GEOCHEMISTRY, AND FELDSPATHIC STUDIES OF PAN AFRICAN GRANITES AROUND ADO EKITI, EKITI STATE, SOUTHWEST, NIGERIA.

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Abstract

The geochemistry and feldspathic studies of granite and charnockitic rocks in Ado Ekiti areas are studied. Geochemical data from the inductively coupled plasma-mass spectrometry (ICP-MS) analysis show that the rocks are forran (Fe-rich) and magnesian, alkaline and subalkaline using classification schemes. They are also classified as mafic and felsic having mafic silicate minerals such as biotite, hornblende, pyroxene, and plagiocle feldspar in varying proportions and felsic minerals such as quartz, muscovite orthoclase feldspar and albite. These rocks are formed from the granite clan of rocks from partial melting of basaltic rocks. The magnesian rocks have poor iron enrichment relative to forran rocks but both forran and magnesian rocks are of the family of feldspathic rocks. Forran rocks are those whose evolved magmas are from intraplate environments. .The presence of pyroxene, magnetite (opaque mineral), and Ca- plagioclase minerals suggests fractionation during the evolution of the magma while the low ratio (0.43-1.68) of Na_2O/K_2O) reflects a loss during alteration / metamorphism. The increase in SiO_2 and decrease in Fe_2O_3, MgO, CaO, AL_2O and Na_2O indicate fractional crystallization as affirmed also by an enrichment in incompatible elements, Rb (127.36), Zr (283.22), and depletion of compatible elements (Sc, 13.58, V, 50.62, Cr 39.47, Ni 21.34) .The ratio of K_2O/ Na_2O ranges between 0.59 and 2.30 and $K_2O > Na_2O$, reflect the abundance of K-bearing minerals relative to Na -plagioclase (albite) contents in the rocks. The plotting of the rocks in the volcanic arc and within plate environments indicate the possibility of their emplacement during the Pan African orogeny occasioned by the volcanic arc magmatism.

Key words: geochemistry, feldspathic, forran, magnesian, fractionation, K-bearing,volcanic arc

1.0 INTRODUCTION

Granites and charnockitic rocks are part of the granite suites that form part of the Pan- African granite of Nigerian Basement Complex . Rocks of the Older granite as it is called are visible and widely spread around Ado Ekiti and environs. These rocks intruded into the pre-existing migmatites gneiss quartzite complex and metasediments (schist) of Liberian (2700Ma), Eburnean (2000-2700Ma) and probably Kibaran (1100 Ma) ages during the Pan African Orogeny (600 ± 150 Ma [1]. The present study seeks to determine the geochemistry, classification and provenance of the rocks. The geochemical data from the rocks will show the characteristic abundances of the major oxides, trace and rare earth elements contained in the rocks. The data will equally decipher the magmatic sources and the conditions under which the rocks were formed. The geology of the study area has been reported severally by scholars such as [2] and that prompted the interest to work on the geochemistry.

Aims of the study.

The study aims at providing geochemical data for granites and charnockites in Ado Ekiti area. Thin sections were prepared for petrographic studies while the available geochemical data were used to classify and identify the feldspathic nature of the rocks.The tectonic discrimination of the rocks were equally determined.

2.0 Materials and Methods

2.1 Field Work

The field mapping in the study areas was carried out in May 2017 covering Iworoko, Adebayo road, Iyin-Ekiti road, textile area, Omolayo area, Federal Polytechnic road as well as Odo Ado areas. Ten sampled points are marked in green colour as shown in Fig.1.

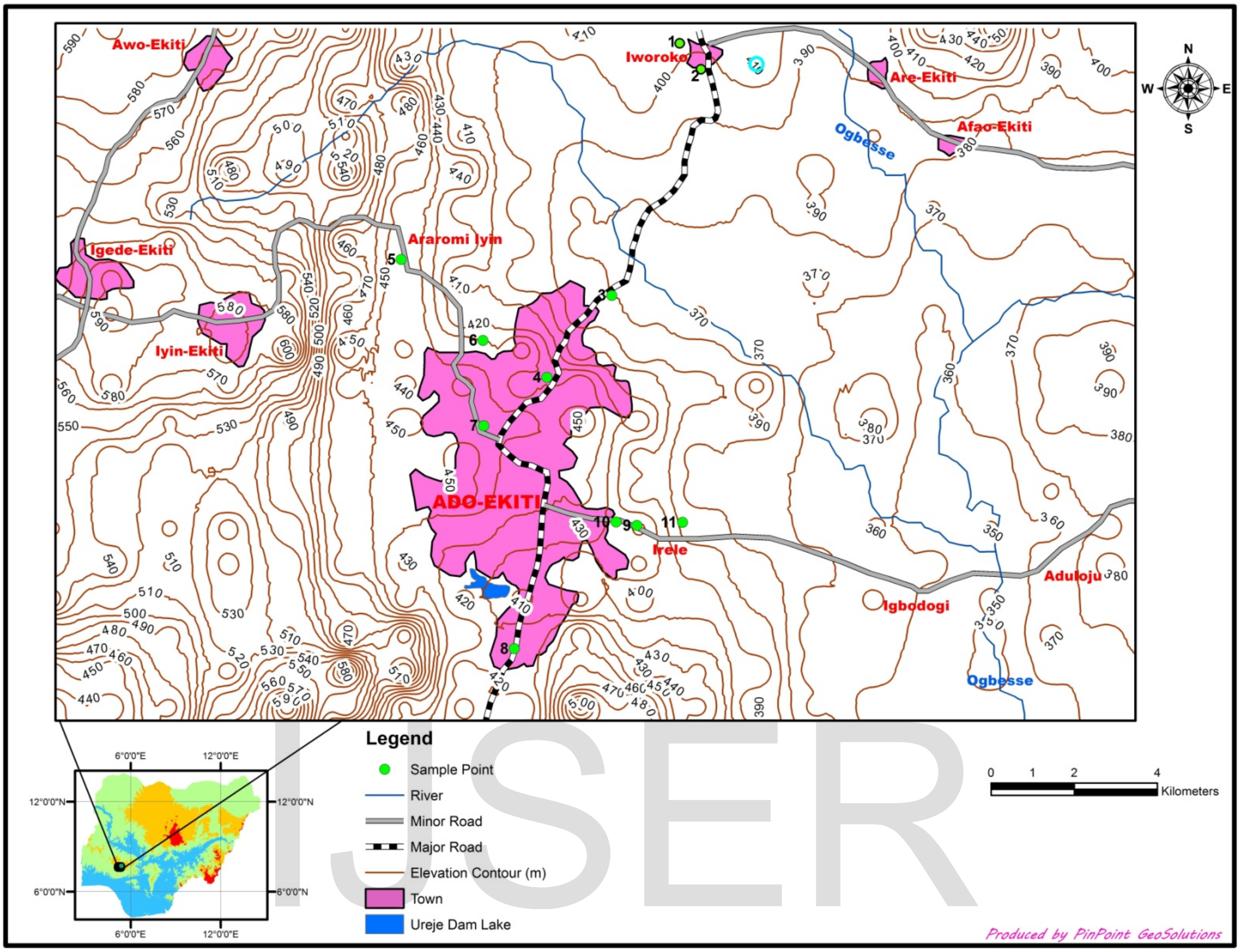

Fig.1: Topographical map of Ado Ekiti showing the sample points.

Table 1 presents all the field data recordings , the co-ordinates, elevation, mineralogy, rock types, locations and field observations. The elevation shows a low to moderate massive rocks that range between 383 and 453 meters (Fig 2).

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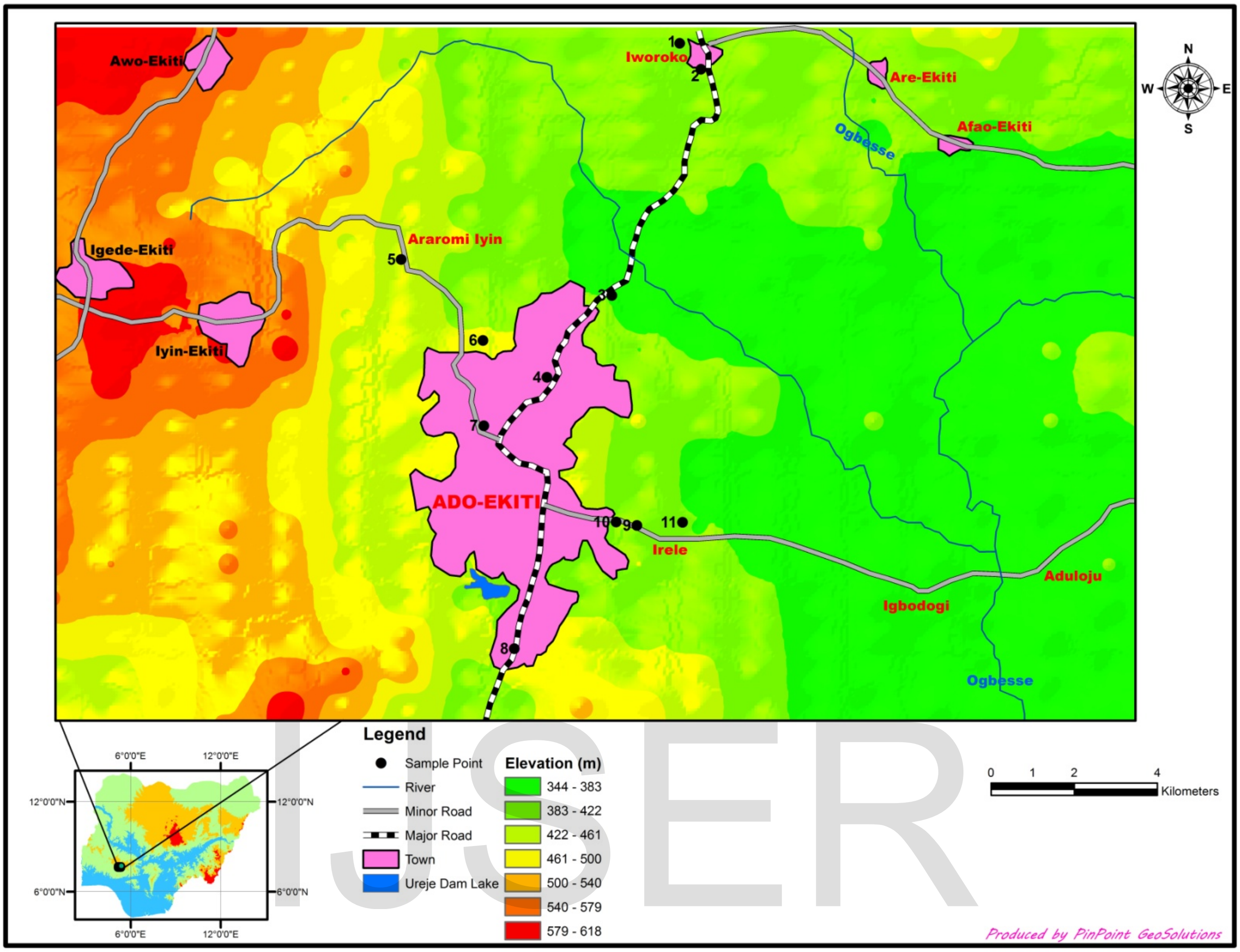


Fig .2: Interpolated digital elevation map of Ado Ekiti.

The macroscopic minerals observed in the field range from quartz, feldspar, to biotite while the rocks range between migmatite gneiss, granite gneiss, porphyritic granite, and charnockites (Table 1).

