Geochemistry, Classification and Geotectonic study of the Basement Rocks Around Orin -Ekiti, South West, Nigeria.

Obasi, Romanus Ayoola
Department of Geology. Ekiti State University,
PMB 5363, Ado-Ekiti, Ekiti State Nigeria.
Corresponding author: E.mail: romanus.obasi@eksu.edu.ng,
Phone number: 07032448351

Abstract

Rock geochemistry, classification and geotectonic setting of the basement rocks of Orin Ekiti are studied using data analysed by X-ray fluorescence (XRF) at the Central laboratory of Stellenbosch University, South Africa. The data revealed an unusually low (40.13--40.77%) and moderate (52.10--70.22%). SiO_2 contents that correspond to approximately basic (40-52wt %) and acid (> 66.0 wt %) rock compositions respectively in the rock suite. CaO contents range from 1.71 to 12.38. SiO_2, CaO and Na_2O + K_2O relatively show a contrasting variation, where CaO decreases with increasing SiO_2 and Na_2O + K_2O. Harker variation plots of oxides; NaO_2 MgO, TiO_2, Fe_2O_3, Al_2O_3, CaO with SiO_2, showed a negative trend while K_2O showed a positive linear trends with SiO_2. The variation in the trends suggest different sources of materials mixed up in the rocks during metamorphism. An analysis using the aluminium saturation index (ASI) defined by molecular ratio $Al_2O_3/Na_2O+CaO+K_2O$ reveal that the ratio (0.8 and 1.52) displays two contrasting data where four samples 1, 2, 3 and 10 are less than one (1.1) and six samples (4-9) are greater than unity (1.1) implying that some of the basement rocks are metaluminous (I-Type) while others are peraluminous (S-Type) granitic rocks thus collaborating with mixed sources of materials. The rocks under study can be classified as calcic, alkalic and calc-alkalic based on the crossplots of Na_2O+K_2O versus SiO_2. They are granite, quartz monzonite, gabbroic diorite and the granodiorite based on the plot of Na_2O+ Na_2O against SiO_2. Some of the rocks are iron -rich (ferroan) while others are magnesium rich (magnesian) . A plot of K_2O/Na_2O versus SiO_2 classified the geotectonic setting of the rocks into the passive margin and the oceanic island arc .

Keywords: Mixed sources, metaluminous (I-Type) , peraluminous (S-Type), passive margin and oceanic island arc.

1.0 Introduction

The study area is underlain by crystalline rocks of the basement complex of the Southwest Nigeria comprising majorly granite gneiss, migmatites gneisss, charnockites, Older granites, (granitoids) and medium to coarse- grained banded gneiss. Some scholars have suggested that probably individual granitic rocks have a simple source of origin using the chemistry of the rocks. However, scholars such as [1] proposed that in reality granitoids (field term for light granites) rarely come from single sources, but instead are mixtures of mantle-derived mafic melts and melts of crustal rocks that may or may not contain metasedimentary components. This has prompted the classification of granites into ‘type’ S- and I-type by authors like [2] who have studied rocks such as the Lachlan Fold Belt. [3, 4] suggested also that granitic rocks crystallize into a broad spectrum of compositions such that significant overlap exists between I-types and S-types.[5] has for long introduced more detailed classifications, but none has achieved wide use. Granites can be differentiated by chemical, mineralogical or field observations. [6] recognized two distinct granitoid types, the I-type metaluminuos formed from a mafic metaigneous source and the S-type peraluminuous formed from the melting of metasedimentary rocks) in their geochemical schemes for classification of granitic rocks. The present study has been invoked by this existing overlap between the I and S types of granites in proffering the classification of granites in Orin- Ekiti.

1.2 Geomorphology.

The study area lies between latitudes 7° 48' and 7° 72'N and longitudes 5° 10'E to 5° 36'E. The area is agrarian and most people are farmers and some live in the settlements within which the samples were collected. The landform rises from lowland to an elevation of about 640 meters as shown in Fig 2 which is the interpolated elevation map of Orin Ekiti area.

