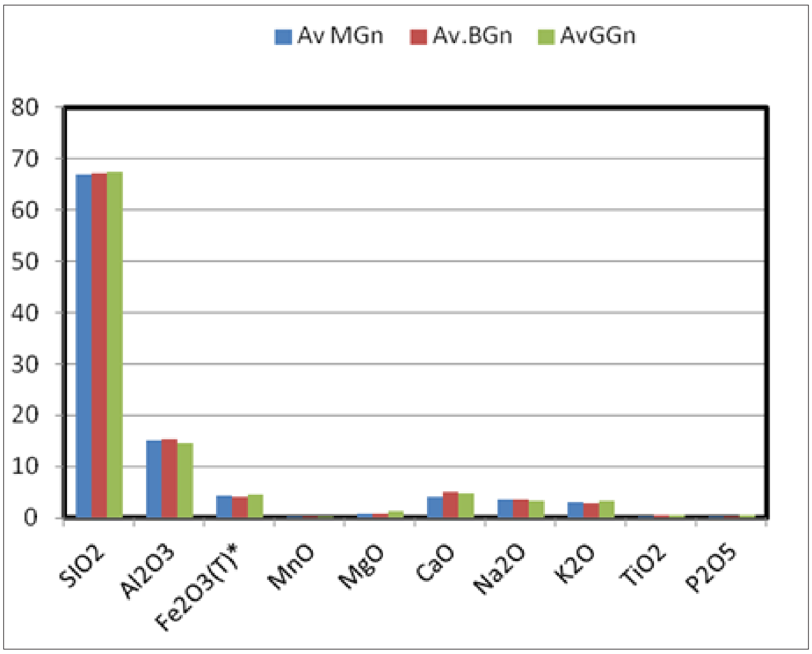

Figure 3: Major Oxides Composition in the Rocks of the Study Area

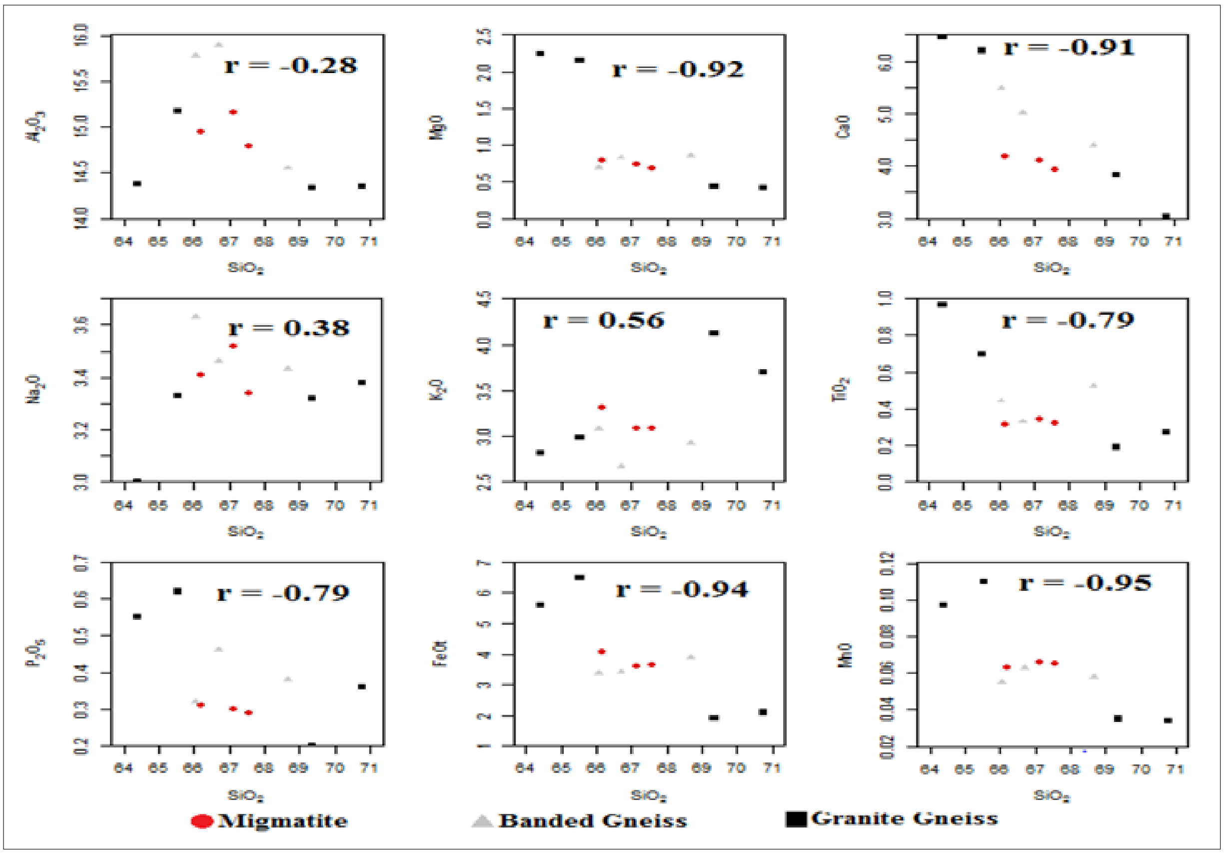

Figure 4: Harker Diagrams Showing Variation of Major Oxides with Silica

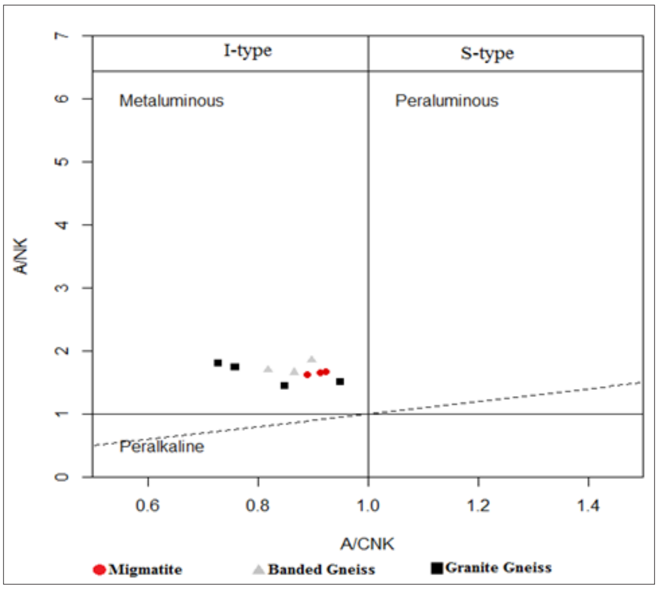