Table 1: Field data recordings .

SAMPLE NUMBER	Coordinates	Elevation (m)	Mineralogy	Rock Types	Locations	Field Observation
Adl1	N07˚44' 08 .6'' E005°15' 12.3''	423	Quartz	Migmatite gneiss	Along Ifaki Rd Iworoko	Folds,highly weathered,quartz veins
AdL2	N07 43.61.6'' E005°15' 50.3'	426	Feldspar	Granite gneiss	OriApita Iworoko	Highly weathered, felsic mineralization

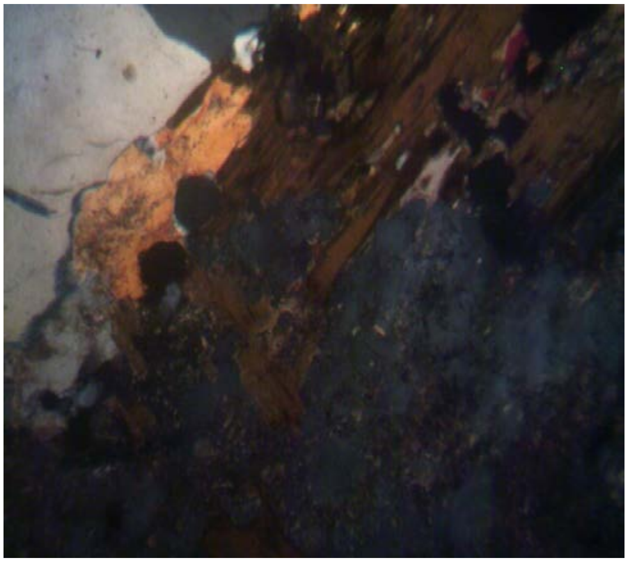
Ad3	N07 39.40 2' E005°14' 32.4'	383	Plagioclase feldspar, biotite, quartz.	Granite gneiss	Adehun	Low lying dyke
AD4	N07°38 78.1″ E005°51 34.8'	425	`quartz, feldspar Biotite	Porphyritic granite	School of nursing	Low lying massive rock.
AD5	N07°40 30.6″ E005°11 59.8″	431	Feldspar ,quartz	Porphyritic granite	Iyin quarry	Inselberg
Ad6	N07°38 15.6″ E005°12 66.7″	453	Feldspar	Weathered pegmatite granite	St Jude Church	Pegmatite dyke
Ad7	N07°35'27.2″ E005°13 06.1″	424	Biotite	Porphyritic granite/ charnockite	Omolayo	Foot of a hill
Ad8	N07°36 86.6″ E005°14 46.4″	415	Feldspar	Pegmatite/charnockite	Polytechnic road	Boulders
Ad9	N07°36ı91.0″ E005°14 37.9″	421	Biotite	Charnockitic granite	Ugbamgba road	Foot of a hill
Ad 10	N07°36 90.5″ E005°14 37.7″	434	Biotite	Charnockite	Odo Ado	Foot of a hill

Table 2: Modal composition of Ado Ekiti rocks (%).

	1	2	3	4	5	6	7	8	9	10	Total	% total
Quartz	69.4	45.6	72.5	40.6	64.4	19.4	57.2	71.2	53.3	33.8	527.4	55.7
Microcline	4.1	13.1	12.5	44.7	21.9	43.1	16.9	9.4	-	-	165.7	17.5
Plagioclase	9.4	18.1	-	-	7.5	3.8	-	3.4	22.5	20.0	84.7	8.9
Biotite	14.1	16.3	6.9	7.2	4.1	11.6	1.0	12.8	9.4	15.9	99.1	10.4
Hornblende	-	-		-	-	20.6	12.8	1.3	-	3.1	37.8	3.9
Muscovite	0.9	4.7	1.3	0.3	-	-	-	-	-		7.2	7.6
Opaque	0.9	-	-	-	-	-	0.9	-	0.6	3.4	5.8	6.1
Orthoclase	-	-	-	6.3	-	-	2.2	-	-	9.7	18.2	1.9
Mymickite	-	-	-	-	-	-	1.6	-	-		1.6	1.6
Pyroxene		-	-	-	-	-	1.9	-	-	12.5	14.4	1.5
Modal % of mineral	98.8	97.8	93.2	99.1	97.9	98.5	91.0	98.1	85.8	85.9	946.1	113.7

2.2 Petrographic studies

The thin sections interpretations showing the modal compositions of the rocks in percent are shown in Table 2. They indicate the average quartz contents as 55.7 %, microcline (17.5%), biotite (10.4%) plagioclase (8.9%) with pyroxene as the least with (1.5%) ,all showing the attributes of a granitic rock. The petrographic study of the granite and charnockites in plates (a-h) identified quartz, feldspars, hornblende, biotite and some opaque minerals with porphyritic textures .There is microperthite intergrowth of feldspars and well-formed large crystals of both microcline and plagioclase with their characteristic twinning in some of the plates. Quartz crystals are of various sizes. In the photomicrographs, quartz is the dominant mineral followed by the feldspars. Biotite displays the interference brown colour especially in plate (g) when viewed under the cross polarized light.



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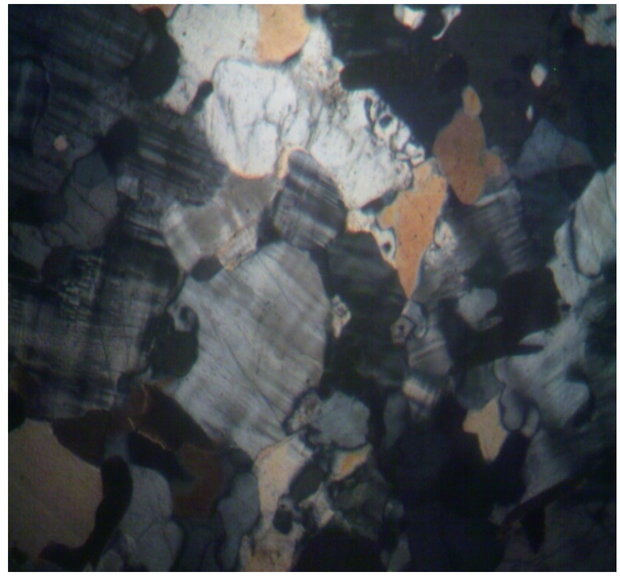

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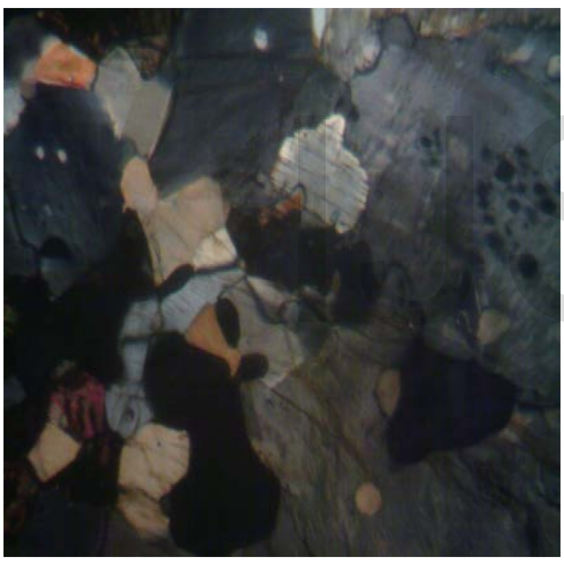

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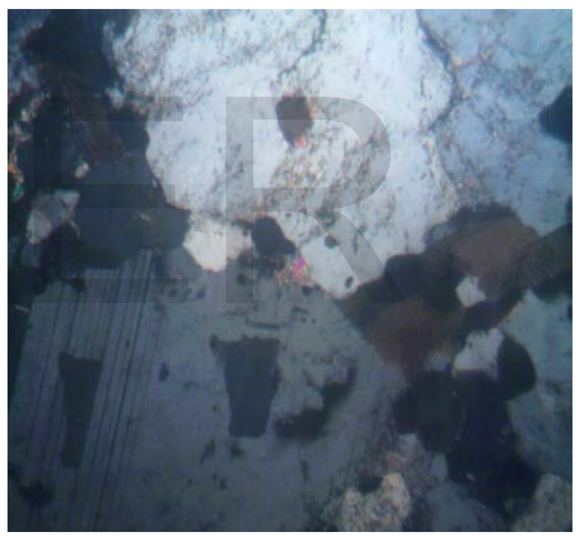

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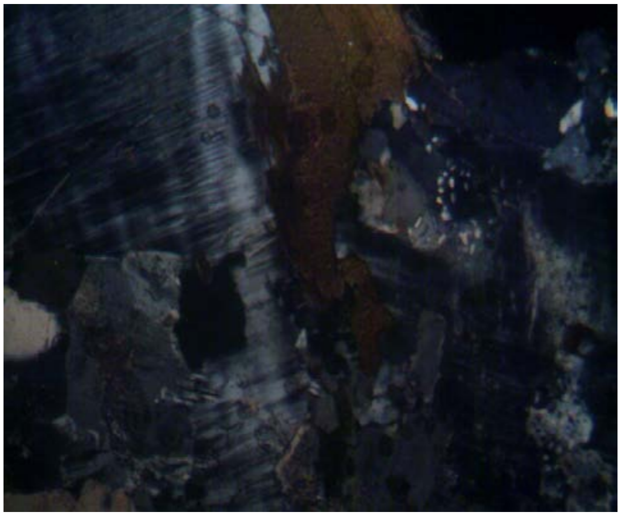
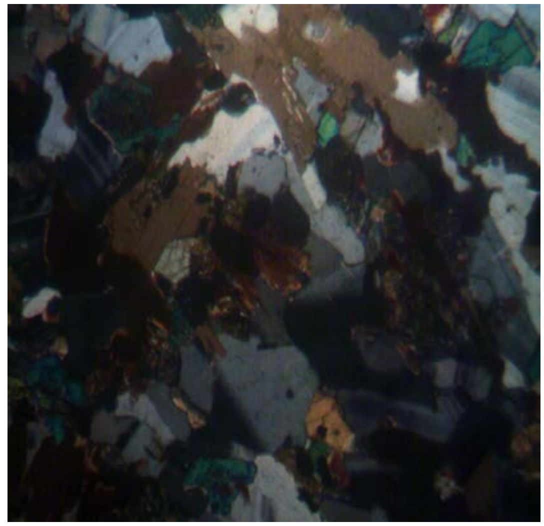
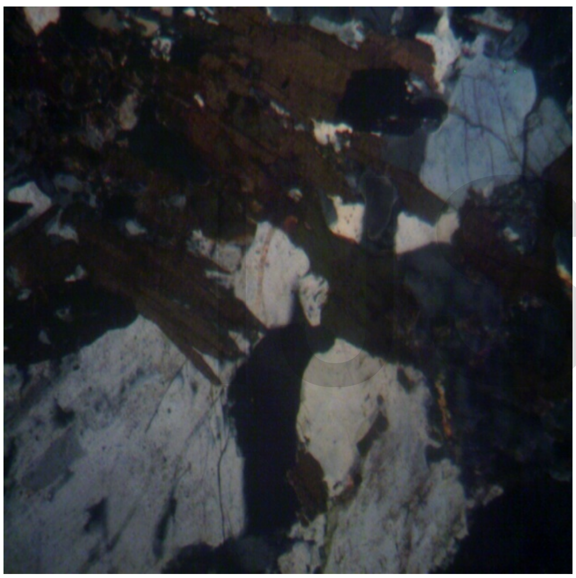
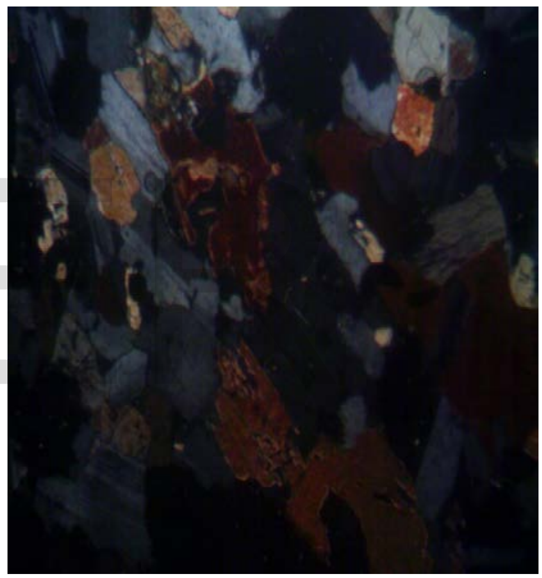