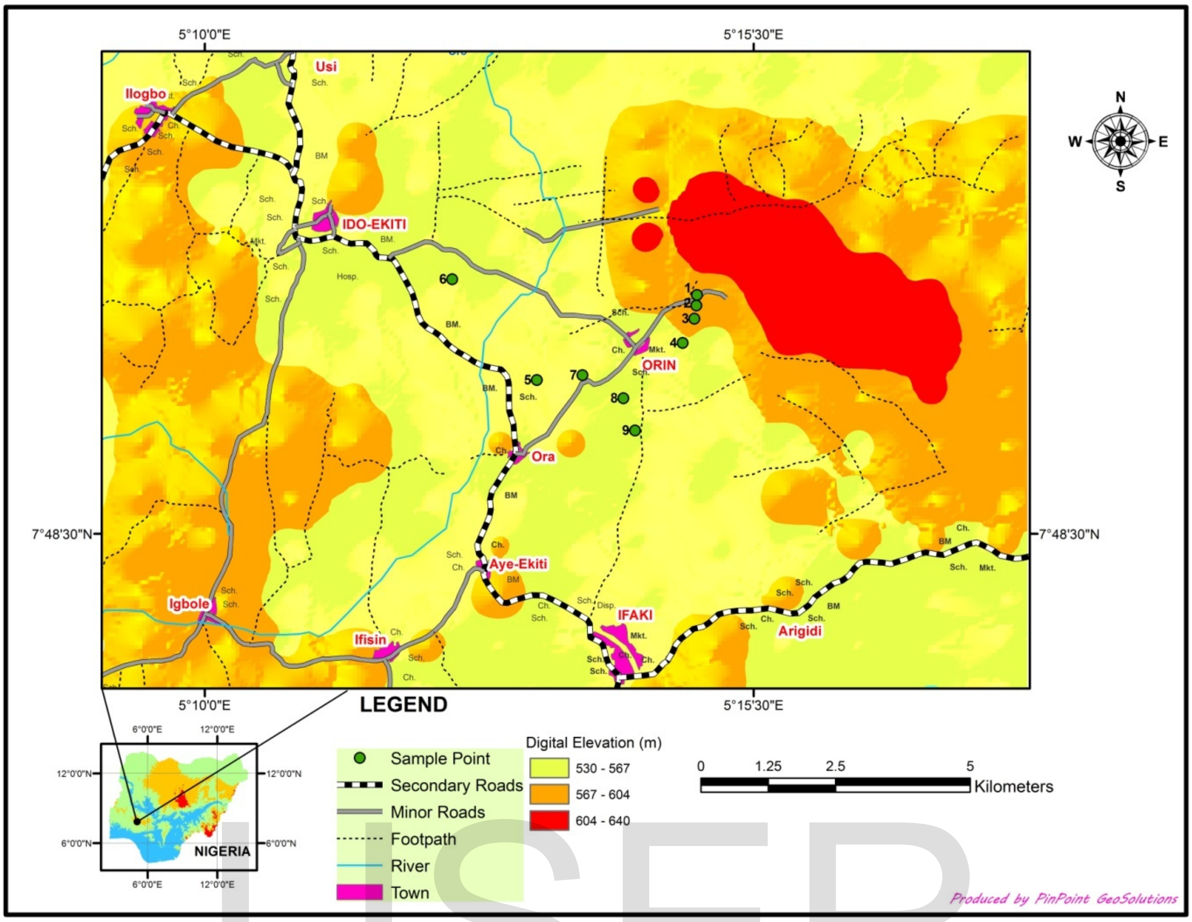


Fig 2: The interpolated elevation map of Orin Ekiti

2.0 Methods and Materials

Ten samples of different rock types were collected as shown in the topographical map (Fig 1) of Orin Ekiti and environs.