Figure 5: Geochemical Plot of A/CNK Versus A/NK Rocks in the Study Area [14].

Plots of K_2O versus SiO_2

On the plot of K_2O vs SiO_2 diagram (Figure 6), the rock samples fall mainly into the high K calc-alkaline series [27].

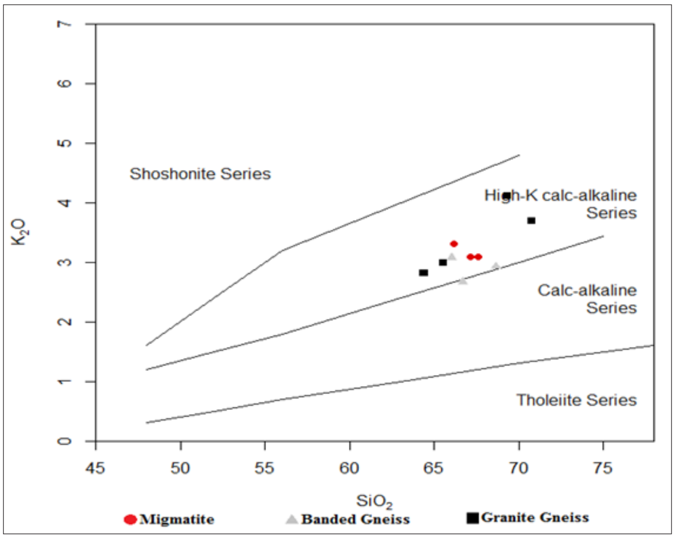

Figure 6: The K_2O Versus SiO_2 Diagram of the Rock Units [27].