e **f**





g **h**

Plates (a-h): Photomicrographs in cross polarized light (a) muscovite in N-S trend at the top central side (b) plagioclase with twin lamellae; (c) Hornblende with rims at the left bottom side of the field, microcline in extreme right hand side in N-E trend; (d) plagioclase at the extreme bottom of the field with quartz at the central top.(e) cross hatched twinning characteristic of microcline in cross polarized light and intruded by large hornblende trending in a N-S direction. (f) feldspar top centre, quartz at the centre and opaque minerals. (g) biotite with muscovite on top left hand side and (h) crystals of quartz, plagioclase, orthopyroxene and opaque minerals.

2.3 Methods of geochemical analyses.

Six granites and four charnockite samples were crushed and pulverized into powder for whole- rock analyses. The major oxides were analyzed using the X-ray fluorescence spectrometry (XRF) at the Central laboratory of the Stellenbosch University, South Africa. The oxides SiO_2 Al_2O_3, Fe_2O_3, CaO, K_2O, MgO, Na_2O, MnO, Cr_2O_3, P_2O_5 and LOI as analyzed are presented in Table 3. These oxides were determined by using the XRF spectrometry on a PANalytical Axios Wavelength Dispersive Spectrometer following the proposal of [3].The gas-flow proportional counter uses a 90% Argon-10% methane mixture of gas. Major elements were analyzed on a fused glass disk using a 2.4kW Rhodium tube. The trace and rare earth elements concentrations were determined by inductively coupled plasma-mass spectrometry (ICP-MS). Major and trace element abundances were determined using a PS-950 X-ray fluorescence (XRF) and a 7500a La-ICP-MS, respectively. The concentration of the control standards that were used in the calibration procedures for major element analyses fit the range of concentration of the samples. Amongst these standards were NIM-G (Granite from the Council for Mineral Technology, South Africa) and BE-N (Basalt from the International Working Group).

3.0 Results and Discussion

The results of the analysis of the major element concentrations are presented in Table 3. They have a wide span of composition with ranges of silica, SiO_2 (52.98 - 74.23 %), MgO (0.09 - 4.02 %) and MnO (0.03 - 0.40 %) indicating varying protoliths.

Table 3: Major element data of rocks from Ado Ekiti.

	Granite gneiss						Charnockite				Mean
Oxides	1	2	3	4	5	6	7	8	9	10	11
SiO_2	71.29	70.29	74.23	65.64	66.69	69.52	52.98	62.09	53.38	59.39	64.55
Al_2O_3	13.49	14.70	12.08	13.15	15.11	13.59	15.76	16.38	15.94	16.43	14.66
K_2O	2.73	5.41	5.43	4.79	6.27	5.41	2.12	6.03	2.55	5.86	4.66
Na_2O	3.14	2.89	2.36	3.06	2.85	2.87	3.58	3.69	3.33	4.26	3.20
Fe_2O_3	3.67	2.71	3.34	6.76	4.31	4.15	10.75	6.06	10.36	8.76	6.08
MgO	0.96	0.66	0.09	0.89	0.57	0.57	4.02	0.47	3.98	0.15	1.24
CaO	2.88	2.02	1.19	2.94	1.89	2.27	7.30	2.74	6.95	3.11	3.33
P_2O_5	0.29	0.18	0.03	0.34	0.16	0.23	0.58	0.20	0.55	0.16	0.27
TiO_2	0.52	0.42	0.30	1.01	0.64	0.65	1.96	0.75	1.79	0.87	0.89
Cr_2O_3	0.01	Bdl	Bdl	Bdl	Bdl	bdl	Bdl	bdl	bdl	Bdl	-
MnO	0.03	0.03	0.06	0.12	0.05	0.06	0.14	0.40	0.15	0.20	0.12
LOI	0.48	0.15	0.15	0.38	0.35	0.37	0.05	0.54	0.26	0.31	
Sum of conc.	99.49	99.46	99.26	99.08	98.89	99.69	99.24	99.05	99.24	98.88	

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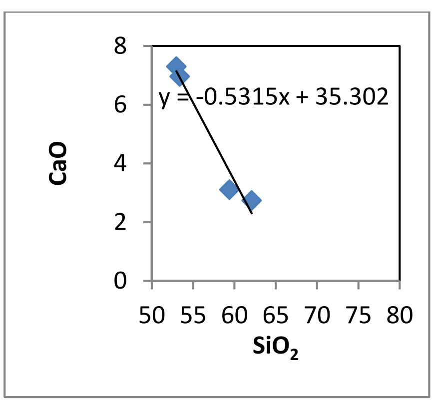
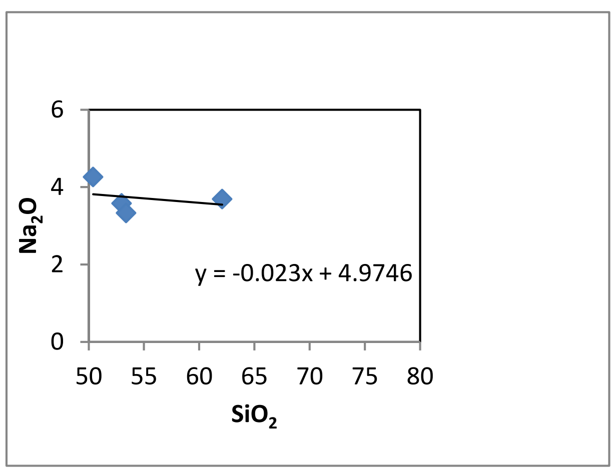
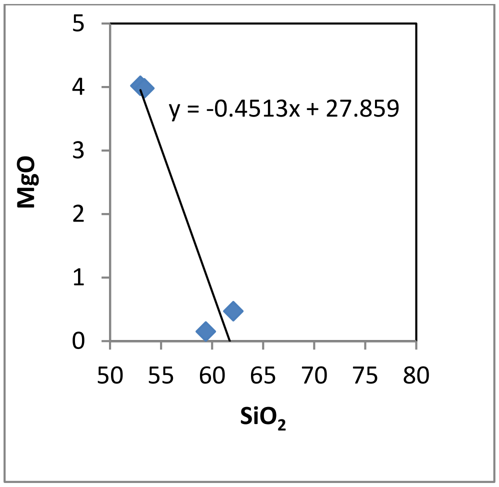
However, the first six samples (1-6) are more siliceous (65.64-74.23) than the last four samples (52.98 - 62.09 %) which are chanockitic. (Table 2).The alumina (Al_2O_3) content varies between 12.08 and 15.11% in the granite suite and between 15.76 and 16.43% in the chanockites. The values are as high as those of calc-alkaline rock series. The iron oxide (Fe_2O_3) contents in the granites vary from 2.71% to 6.76%, and from 6.06 to 10.75% in the charnockites. The immobile oxides of alumina, ferric iron and titania have higher concentrations than mobile oxides of K^+, Na^+, Ca^{2+} and Mg^{2+} (Table 2). The potash (K_2O) generally varies from 2,12 to 6.27 % in both granite and charnockites thus reflecting the feldspar abundance in the rocks. Iron content (Fe_2O_3) appears to vary widely between the granitic suite and the charnockitic suites. While the granites have values ranging from 2.71 to 6.76 , the charnockites have values of between 6.06 and 10.76 % displaying a relatively higher range. The ratio of Fe_2O_3/MgO ranges between 2.60 and 58.40% .The high iron ratio relatively reflects an abundant secondary opaque phase (magnetite). TiO_2 values are generally < 1 %, except in three samples of which two are in the charnockitic rocks. Those that are less than 1 are seemingly within the range accepted in calc-alkaline lavas of [4,5].The majority of samples in the granite suites have CaO values less than 3.0% and three samples in the charnockites show values that are higher than 3.0% showing relatively the presence of epidote and non-intensiveness of metamorphism in the areas under study [6].The average values of SiO_2, K_2O and MnO in granite and charnockites are higher than the crustal averages while the crustal averages are higher in Al_2O_3, Fe_2O_3, MgO, CaO, and TiO_2 (Table 4). The Na_2O abundances in the rocks range from 2.36 in the granite to 4.26 in the charnockites, while the ratio of Na_2O/K_2O (0.43- 1.68) is low when compared with the typical values of [7]for calc-alkaline rocks, thus reflecting a loss during alteration and metamorphism. Most of TiO_2 values are generally < 1 %, and therefore fall within the range accepted in calc-alkaline lavas of [4,5].

The Harker variation plots [8] for granite suites and charnockites indicate that most of the major elements in the rocks correlate with SiO_2.. Interestingly, Al_2O_3 and K_2O are strongly and positively correlated with SiO_2 in the charnockites. Al_2O_3 increases as SiO_2 decreases while Fe_2O_3, MgO, CaO Al_2O and Na_2O show negative linear trend with SiO_2 meaning that SiO_2 increases as Fe_2O_3, MgO, CaO Al_2O and Na_2O decrease (Fig.3). The variations in the correlation indicate fractionations in the magma systems that produced the rocks .