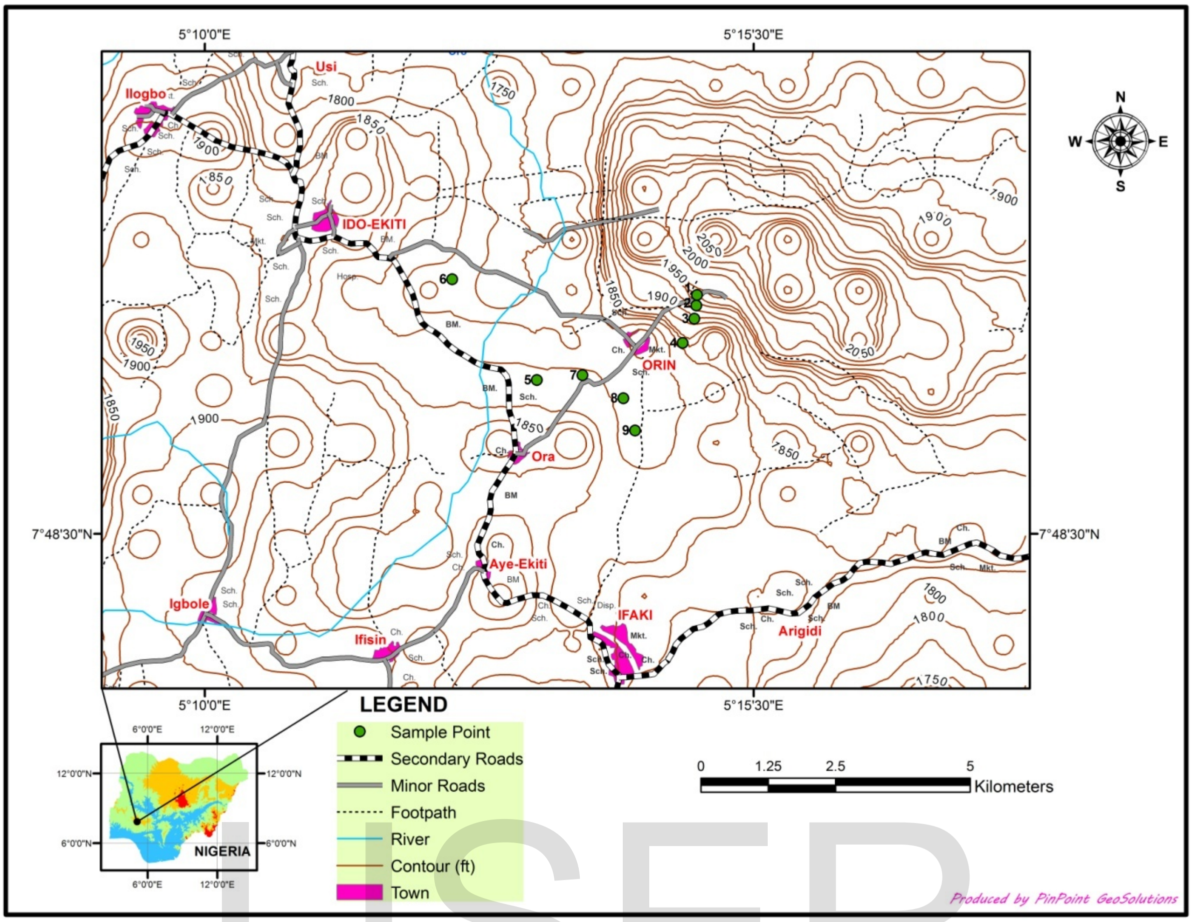


Fig 1: Topographical map of Orin Ekiti showing sample points.