AFM Diagram

Aluminum-total iron-magnesium (Figure 6), enables classification of the rocks into calc-alkaline and tholeiite series based on the portion of their Na_2O, K_2O, Fe_2O_3 and MgO contents [28]. The rocks plot in the field of calc-alkaline series.

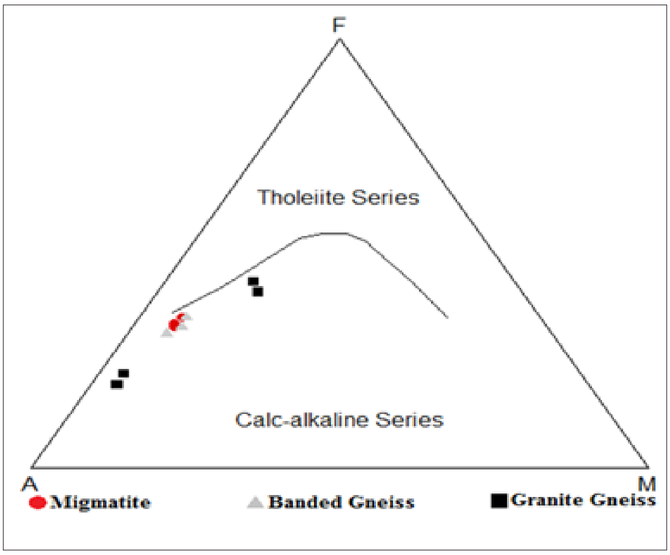

Figure 7: AFM Diagram (A= Na_2O+K_2O, F= Fe_2O_3, M= MgO) [28].

According to Wilson, the AFM diagram (Figure 7) revealed that the magma from which the rocks were formed was calc-alkaline in nature and was restricted in occurrence to the subduction – related environment [29]. This by implication means that the source of the rocks from the study area was derived from a subduction tectonic environment.

Protoliths Precursor Diagrams

The following graphical plots; SiO_2 versus $Na_2O + K_2O$ and TiO_2 versus SiO_2 were employed for the protoliths precursor of the rocks in the study area.

SiO_2 versus $Na_2O + K_2O$

Plot of SiO_2 versus Na_2O+K_2O (Figure 8) shows the granitic protoliths of the gneissic rocks [30]. The plots are within the granodiorite and granite group supporting the granitic character of these rocks. It also suggests the partial melting of granodiorite to granite crustal rocks.

TiO_2 Versus SiO_2

There are contrasting views concerning the evolution of gneisses. Most of the authors believe that gneisses are of igneous protoliths [6,10-12,31] to mention a few, while authors like McCurry and Burke et al., believe that gneisses evolved from granitization of pre-existing met sediments [7,32].