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2
1
0
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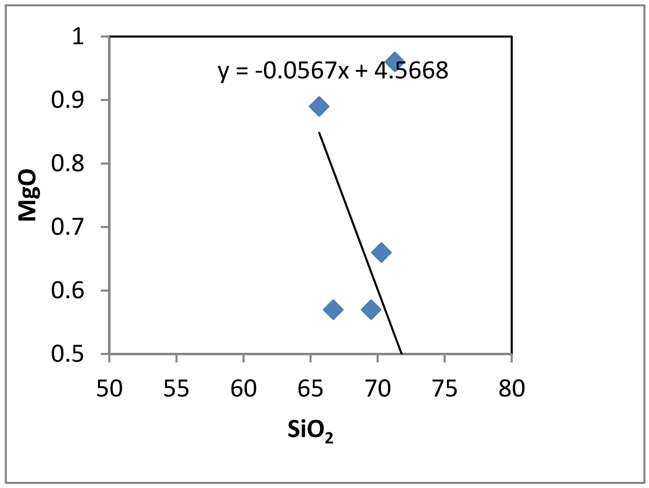
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0.7
0.6
0.5
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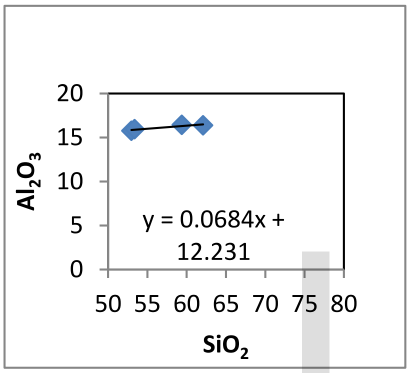
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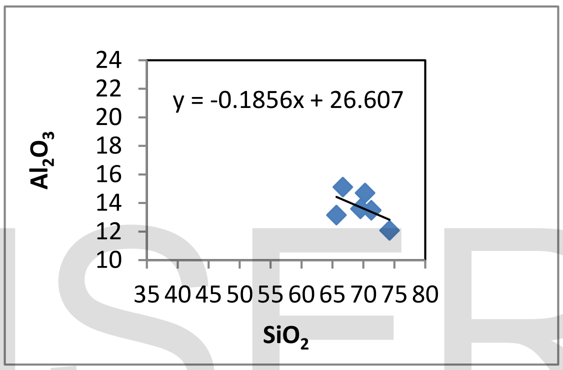
15
10
5
0
50 55 60 65 70 75 80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20
18
16
14
12
10
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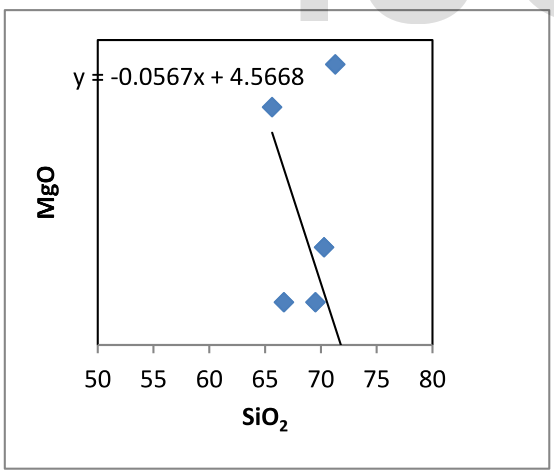
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SiO2
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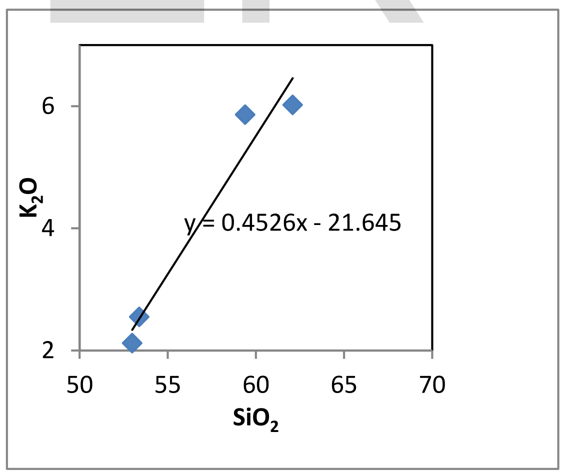
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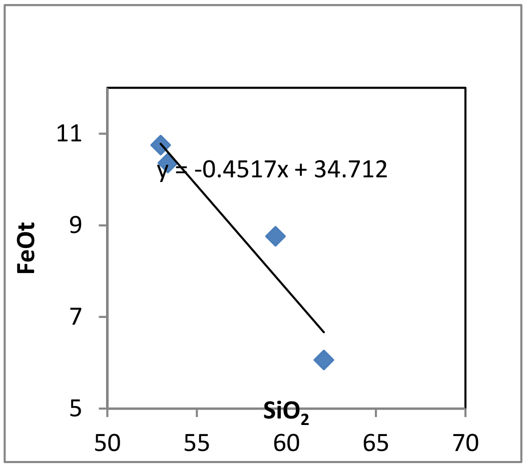
SiO2
6
4
2
50 55 60 65 70



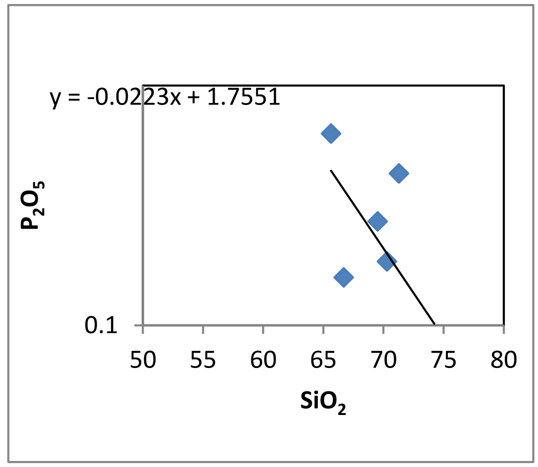


Fig.3.Harker variation plots of [8] silica (SiO2 %) plotted against a range of major elements for granite suite and charnockites of Ado Ekiti areas.

3.1 Geochemical Classification of the Rocks.

The ratios of Na_2O/K_2O, $Al_2O_3/Na_2O + K_2O + CaO$, $Na_2O + CaO + K_2O/ Al_2O_3$, and K_2O/ Na_2O for the various samples are shown in Table 4.

Table 4: Major oxides with some ratios.

Oxides	1	2	3	4	5	6	7	8	9	10	C.A
SiO_2	71.29	70.29	74.23	65.64	66.69	69.52	52.98	62.09	53.38	59.39	60.3
Al_2O_3	13.49	14.70	12.08	13.15	15.11	13.59	15.76	16.38	15.94	16.43	15.6
K_2O	2.73	5.41	5.43	4.79	6.27	5.41	2.12	6.03	2.55	5.86	2.5
Na_2O	3.14	2.89	2.36	3.06	2.85	2.87	3.58	3.69	3.33	4.26	3.2
Fe_2O_3	3.67	2.71	3.34	6.76	4.31	4.15	10.75	6.06	10.36	8.76	7.2
MgO	0.96	0.66	0.09	0.89	0.57	0.57	4.02	0.47	3.98	0.15	3.9
P_2O_5	2.88	2.02	1.19	2.94	1.89	2.27	7.30	2.74	6.95	3.11	0.11
CaO	0.29	0.18	0.03	0.34	0.16	0.23	0.58	0.20	0.55	0.16	5.8
TiO_2	0.52	0.42	0.30	1.01	0.64	0.65	1.96	0.75	1.79	0.87	1.0
Cr_2O_3	0.01	Bdl	Bdl	Bdl	Bdl	bdl	Bdl	Bdl	bdl	Bdl	-
L.O.I	0.03	0.03	0.06	0.12	0.05	0.06	0.14	0.40	0.15	0.20	-
MnO	0.48	0.15	0.15	0.38	0.35	0.37	0.05	0.54	0.26	0.31	0.10
Sum of conc.	99.49	99.46	99.26	99.08	98.89	99.69	99.24	99.05	99.24	98.88	-
Na_2O/ K_2O	1.15	0.53	0.43	0.64	0.45	0.53	1.68	0.61	1.31	0.72	-
$Al_2O_3/Na_2O+CaO+ K_2O$	1.54	1.42	1.35	1.22	1.37	1.29	1.21	1.37	1.24	1.24	-
Na_2O+K_2O	5.87	8.30	7.79	7.85	9.12	8.28	5.70	9.72	5.88	10.12	-
$Fe_2O_3/ Fe_2O_3+ MgO$	0.79	0.80	0.97	0.88	0.88	0.87	0.73	0.93	0.72	0.98	-

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Al_2O_3/Na_2O+K_2O	2.29	1.77	1.55	1.68	1.66	1.64	2.76	1.68	2.71	1.62	-

CA= Crustal average [9] .

The ratio of Na_2O/K_2O in both rocks varies from 0.43 in the granite suite to 1.68 in the charnockitic rock. Rocks with low values of CaO (0.03-0.58), MgO (0.09-4.02), as well as low ratio Na_2O/K_2O (0.43-1.65) are attributes of peraluminous rocks [10,11]. Rocks whose alumina saturation index (ASI) defined by molecular ratio Al_2O_3/ CNK > 1.1 are said to be peraluminous. However, few of the samples using the ASI plotted in the peraluminous S-type field while the rest plotted in the metaluminous I-type field (Figure 4). The ratio of K_2O/ Na_2O ranges between 0.59 and 2.30 and when the ratio K_2O/ Na_2O > 1 and $K_2O > Na_2O$, it implies that such rocks do not possess the characteristics of a sedimentary origin, but shows that the K-bearing minerals are more than the Na -plagioclase (albite) in the rocks. The plot of Al_2O_3 /(Na_2O + K_2O) versus Al_2O_3/(Na_2O +K_2O +CaO) of [12] indicates that the samples plotted in both peraluminous and metaluminous fields all suggesting to a mixed sources of origin (Fig.4). Peraluminous granites contain crustal or sedimentary materials in their original magma [13] and they are characterized by the presence of moderate silica, microcline, plagioclase, biotite and mica minerals. The highly metaluminous nature of the rocks suggest a source rock that is dehydrated and which have a lower crustal characteristics [14,15] .

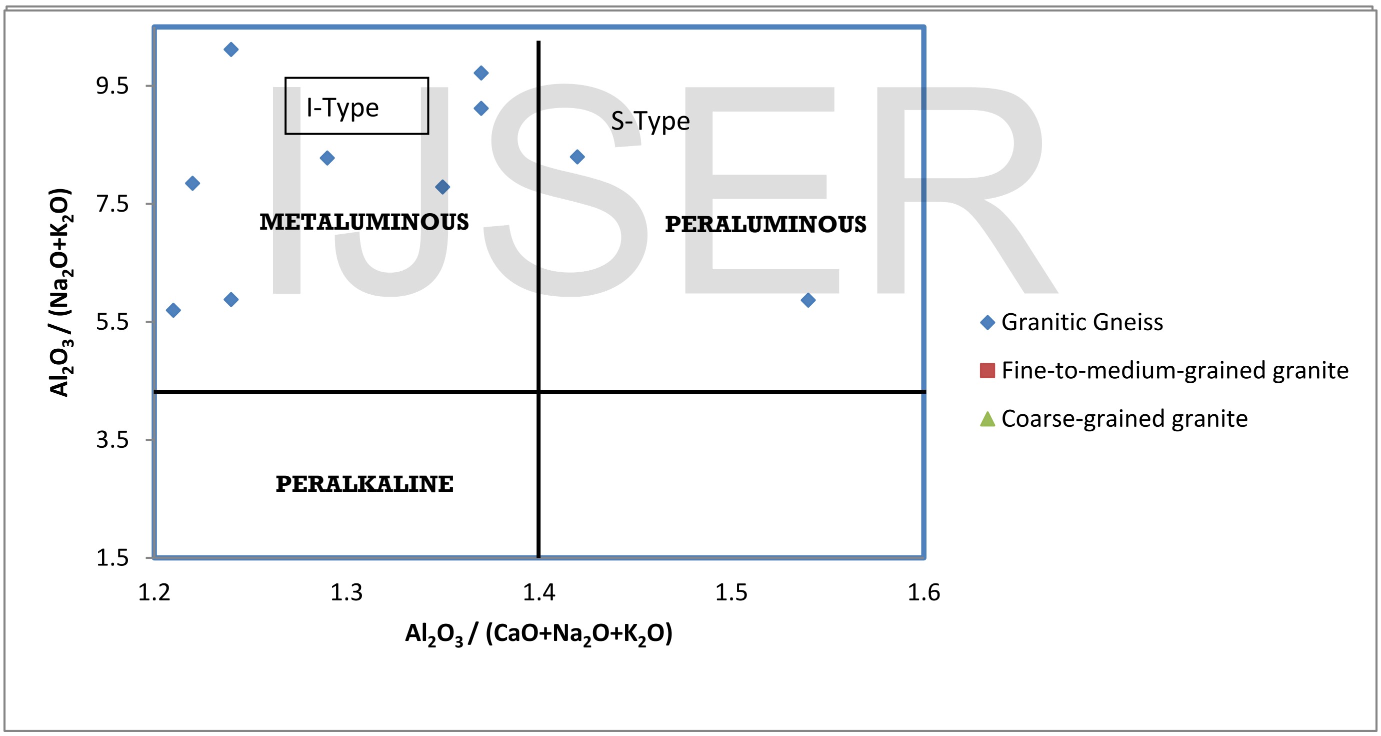

Fig.4 : Al_2O_3 /(Na_2O + K_2O) versus Al_2O_3/(Na_2O +K_2O +CaO) molecular plot [12] .