The samples are crushed in a jaw crusher and pulverized into fine powder (particle size <70 µm**).** in a Denver pulverizer in the laboratory of the Ekiti State University, Ado Ekiti. Glass disks were prepared for XRF analysis using 7g of high purity trace element and rare earth element-free flux ($LiBO_2$ = 32.83%, $Li_2B_4O_7$ = 66.67%, LiI = 0.50%) mixed with 0.7g of the powder sample. Whole-rock major element compositions were determined at the Central laboratory of Stellenbosch University, South Africa. using XRF spectrometry on a PANalytical A xios Wavelength Dispersive spectrometer following the proposal of [7] . The spectrometer is fitted with an Rh tube and with the following analyzing crystals:LIF200, LIF220, PE 002, Ge 111 and PX1. Major elements were analyzed on a fused glass disk using a 2.4kW Rhodium tube. Matrix effects in the samples were corrected for by applying theoretical alpha factors and measured line overlap factors to the raw intensities measured with the Super Q P ANalytical software. 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). The results of the analysis are presented in Table 1.

2.0 Results and Discussions

2.1 Geochemical analyses of rocks in Orin-Ekiti and environs.

Ten rocks samples from Orin Ekiti were analyzed and their major element compositions are shown in Table 1.The analysis shows an unusually low SiO_2 contents for the first three samples (40.13-40.77%) and moderate contents for the remaining samples (52.10-70.22%) thus corresponding to approximately basic (40-52) and acid > 66.0 wt % compositions respectively. The concentration of Al_2O_3 varies between 12.96 and 21.26 Wt % .This relatively high Al_2O_3 content is a reflection of calc alkaline affinity just as CaO contents range from 1.71 to 12.38 in the overall data in Table 1. K_2O contents range from 0.82 to 5.98 Wt % while Na_2O contents vary from 2.20 to 3.51%. MnO contents are less than one (1) while the loss on ignition (LOI) concentrations are negative for samples 1 to 3 while samples 4 to 10 varies from 0.03 to 0.37.

Table 1: Geochemical composition of basement rocks from Orin Ekiti.

Oxides	1	2	3	4	5	6	7	8	9	10
SiO_2	40.13	40.22	40.77	52.10	68.32	70.22	65.21	66.37	62.77	55.22
Al_2O_3	13.99	14.03	13.77	21.26	13.14	13.52	14.53	14.17	13.56	12.98
K_2O	0.86	1.07	0.82	1.33	5.41	5.98	5.49	4.18	5.05	4.64
Na_2O	2.63	2.66	2.59	3.51	2.53	2.72	2.84	2.78	2.20	2.70
Fe_2O_3	15.53	16.44	15.95	6.28	5.79	4.08	4.39	5.68	9.27	7.96
MgO	4.28	3.46	4.65	3.82	0.42	0.15	1.74	1.46	0.98	7.38
P_2O_5	4.73	4.63	4.32	0.80	0.22	0.09	0.47	0.21	0.44	1.31
CaO	12.38	11.75	11.84	9.14	2.38	1.71	3.81	3.49	3.09	5.91
TiO_2	4.38	4.85	4.54	0.81	0.70	0.42	0.33	0.57	1.20	0.72
Cr_2O_3	bdl	Bdl	Bdl	0.01	Bdl	Bdl	Bdl	0.01	bdl	0.06
MnO	0.17	0.20	0.18	0.09	0.07	0.06	0.09	0.08	0.11	0.14
LOI	-0.07	-0.31	-0.16	0.15	0.03	0.11	0.24	0.17	0.37	0.16
Sum of conc.	99.01	99.00	99.27	99.30	99.01	99.06	99.14	99.17	99.04	99.18

Fig.3 shows various Harker variation plots of some major oxides against SiO_2. The major oxides, NaO_2 MgO, TiO_2, Fe_2O_3, Al_2O_3 and CaO show negative linear plots with SiO_2. K_2O oxide showed strong positive linear trend with SiO_2. The negative linear trends of these oxides indicate chemical affinity that suggest their origin to have come from the same parent magma. However, the strong positive correlation of K_2O with SiO_2 in Fig 2. implies that a different source of material might have mixed up in the rocks during metamorphism of the parent rock. NaO_2 and Al_2O_3 though negative do not display very obvious variation trend with SiO_2 like other major oxides (Fig. 3). for the granite gneiss of the study area