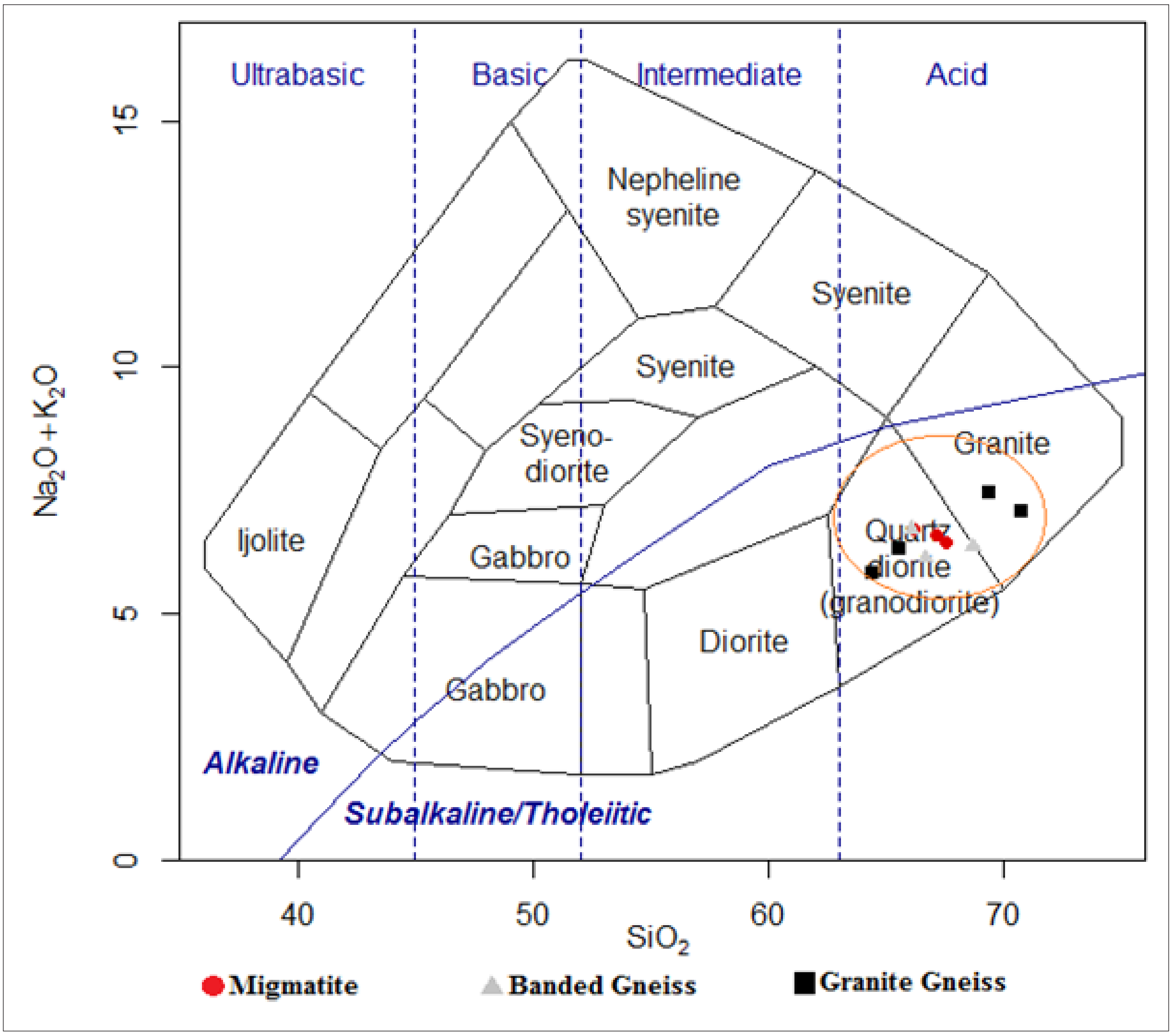

Figure 8: Bivariate Discrimination plot of SiO_2 Versus Na_2O+K_2O of the Rock Units in the Study Area [30].

Rocks can be classified according to the presumed origin of the parent rocks. On the plot of TiO_2 versus SiO_2 discriminatory diagram (Figure 9), the rocks plot in the igneous field, which indicates an igneous protoliths [33].

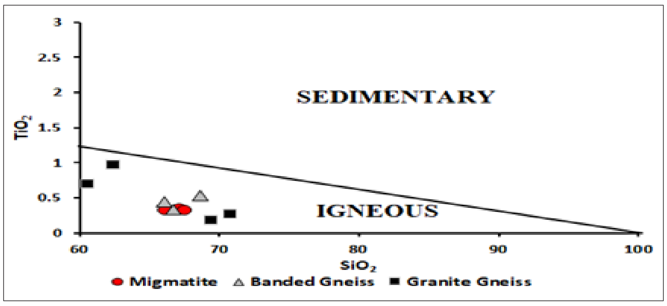

Figure 9: TiO_2 Versus SiO_2 Discrimination Diagram showing the Protolith of the Rock Units in the Study Area [33].