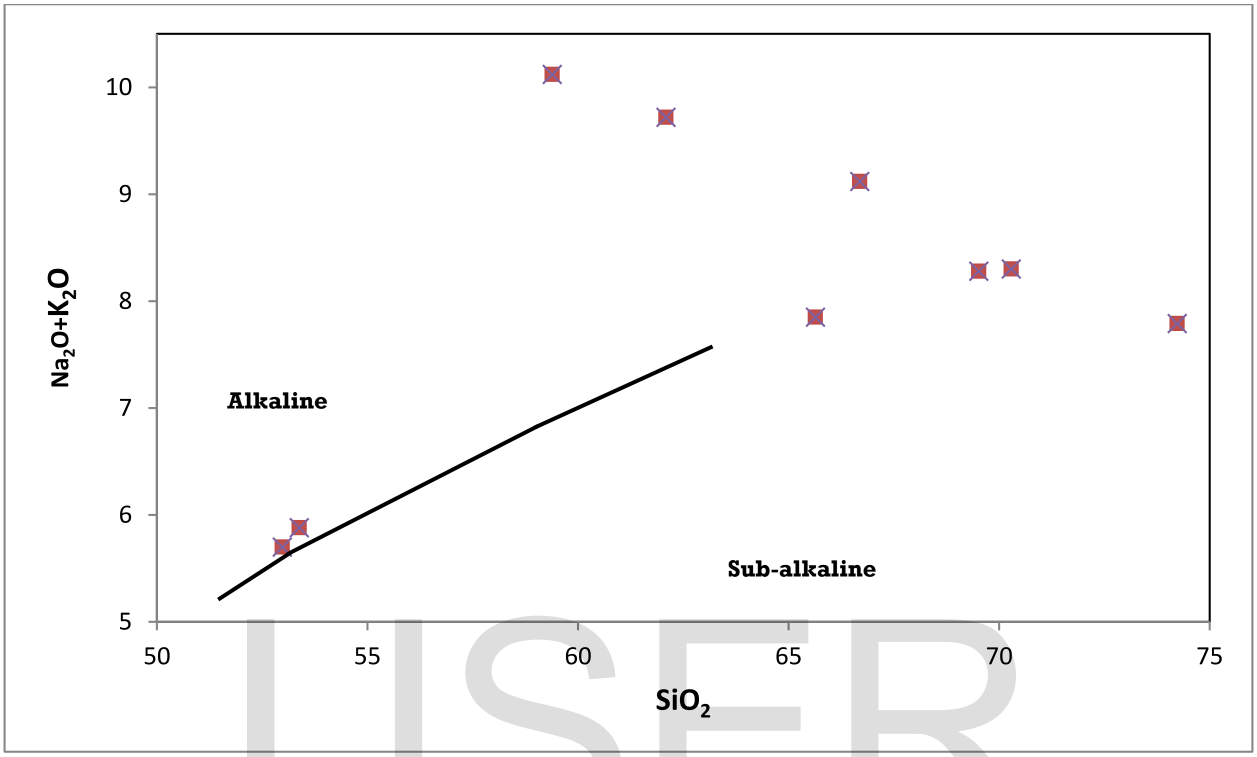

Fig. 5. Alkali-SiO_2 discrimination diagram for the Ado Ekiti rocks [4]

The magmatic rock types as defined by the plot of Na_2O+ K_2O versus SiO_2 diagram of [4] display alkaline to slight sub-alkaline affinity (Fig.5) **.**

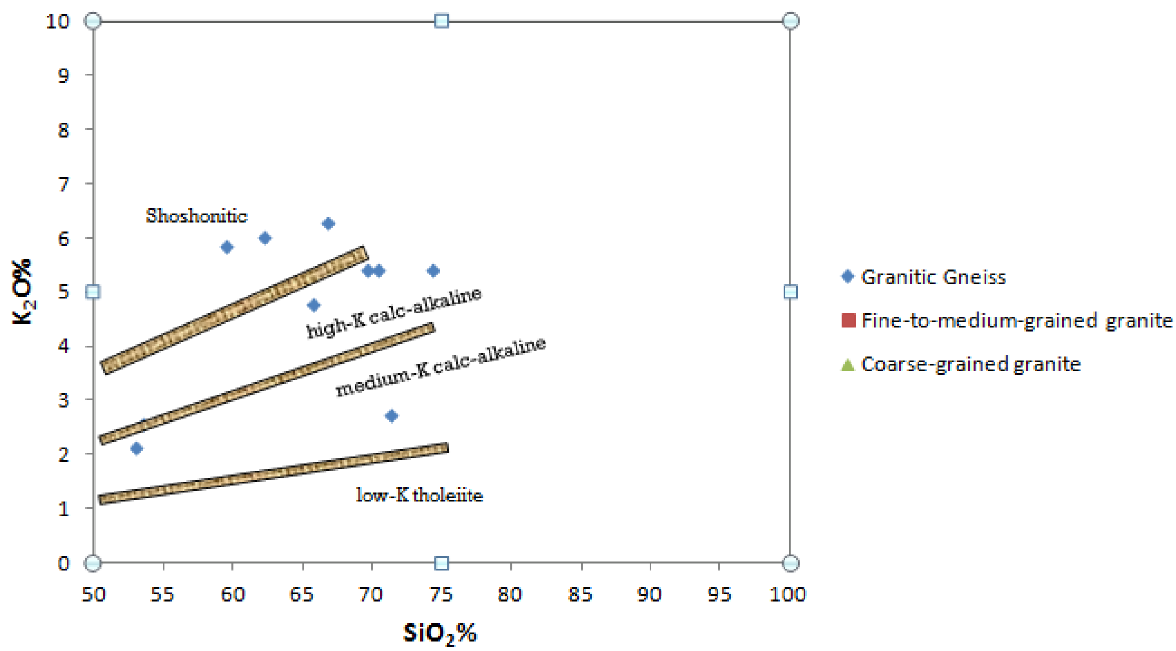

Fig.6: Plot of K_2O versus SiO_2 of [16] .

The plots of K_2O versus SiO_2 [16] indicate that the granites and charnockitic rock samples fall into shoshonite , high- K calc-alkaline, and medium -K calc alkaline fields respectively (Fig.6). [17,18] reported that all granites are products of partial melting of hydrous calc-alkaline to high -K calc-alkaline mafic within the crust.

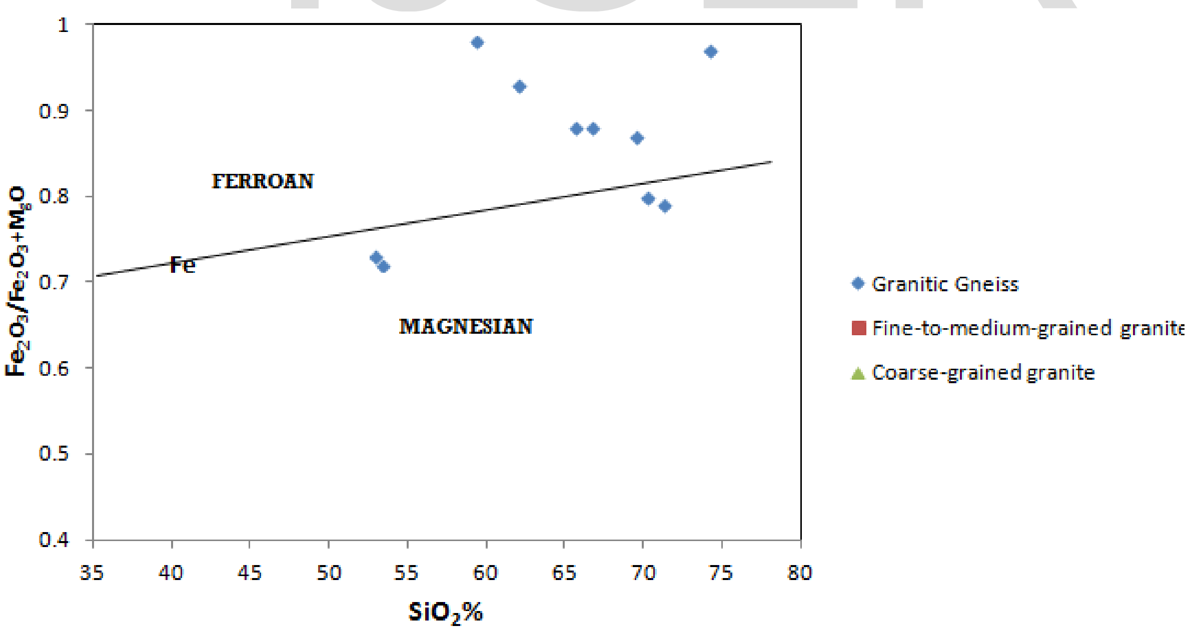

Fig.7: A plot of ratio Fe_2O_3 / Fe_2O_3 + MgO versus SiO_2 [19] .

The plot of Fe_2O_3/Fe_2O_3 + MgO against SiO_2 show that both the charnockite and granitic rocks fall in the fields of ferroan (Fe-enriched) and magnesian (Fig.7). The rocks that are of the magnesian type of granitoids are related to cordillerian types of granitic rocks [20]. Ferroan and magnesian are two out of the four families that belong to the fieldspathic rocks. [21] .The other two are the leucogranites and potassic and ultrapotassic rocks. Rocks which have Fe-number < 0·5 means that Mg is molecularly more abundant than Fe, though, there may be exceptions. The plots of Fe_2O_3/Fe_2O_3 + MgO against SiO_2 in Figure 7, show more of the ferroan than the magnesian in the porphyritic granite and charnockitic rocks. [22] pointed out that ferroan granitic rocks are associated with low oxygen fugacity during melting. [22,23] pointed that most Fe-rich rocks form by differentiation or partial melting of basaltic parents. Some of the rocks under study are mafic containing mafic minerals; biotite, hornblende, pyroxene and plagioclase feldspar.