ISSN 2229-5518

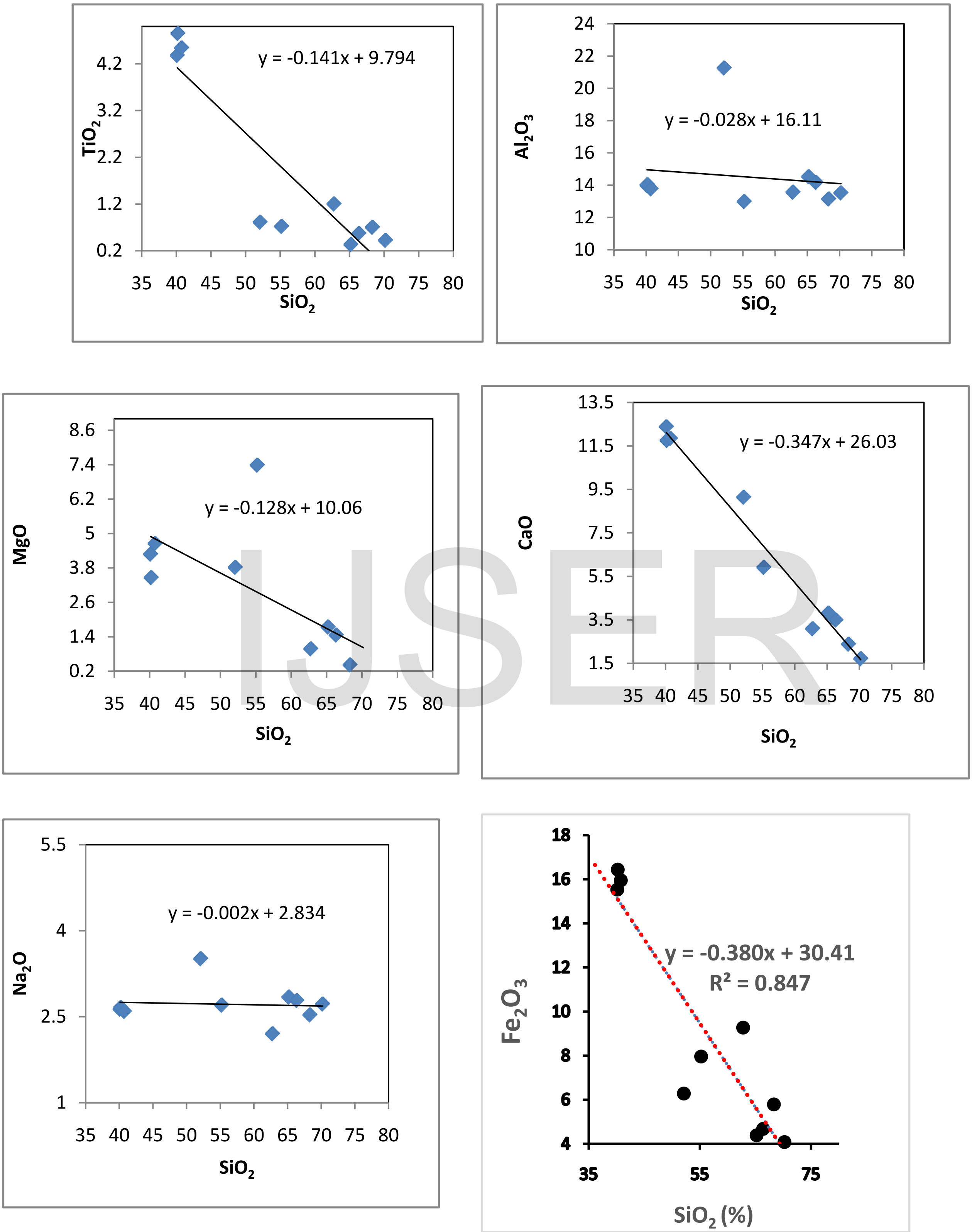


Fig.3: Harker variation diagrams; silica (SiO_2 wt %) plotted against a range of major oxides (in wt %)