Trace Elements

The compositions of the trace elements of the rocks in the study area are presented in Table 2. The concentrations of the High Field Strength Elements (HFSE) (Be,U, Sn,W, Zr, Nb, Hf, Ta) and the Large Ion Lithophile Elements (LILE) (Rb, Cs, Ba, Pb, Sr,Th) have no correlation with the values of average granite and crust. The LILE are rock loving with large ionic radii and could concentrate in the crust. They are often used as tracers for geological processes. However, they are highly mobile and can be transported easily by magmatic and metamorphic fluids. Thus, they can be depleted from the elements that make up the earth crust. As for the HFSE, they often exhibit complex behavior in geological systems; the elements are often incompatible with major minerals in granite and crust, leading to their exclusion from their crystal lattice. They could be mobilized by fluids, which could result in their transportation and deposition in different geological settings. There are great variations among the trace elements compare to the average granite and crust values (Figure 10). However, Zr (855ppm) showed abnormally high values compared to average granite (180ppm) and crust (165ppm). Also, Ba (978.2ppm) value was equally very high compare to average granite (600ppm) and crust (425ppm). The abnormal high value of Zr could be from the Zr grains present in the protoliths which can survive metamorphism. The high values of Ba on the other hand could be from metamorphic fluids that leached out Ba from the surrounding rocks apart from the ones introduced through hydrothermal veins and alteration zones. Rb/Sr ratios ranging from 0.22 to 0.40 ppm compare well with the melanocratic biotite-hornblende rocks and microcline-plagioclase-biotite banded gneiss reported from southern parts of Ilesha and Iperindo [8]. Also, the low average ratio of Rb/Sr (0.284) for the rocks in the study area signifies possible depletion of Rb and/or enrichment of Sr in the gneisses [34]. The high occurrence of Zr and Ba signify derivation from felsic magmatic source [35].

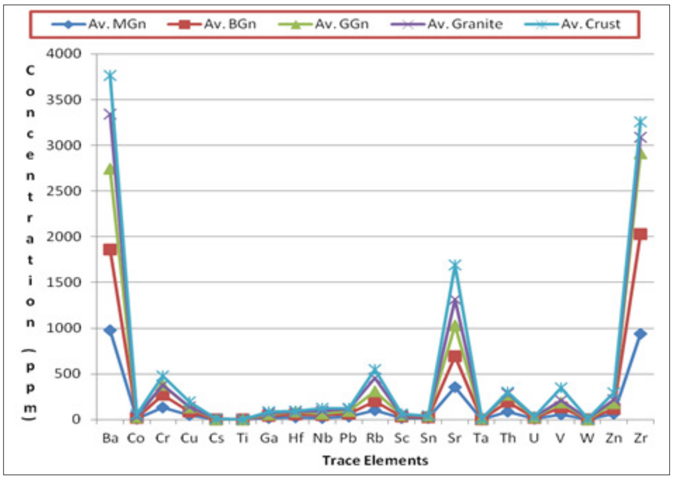

Figure 10: Comparative Values of Trace Elements in the Gneisses to Av. Granite and Av. Crust

Table 2: Trace Element (ppm) Composition of Rocks in the Study Area (Migmatite, Granite and Banded)

Rock names	Migmatite-gneiss			Banded-gneiss			Granite-gneiss				AVR	RANGE	AVR Granite	AVR Crust
Samples	M32	M35	M38	M33	M36	M39	M31	M34	M37	M40				
Ba	1212	1222	1138	858	782	1032	839	740	1181	778	978.2	740 – 1222	600	425
Be	3	2	3	2	2	2	1	2	2	3	2.3	1 – 3		
Co	6	7	6	7	7	5	4	14	4	13	7.3	4 – 14	1	25
Cr	60	60	70	70	80	90	100	70	110	150	86	60 – 150	4	100
Cu	20	30	20	20	20	20	20	40	70	30	29	20 – 70	10	55
Cs	3.3	0.9	2.9	1.9	1	0.9	1.1	2.2	1.8	1.4	1.74	0.9 – 3.3	5	3
In	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2			
Ti	0.6	0.5	0.5	0.5	0.4	0.3	0.8	0.4	0.5	0.4	0.49	0.3 – 0.8	0.75	0.45
Ge	1	1	1	1	1	1	<1	2	1	2	1.22	1 – 2		
Ga	18	18	19	18	18	19	18	19	17	20	18.4	17 – 20	18	15
Hf	25.1	23.4	25.3	19.1	25.6	24.8	26.8	21.1	19.2	35.7	24.61	19.1 – 35.7	4	3
Nb	9	7	13	6	16	15	5	15	7	34	12.7	5 – 34	30	32
Pb	28	29	34	33	28	25	32	27	34	30	30	25 – 34	20	12.5
Rb	113	97	114	87	97	89	121	100	118	89	102.5	87 – 121	150	90
Sc	11	11	12	14	12	13	4	19	6	22	12.4	4 – 22	5	16
Sn	3	3	4	11	8	8	5	14	13	14	8.3	3 – 14	3	2