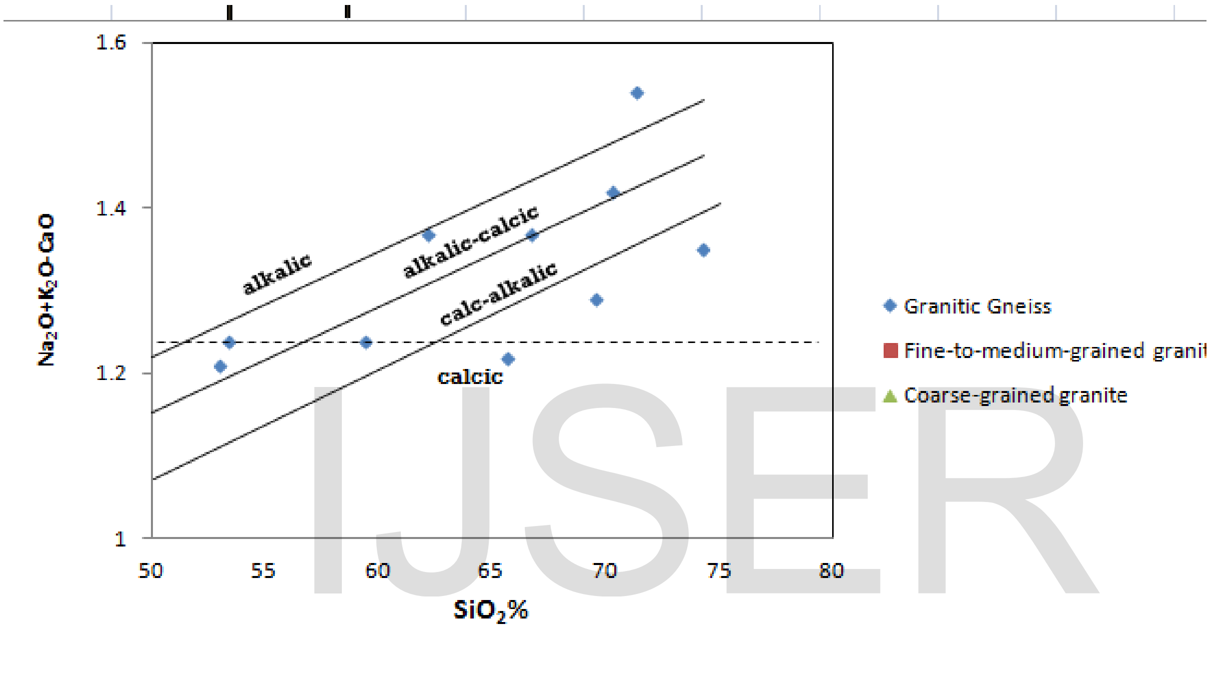

Fig.8: Na_2O+K_2O-CaO versus SiO_2 plot [19] .

On the plot of Na_2O+K_2O-CaO versus SiO_2 , the rock samples aggregated in the calcic, alkalic - calcic and calcic alkalic fields in line with the modified alkali –lime index (MALI) classification. The MALI has been used to classify volcanic suites into four as in the plot of Fig.8.When the SiO_2 content at which Na_2O + K_2O in a suite of lavas is equal to CaO, those rock suites whose alkali–lime index > 61 are calcic, those that are between 56 and 61 are calc-alkalic, those between 51 and 56 are alkali–calcic and while those that is < 51 are alkalic. The modified alkali–lime index increases with increasing weight percent silica, SiO_2 and where MALI equals 0·0, the silica content is equivalent to the alkali–lime index of [24]. The variations in the MALI can be as a result of either differentiation history or source region of the magma that formed the rocks [19] . However, the calc-alkalic nature of the granitic and charnockitic rocks along with the characteristics of the within plate affirm their different magma sources.

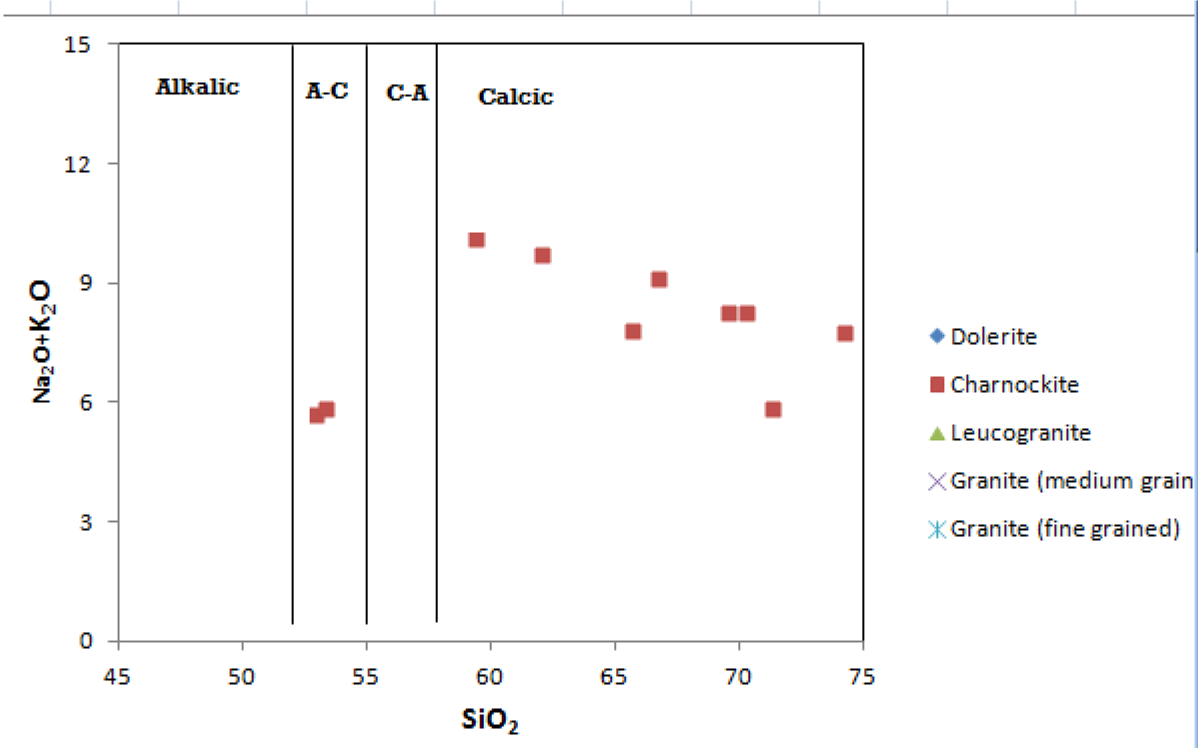

Fig. 9: Classification of rocks based on $Na_2O + K_2O$ against SiO_2 [24]

3.3 Alteration and Element Mobility

Table 4 shows that most of the major oxides: MgO, K_2O, CaO and Na_2O have low concentrations and therefore seem to be altered to some extent due to either low-grade metamorphism or extensive deformations, as reflected in the contents of the more mobile elements even though [25,26] were of the opinion that the geochemical signatures of the present day rocks may not be the same as the protoliths at the time of formation. However, to actually present the possible alteration effects of metamorphism, we refer to the element mobility using the plotted major oxides against silica in Figure.3. In Harker diagram shown in Fig.3,the major compatible oxides, MgO, Fe_2O_3, Al_2O_3, K_2O and CaO have normal, correlated and continuous differentiation trends, as they tend to decrease systematically with SiO_2 increases. Al_2O_3 and K_2O tend to increase with decreasing SiO_2. It is observed that the positive trend exhibited by Al_2O_3 against SiO_2 occurred only in the Charnockite samples. This scenario suggests that pyroxene, magnetite (opaque mineral), and Ca- plagioclase were major fractionating phases during the evolution of the magma. Table 4 indicates high enrichment of immobile elements Fe_2O_3 and Al_2O_3 and depletion of MgO, K_2O, CaO and Na_2O an indication that a chemical breakdown of some minerals in the rocks have occurred resulting in the formation of hydroxyl group and subsequent removal of soluble cations of K^+, Na^+, Ca^+ and Mg^{2+} [27]s. However, workers like [28,29,30,31,32,33] have related the mobility of elements to the mineral breakdown with the progressive weathering apart from other factors like solubility of parent mineralogy, pressure, temperature, redox potential and they suggested that the type of leaching agents generally control the mobility of elements during weathering [27] .

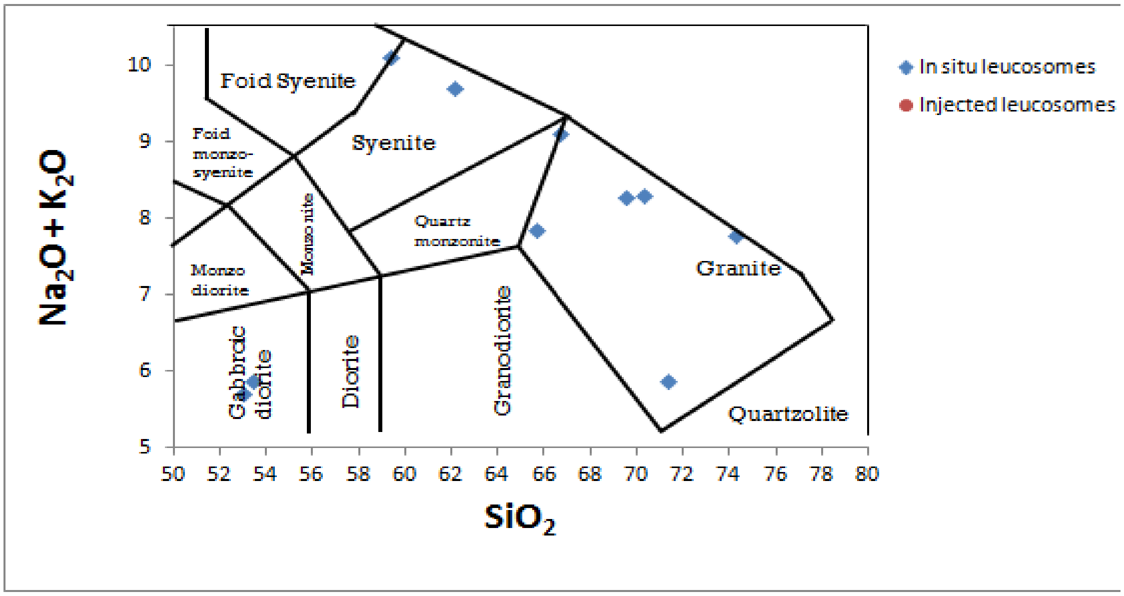

Fig.10: Total Alkali (Na_2O+ K_2O) versus Silica (SiO_2)

A plot of the alkali against silica in Fig.10 shows an Older granite suite that contains granite, syenite and gabbroic diorite types of rocks, the implication of which is the different rocks of the same petrogenic family

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3.4 Trace element geochemistry

The abundances of trace and rare earth elements are presented in Table 5. The incompatible trace elements show variations in the rocks. For example, Ba varies from 564.41 to 1336 ppm (average 950.21ppm) on the granite side and from 241.95 to 1425.72 ppm on the charnockite side (average =833.81ppm). These average values are higher than the average crustal values of [9] implying thus an anomaly (Table 5). In some deposits for example in Omolayo area, the granite and the charnockites are inseparable in the deposit.

Table 5: Trace and Rare Earth Elements Geochemistry (ppm).