Sr	411	415	391	366	377	402	305	325	377	329	363.9	305 – 415	285	375
Ta	0.6	0.5	0.7	0.4	1.2	1	0.4	1.5	0.7	3.5	1.11	0.4 – 3.5	3.5	2
Th	75.5	68.9	85.3	43.1	115	73	84.9	44.6	52.5	124	76.68	43.1 – 124	17	10
U	4.4	4.8	16.2	2.7	6.2	5.4	4.7	9	6.5	10	6.99	2.7 – 16.2	4.8	2.7
V	31	34	31	40	41	35	19	93	21	94	43.9	19 – 94	20	135
W	2	<1	<1	2	<1	<1	2	1	2	1	1.67	1 – 2	2	1.5
Zn	50	50	50	80	50	50	40	80	<30	60	56.67	40 – 80	40	70
Zr	886	848	895	640	854	895	888	767	657	1226	855.6	640 – 1226	180	165
Th/Yb	15.10	14.98	13.98	10.78	26.14	13.52	42.25	6.97	20.19	13.63	17.754	6.97 – 42.25		
Ta/Yb	0.12	0.12	0.21	0.10	0.27	0.19	0.20	0.23	0.27	0.38	0.209	0.1 – 0.38		
Ba/Nb	134.67	174.60	87.54	143.00	48.88	68.80	167.80	49.33	168.71	22.88	106.621	22.88 – 174.6		
Th/U	17.16	14.35	5.27	15.96	18.55	13.52	18.06	4.96	8.08	12.40	12.831	4.96 – 18.55		
Sr/Y	7.90	8.83	6.63	10.17	6.50	7.60	10.89	5.60	16.39	4.11	8.462	4.11 – 16.39		
U/Pb	0.16	0.17	0.48	0.08	0.22	0.22	0.15	0.33	0.19	0.33	0.233	0.08 – 0.48		
Rb/Sr	0.27	0.23	0.29	0.24	0.31	0.22	0.40	0.30	0.31	0.27	0.284	0.22 – 0.4		
Lu/Hf	0.03	0.03	0.04	0.03	0.25	0.03	0.01	0.05	0.02	0.04	0.053	0.01 – 0.25		

The average Zr content from MGn (876.03ppm), BGn(796.33ppm) and GGn (884.50ppm) from the study area compares favorably with similar rocks from the basement complex of Nigeria (e.g. Idanre migmitite (212.05ppm), Ita-Ogbolu banded gneiss (556.45ppm) and Ado-Ekiti granite (1564.75ppm). They are within acceptable range for crustal rocks of granitic composition [35].

Rare Earth Element (REE)

The rocks display a great range of rare earth element (REE) concentrations with Ce and Nd enrichment (Figure 11). This resulted from variations between and within the rocks. These essentially include the 15 lanthanide elements and yttrium and are presented in Table 3 below.

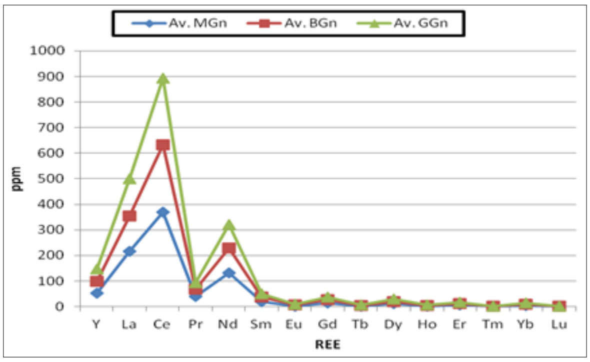

Figure 11: REE Composition of Rocks in the Study Area

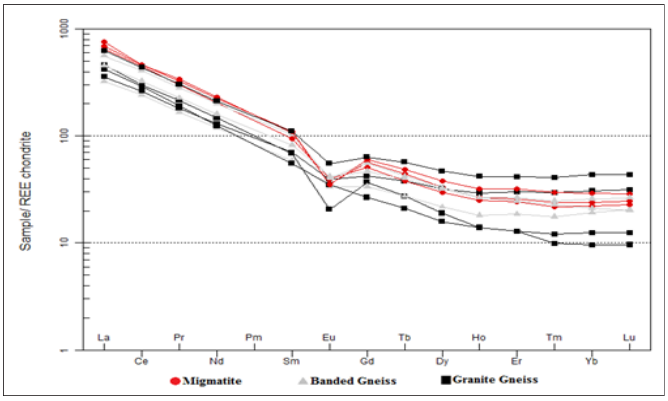

Figure 12: Chondrite-Normalized REE Abundances Normalized Values [36].

Table 3: Showing Rare Earth Element Composition of Gneisses (Migmatitic, Banded, and Granite)

Rock names	MGn	MGn	MGn	BGn	BGn	BGn	GGn	GGn	GGn	GGn		
Samples	**M32**	**M35**	**M38**	**M33**	**M36**	**M39**	**M31**	**M34**	**M37**	**M40**		
Elements(ppm)											**AVR**	**RANGE**
Y	52	47	59	36	49	53	28	58	23	80	48.5	23 – 80
La	234	201	214	100	174	141	143	111	131	195	164.4	100 – 234
Ce	374	361	376	196	330	263	242	213	236	354	294.5	196 – 376
Pr	41.3	36.6	39.8	20.5	34.4	27.6	26.2	22.2	23.3	37.2	30.91	20.5 - 41.3
Nd	139	123	135	71.2	120	96.2	88.8	78.1	74.7	127	105.3	71.2 – 139
Sm	20.9	18.5	21.5	11.5	20.3	16.1	13.4	13.7	10.8	21.6	16.83	10.8 - 21.6
Eu	2.62	2.94	2.57	2.46	2.98	3.06	1.51	2.89	2.57	4.06	2.77	1.51 - 4.06
Gd	14.6	13.3	15.7	8.7	14.4	12.1	9.6	10.9	6.9	16.5	12.27	6.9 - 16.5
Tb	2.1	1.8	2.3	1.3	2	1.9	1.3	1.8	1	2.7	1.82	1 - 2.7
Dy	10.6	9.6	12.3	7	10.6	10.3	6.1	10.4	5.1	15.1	9.71	5.1 - 15.1
Ho	1.9	1.8	2.3	1.3	1.9	1.9	1	2.1	1	3	1.82	1 – 3
Er	5.4	5.1	6.7	3.9	5.2	5.6	2.7	6.3	2.7	8.7	5.23	2.7 - 8.7
Tm	0.78	0.71	0.96	0.57	0.74	0.8	0.32	0.96	0.39	1.32	0.76	0.32 - 1.32
Yb	5	4.6	6.1	4	4.4	5.4	2	6.4	2.6	9.1	4.96	2 - 9.1
Lu	0.79	0.73	0.93	0.66	0.65	0.85	0.31	1.01	0.4	1.4	0.77	0.31-1.4
ΣREE	852.99	780.68	836.16	429.09	721.57	585.81	538.24	480.76	498.46	796.68	652.044	429.09-852.99
ΣLREE	809.2	740.1	786.3	399.2	678.7	543.9	513.4	438	475.8	734.8	611.94	399.2-809.2
ΣHREE	43.79	40.58	49.86	29.89	42.87	41.91	24.84	42.76	22.66	61.88	40.104	22.66-61.88

Table 4: Chondrite Normalized Elemental Ratios for Rocks in the Study Area using Normalizing values of Boynton [36].

Rock names	MGn	MGn	MGn	BGn	BGn	BGn	GGn	GGn	GGn	GGn		
Samples	**M32**	**M35**	**M38**	**M33**	**M36**	**M39**	**M31**	**M34**	**M37**	**M40**		
Ratio											AVR	RANGE
Eu/Eu*	0.46	0.57	0.43	0.75	0.53	0.67	0.41	0.72	0.91	0.66	0.611	0.41 – 0.91
LaN/YbN	31.55	29.46	23.65	16.85	26.66	17.60	48.20	11.69	33.97	14.45	25.408	11.69 – 48.2
LaN/SmN	7.04	6.83	6.26	5.47	5.39	5.51	6.71	5.10	7.63	5.68	6.162	5.1 – 7.63
CeN/YbN	19.35	20.30	15.94	12.67	19.40	12.60	31.30	9.61	23.48	10.06	17.471	9.61 – 31.3
EuN/YbN	1.49	1.82	1.20	1.75	1.93	1.61	2.15	1.28	2.81	1.27	1.731	1.2 – 2.81

The Migmatite gneiss are much more enriched with ΣREE values of 852.99ppm, 780.68ppm and 836.16ppm, the banded gneiss has enriched ΣREE values of 429.09ppm,721.57ppm and 585.24ppm while the granite gneiss has ΣREE values of 538.24ppm, 480.76ppm, 498.46ppm and 796.68ppm respectively (Table 3).