Element	1	2	3	4	5	6	7	8	9	10	11	12
Sc	9.39	8.58	8.24	15.55	8.84	11.16	20.28	13.9	21.0	18.76	**22**	13.58
V	37.79	29.15	8.75	38.76	27.58	29.1	153.78	15.50	156.89	8.77	135	50.62
Cr	47.59	36.44	27.46	35.42	32.96	49.03	39.99	38.86	59.76	27.21	**100**	39.47
Co	7.54	4.60	1.29	7.85	4.64	6.05	31.77	4.73	29.70	2.58	**25**	-
Ni	17.40	10.05	9.74	14.58	11.71	14.02	53.60	11.12	60.48	10.73	**75**	21.34
Cu	20.64	19.08	35.65	27.98	18.68	25.57	45.81	27.66	32.37	20.29	**5 5**	**5 5**
Zn	62.28	38.60	77.01	105.27	54.29	62.96	117.06	98.59	110.93	131.92	**70**	85.88
Rb	102.37	159.61	208.46	116.42	229.27	152.31	49.20	99.05	74.20	82.67	**90**	127.36
Sr	473.78	604.27	129.74	155.91	223.16	236.51	452.71	206.5	412.28	97.23	**375**	305.21
Y	9.61	8.10	51.79	86.38	37.88	47.82	39.60	34.67	8.98	9.42	**33**	-
Zr	288.97	283.22	501.72	1137.51	701.19	791.92	395.65	1324.43	393.99	2239.91	**165**	804.85
Nb	9.58	11.43	22.70	60.10	20.68	33.91	24.23	42.55	23.80	54.94	**20**	-
Mo	5.11	1.54	27.28	6.77	3.47	7.00	3.34	8.67	4.00	4.64	-	-
Cs	1.51	1.26	0.20	0.63	1.06	0.30	0.29	0.26	0.46	0.17	**3**	-
Ba	564.41	1336.42	1031.26	700.64	1308.55	1048.27	241.95	1425.72	801.83	693.25	**425**	915.23
Pb	18.56	29.21	49.74	26.07	30.89	26.25	14.24	24.77	13.98	19.86	**13**	25.36
Th	26.28	37.42	119.46	41.66	100.65	21.11	4.70	20.89	2.51	3.78	**9.6**	-
Ta	0.42	0.60	0.76	3.18	0.63	1.65	1.45	1.78	1.28	2.00	**2**	-
Hf	7.86	7.57	14.19	19.55	17.40	19.31	9.70	29.53	9.43	48.96	**3**	-
La	62.49	7.78	142.36	194.17	367.17	113.86	67.21	120.35	62.45	53.42	**30**	-
CS	1.51	1.26	0.20	0.63	1.06	0.30	0.29	0.26	0.46	0.17	**3**	-
U	1.43	3.25	3.31	5.05	1 .92	3.25	0.99	2.30	0.88	1.52	**2.7**	-
Y/Nb	1.0	0.71	2.28	1.44	1.83	1.41	1.63	0.81	0.38	0.17	-	-
Nb/Y	0.99	0.99	0.44	0.69	0.54	0.71	0.61	1.22	2.65	5.83	-	-
La/Th	2.38	0.21	7.32	4.66	3.64	5.39	14.3	5.76	24.88	14.13	-	-
La/Y	6.50	6.50	2.75	2.25	9.69	2.38	1.69	3.47	3.47	5.67	-	-
La/Sc	6.65	0.91	17.27	12.82	41.53	10.20	3.31	8.61	2.97	2.84	-	-

Numbers 1-10: (Present study), 11 , (Crustal average ,Taylor 1964) , 12 average value (present study); 1-6 = granites and 7-10 charnockites from the field work.

The values of Sr ranges from 97.23to 604.27 ppm, Y (8.10-111 ppm) and La (7.78 - 194.17 ppm), Zn (38.60 -131.92 ppm), Th (2.51-119.46 ppm), Ni (9.74 – 60.48 ppm) and Zr (283.22 -1324.43 ppm). The Cr varies between 27.21 and 59.76 ppm and it is generally low. The mean value (39.47) is less than the crustal average (100). The mean values of Sc (13.58), V (50.62), Cr (39.47), Ni (21.34), Cu (27.37) and Sr (305.21) are all lower than the crustal averages of 22, 135, 100, 75, 55 and 375) respectively whereas Zn (70), Rb (90), Zr (165), Ba (425) and Pb (13) crustal values are greatly lower than the mean values of the elements. (It is observed that Zr and Ba are anomalous. Table 5 shows depletion of Sc, V, Cr, Ni, Cu and Sr elements as well as Na, Ca is due to their lost in solution when feldspars are weathered to clay minerals. Other element abundances are, La (7.78 ppm), Nb (9.58 - 60.10 ppm), Pb (14.24-49.74), Th (3.78-100.65) and U (0.88-5.05). The ratios of Nb/Y (0.99-5.83), Y/Nb (0.38- 2.28), La/Sc (0.91-6.65) La/Th (0.21-24.88) and Nb/Y 0.96-6.50) respectively are shown in Table 5. However, Y/Nb is < 1.0 in the charnockitic rocks and is typically calc-alkaline [34] . It is observed that in four of the sampling sites the values of Sr are higher than the crustal value and such rocks show feldspar accumulation [35] and they are also felsic S-Type granites. [36] reports that when the values of La/y < 1 it implies the prevalence of acidic condition and when La/y > 1, it indicates basic conditions. In consonant with this report, only the sample in location 2 is less than one (1) (0.96) whereas in other samples the values are greater than one showing basic conditions of formation.

A plot of the alkali against silica in Figure== shows a Pan African complex that contains granite, syenite and gabbroic diorite types of rocks, the implication of which is the different rocks of the same petrogenic source.

3.5 Provenance and Tectonic Discrimination

The granites and charnockites of Ado Ekiti plot in both the within plate and arc fields of Rb-(Y+ Rb) discrimination diagram of [37] (Figs 11,12). The volcanic arc and within plate environment affinities for the rocks are confirmed by the tectonic discrimination plot of Nb against Y [37].

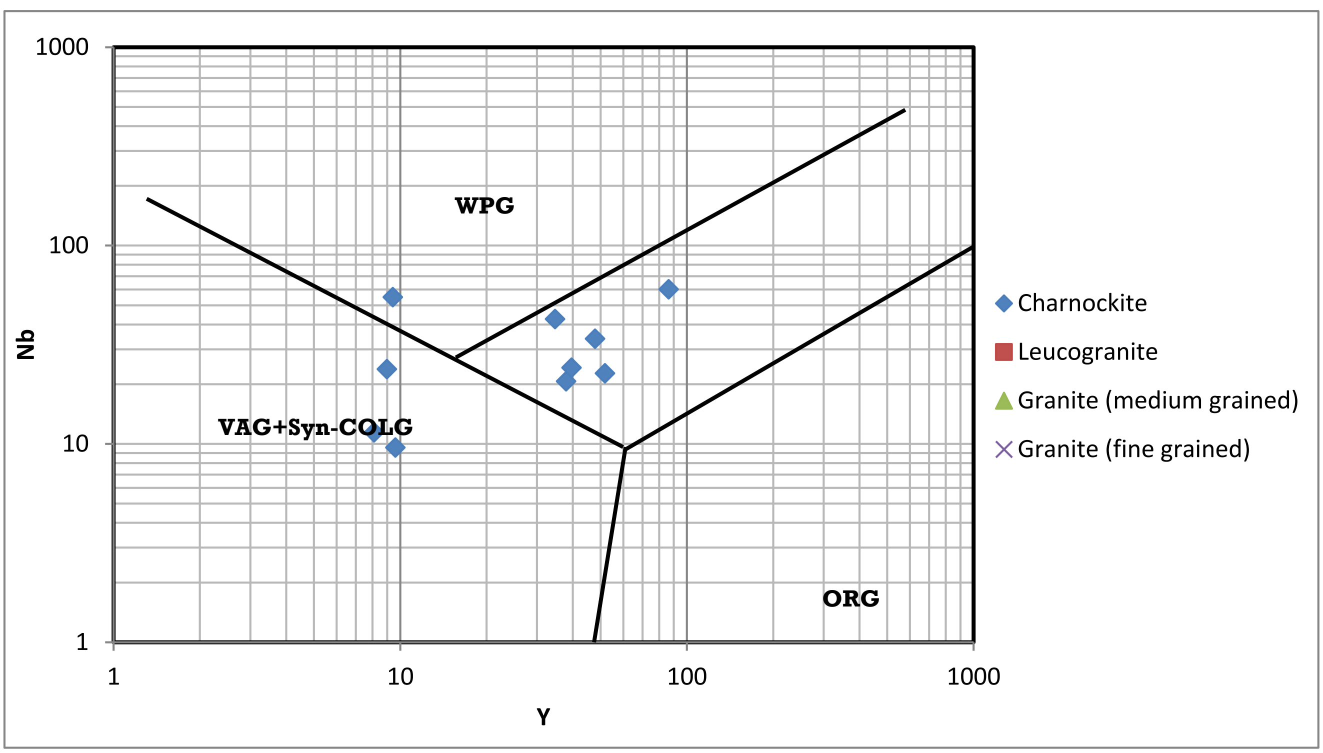

Fig.11: Nb-Y discrimination diagram of rocks from Ado Ekiti areas [37] Syn-COLD= Syn-collision granites; VAG= Volcanic Arc granites; WPG=Within plate granites; ORG= Ocean ridge granites.

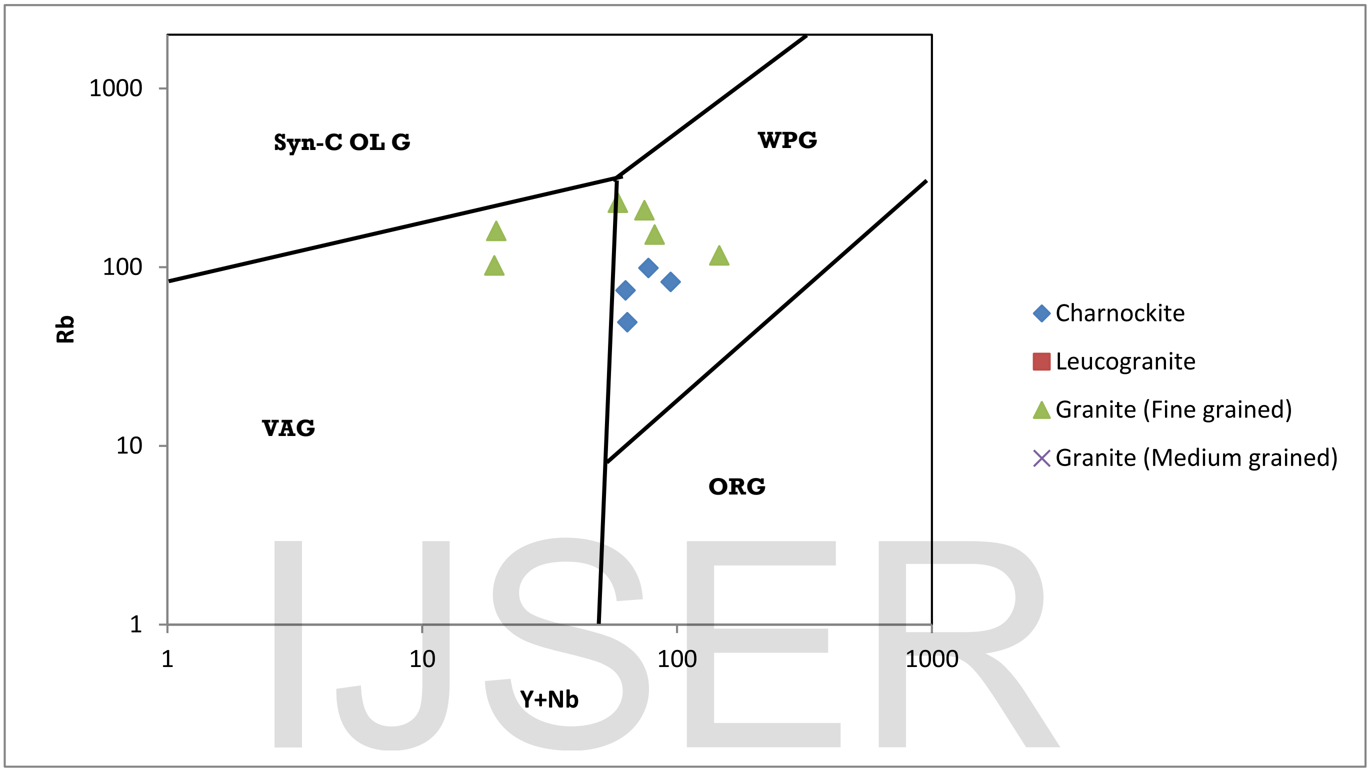

Fig.12: Rb-(Y+Nb) discrimination diagram for the rocks in Ado Ekiti [37]. VAG=Volcanic arc granite; Syn-COLD= Syn-collision granite; WPG=Within plate granite; ORG= Ocean rigde granite.