The plots of rare earth elements (REE) for these rocks on a chondrite normalized diagram of Boynton displayed a high degree of fractionation with steep pattern (Figure 12) as evident from the decrease in REE value from Light Rare Earth Element (LREE) to Heavy Rare Earth Elements (HREE) [36]. The chondrite normalized ratio (Table 4) of LaN/YbN range from 23.65 – 31.55 with an average of 28.22 in the Migmatite gneiss, 16.85 – 26.66, average of 20.37 in banded gneiss and 11.69 – 31.30, average of 27.08 in granite gneiss. The chondrite normalized ratio of CeN/YbN ranges from 15.94- 20.30 with an average of 18.53 in Migmatite gneiss, 12.60 – 19.40 with an average of 14.89 in banded gneiss, and 9.61 – 31.30 with an average of 18.6 in granite gneiss. The chondrite normalized ratio of LaN/SmN range from 6.26 – 7.04 with an average of 6.71 in Migmatite gneiss, 5.39 - 5.51 with an average of 5.5 in banded gneiss, and 5.10 – 7.63 with an average of 6.28 in granite gneiss. The high values of normalized ratio of La to Yb, Ce to Yb and La to Sm are evidence of high fractionation in these rocks.

These gneissic rocks also show a negative Eu/Eu* anomalies with an average of 0.49, 0.65 and 0.68 for Migmatite gneiss, banded gneiss, and granite gneiss respectively. The negative Eu anomalies in the gneissic rocks (Figure 12) show that high amount of plagioclase was removed from the magma during fractional crystallization [37]. The similarities in the rare earth elements (REE) pattern of the gneissic rocks suggest similar origin. The high LREE enrichment trend possibly indicates high abundance of cerium earth which has affinity for LREE concentration relative to HREE, the behavior and the range of the REE are within rocks of igneous origin [20].

Conclusion

Field observation revealed 3 rock units comprising of migmatite gneiss, banded gneiss and granites gneiss. The geochemical composition of the country rocks revealed that they are felsic rocks while the compositional features revealed a descending trend in the oxides as shown; $SiO_2 > Al_2O_3 > CaO > Fe_2O_3 > Na_2O > K_2O > MgO > MnO > TiO_2 > P_2O_5$. The compositional trend of the rocks suggests geologic setting of continental crust origin possibly formed during orogenic activity. Discriminant plots revealed strong negative correlation of all the oxides with SiO_2 except for Na_2O that has positive correlation with SiO_2 indicating pyroxene – hornblende and plagioclase fractionations respectively. Evaluation of the alumina variation of the rocks indicated metaluminous rocks produced from the partial melting of meta-igneous source at low pressure. The rocks are not corundum normative as aluminum saturated index (ASI)<1, typical of type I magmatic rocks. The source of the rocks from the study area was derived from a subduction tectonic environment with granitic protoliths. There are great variations among the trace elements compare to the average granite and crust values. The concentrations of Zr and Ba are exceptionally high indicating felsic source of derivation. Also, the low average ratio of Rb/Sr (0.284) for the rocks in the study area signifies possible depletion of Rb and/or enrichment of Sr in the gneisses. The rocks display a great range of rare earth element (REE) concentrations with Ce and Nd enrichment. The migmatite gneiss is more enrich in the REE compare to the banded gneiss and granite gneiss. The chondrite normalized diagram displayed a high degree of fractionation with steep pattern which was confirmed by the high values of normalized ratio of La to Yb, Ce to Yb and La to Sm. The negative Eu anomalies in the gneissic rocks show that high amount of plagioclase was removed from the magma during fractional crystallization while similarities in the rare earth elements (REE) pattern suggest they have similar origin. The rocks in the area are felsic and met aluminous with igneous origin [38].

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