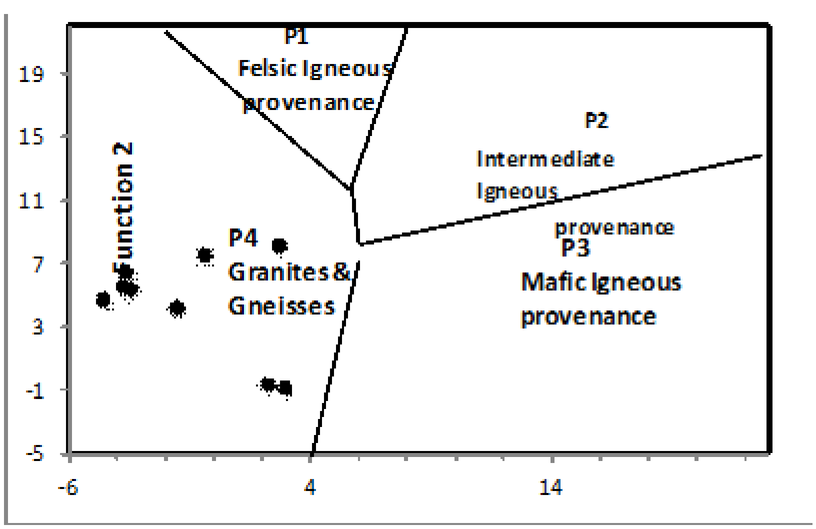

Fig. 13: Discriminant function diagram for provenance signatures of Ado Ekiti rocks [38] .

[38] used discriminant function plots in Figure 13 to define four (4) main provenances: mafic igneous provenance; intermediate igneous provenance; felsic igneous provenance; and granites & gneisses provenance. The major oxides plotted in the granite & gneissess igneous provenance field showing that they are derived from a magmatic source.

4.0 CONCLUSIONS

The geochemistry of granites and charnockites from Ado Ekiti shows crystallization from both peraluminous and metaluminous melts. These rocks are both alkaline and subalkaline using classification scheme. The schemes also classified the rocks from Ado Ekiti as forran (Fe-rich) and magnesian. Most alkaline rocks are forran and forran related granite. Magnesian rocks have poor iron enrichment relative to forran rocks but both forran and magnesian rocks are of the family of feldspathic rocks. Forran rocks are those whose evolved magmas are from intraplate environments [39]. They are mafic and felsic having mafic silicate minerals such as biotite, hornblende, pyroxene, and plagiocle feldspar in various proportions and felsic minerals such as quartz, muscovite orthoclase feldspar and albite . These rocks are formed from the granite clan of rocks from partial melting of basaltic rocks. The subalkaline rocks have evidence of crystal fractionation from magmatic melts. Interestingly, Al_2O_3 and K_2O are strongly correlated with SiO_2 in the charnockite as Al_2O_3 increases with decrease in SiO_2 . Variation diagrams indicate that Fe_2O_3, MgO, CaO Al_2O and Na_2O show negative linear trend with SiO_2 and SiO_2 increases as Fe_2O_3, MgO, CaO AL_2O and Na_2O decrease. The decrease in MgO, CaO AL_2O and Na_2O with increasing SiO_2 is an evidence of fractionation .

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REFERENCES

[1] Ajibade,A.C. 1982.Origin and emplacement of the Older granites of Nigeria: some evidence from Zungeru region. Nigeria. Journal of Mining and Geology.19 (1) 221-230.

[2]Oyinloye,A.O.2004.Petrochemistry, Pb isotopes sytematics and geotectonic settings of the granite gneiss in Ilesha schist belt, Southwestern Nigeria. Global Journal Geol.Sci.2 (1). 1- 13.

[3] Fairchild I., Graham H., Martin Q., Maurice T. 1999.Chemical Analysis of Sedimentary Rocks in:Technique in Sedimentology (ed. T. Maurice). pp. 274-354.

[4] Irvine, T. N. and Barager, W. R. A., 1971. A guide to the chemical classification of the common volcanic rocks. Canadian Journal of Earth Science. 8: 523-548.

[5] Pearce J.A., Cann J.R. 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth and Planetary Science Letters, 19, 290-300. http://dx.doi.org/10.1016/0012-

[6] Jakes, F. and White, A. J. R., 1971. Composition of island arcs and continental growth. Earth Planet. Sci. Lett. 12: 224-230.

[7] Jakes, P. and White A. J. R., 1972. Major trace element abundances in volcanic rocks of orogenic areas. Geol. Soc. Am. Bull. 83: 29–40

[8] Harker, A. 1909. The natural history of igneous rocks. Macmillan, New York. 9p

[9] Taylor, S. R. 1964: Abundance of chemical elements in the continental crust: A new table. Geochim. Cosmochim. Acta, 28, 1273-1285.

[10] Cerny P., Trueman D.L., Zaehlke D.V., Goad B.E., Paul B.J. 1981. Catlake-Winnipe River and the Wekusko lake pegmatite fields, Manitoba. Energy and Mines, Economic Geology.Vol.80, 216-219

[11] Longstaffe F.J. 1982. Stable isotope in the granite pegmatite and related rocks. Mineralogical Association of Canada.Short course Handbook. Vol. 6. 373-404.

[12] Maniar P.D., Piccoli P.M. 1989. Tectonic discrimination of granitoids. Geological Society of America Bulletin 101, 635–643.

[13] Wilson, M. (1991): Igneous Petrogenesis Global Tectonic Approach, Harpar Collins Academy, London Second impression pp. s227-241.

[14] Whalen, J.B, Currie, K.L, and Chappell, B.W (1987). A-type granites: Geochemical characteristics discrimination and petrogenesis.Contribution to Mineralogy and Petrology.95, 407-418.

[15] Frost, G.D.,Frost, B.R., Chamberlain, K.R and Edwards B.R. 1999. Petrogenesis of the 1-43 Ga Sherman batholith, SE Wyoming: a reduced rapakivi-type anorogenic granite. Journal of Petrology, 40, 1771-1802.

[16] Richwood P.C. 1989. Boundary lines within petrologic diagrams which use oxides of major and minor elements. Lithos. 22, 247-263.

[17] Roberts M.P and ClemensJ.D.1993. Origin of high potassium calc alkaline, I-type granitoids. Geology. Vol.21:825-828.

[18] Ukaegbu, V.U, 2003. The Petrology and geochemistry of parts of Obudu Plateau, Bamenda massif, Southeastern Nigeria.Unpublished .Ph.d theis, University of Port Harcourt, Nigeria.

[19] Frost B.R., Arculus R.J., Barnes C.G., Collins W.J., Ellis D.J., Frost C.D. 2001. A geochemical classification of granitic rocks. Journal of Petrology. 42,2033-2048.

[20] Shahabpour, J. (2007) Island-Arc Affinity of the Central Iranian Volcanic Belt. Journal of Asian Earth Sciences , 30, 652-665. https://doi.org/10.1

[21] Frost, B.R and Frost, C.D. 2008. A Geochemical Classification for Feldspathic Igneous Rocks . Journal of Petrology, Vol .49 (11),1955-1969.

[22] Frost, G.D and Frost, B.R. 1997. High -k iron enriched rapakivi type granite: the tholeiite connection.Geology, 25, 647-650.

[23] Loiselle, M.C and Wones, D.S 1979. Characteristics and origin of anorogenic granite.Geological Society of America. Abstract and programs.11, 468.

[24] Peacock M.A. 1931. Classification of igneous rock series. Journal of Geology 39, 54–67.

[25] Irvine, I. J. and Green. H., 1976. Geochemistry and Petrogenesis of the newer baslts of Victoria and South Australia. Journal of Geol. Soc. of Australia. 23 (2).

[26] Alfred, J.E and Michael, G.D.1989. Discrimination between altered and unaltered rocks at the Connemarra and Kathleen Au deposits, Western Australia. Jour.Geochem. Explor., 31. 237-252

[27] Sayyed,M.R.G.2014.Lithological control on the mobility of elements during chemical weathering. Comunicacoes Geologicas,101, (1),63-69.

[28] Colman, S. M., 1982. Chemical Weathering of basalts and andesite: Evidence from weathering rinds. U. S. Geological Survey Professional Paper, 1246, 43.

[29] Eggleton, R. A., Foundoulis, C., Varkevisser, D., 1987. Weathering of basalts: changes in rock chemistry and mineralogy. Clays and Clay Minerals, 35, 3, 161-169.

[30] Nesbitt, H. W., Wilson, R. E., 1992. Recent chemical weathering of basalts. American Journal of Science, 292, 740-777.

[31] Gavshin, V. M., Shcherbov, B. L., Bobrov, V. A., Solotchina, E. P., Sukhorukov, F. V., Mel'gunov, M. S., 1997. Behavior of trace elements in the process of formation of weathering profile on granites. Russian Geology and Geophysics, 38, 7, 1264-1276.

[32] Hill, I. G., Worden, R. H., Meighan, I. G., 2000. Yttrium: the immobilitymobility transition during basaltic weathering. Geology, 28, 10, 923-92.

[33] Patino, L. C., Velbel, M. A., Price, J. R., Wade, J. A., 2003. Trace element mobility during spheroidal weathering of basalts and andesites in Hawaii and Guatemala. Chemical Geology, 202, 343-364.

[34] Garcia, M .O. 1978. Criteria for identification of ancient volcanic arc. Earth and Planetary Science Letters. 14: 147–165

[35] Chappell, B.W and White, A.J.R. 1998. Development of P-rich granites by sequential restite fractional crystallisation: The Koetong suite in the lachlan fold belt. Acta Universisttatis Carolinae Geologica.42.23-27.

[36] Maksimovic, Z.; Panto, G. Contribution to the geochemistry of the rare earth elements in the karst- bauxite deposits of Yugoslavia and Greece. Geoderma 1991, 51, 93–109.

[37] Pearce J.A., Harris N.B.W., Tindle A.G. 1984.Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology. 25: 956-9

[38] Roser B.P. Korsch R.J. 1988. Provenance signatue of sandstone-mudstone determine using discriminant function analysis of major element data. Chem. Geol, Vol.67:119-139

[39] Duchesne, J D and Wilmart, E.1997.Igneous charnockites and related rocks from the Bjerkeim Sokndal layered intrusion (Southwest Norway): a jotunite (hypersthene monzodiorite) derieveda-type granitoid suite. Journal of Petrology. 38, 337-369

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