Table2: Classification of the Rocks

Oxides	1	2	3	4	5	6	7	8	9	10
SiO_2	40.13	40.22	40.77	52.10	68.32	70.22	65.21	66.37	62.77	55.22
Al_2O_3	13.99	14.03	13.77	21.26	13.14	13.52	14.53	14.17	13.56	12.98
K_2O	0.86	1.07	0.82	1.33	5.41	5.98	5.49	4.18	5.05	4.64
Na_2O	2.63	2.66	2.59	3.51	2.53	2.72	2.84	2.78	2.20	2.70
Fe_2O_3	15.53	16.44	15.95	6.28	5.79	4.08	4.39	5.68	9.27	7.96
MgO	4.28	3.46	4.65	3.82	0.42	0.15	1.74	1.46	0.98	7.38
P_2O_5	4.73	4.63	4.32	0.80	0.22	0.09	0.47	0.21	0.44	1.31
CaO	12.38	11.75	11.84	9.14	2.38	1.71	3.81	3.49	3.09	5.91
TiO_2	4.38	4.85	4.54	0.81	0.70	0.42	0.33	0.57	1.20	0.72
Cr_2O_3	bdl	Bdl	Bdl	0.01	Bdl	Bdl	Bdl	0.01	bdl	0.06
MnO	0.17	0.20	0.18	0.09	0.07	0.06	0.09	0.08	0.11	0.14
LOI	-0.07	-0.31	-0.16	0.15	0.03	0.11	0.24	0.17	0.37	0.16
Sum of conc.	99.01	99.00	99.27	99.30	99.01	99.06	99.14	99.17	99.04	99.18
Na_2O/ K_2O	3..06	2.48	3.16	2.64	0.46	0.45	0.52	0.61	0.44	0.58
$Al_2O_3/Na_2O+CaO+K_2O$	0.8	0.91	0.90	1.52	1.27	1.30	1.20	1.36	1.31	0.97
$Na_2O+CaO+K_2O/Al_2O_3$	1.13	1.10	1.11	0.65	0.78	0.76	0.84	0.74	0.76	1.02
Al_2O_3/Na_2O+K_2O	4.00	3.76	4.04	4.39	1.65	1.55	1.74	2.04	1.87	1.77
K_2O/Na_2O	0.32	0.40	0.32	0.38	2.14	2.20	1.93	1.50	2.30	1.72
Na_2O+K_2O	3.49	3.73	3.41	4.84	7.94	8.70	8.33	6.96	7.25	7.34

[6] used a n umber of chemical properties to distinguish between S- and I-type granites . In Table 2, ratios of some oxides are shown. Na_2O/ K_2O ratio varies from 0.44 to 3.16 wt %. There are two aspects of the rocks; the first three samples and the last six samples. Na_2O in the former ranges from 2.59 to 2.66 and therefore not greater than 3.2% but however decreases to 2.2%. The latter varies from 2.53 to 3.51% and only one (1) sample is > 3.2%. Based on the values, it means that majority of the samples are less than 3..2% and therefore belong to S-Type granite. In confirmation, K_2O varies between 1.33 and 5.98 % with four samples falling between 5.05 to 5.98% . The a luminium saturation index (ASI) defined by molecular ratio $Al_2O_3/Na_2O+CaO+ K_2O$ ranges between 0.8 and 1.52 .T he ratio shows two contrasting data where four samples 1, 2, 3 and 10 a re less than one (1.1) and six samples (4-9) are greater than unity (1.1) implying that some of the basement rocks are metaluminous and I-Type while others are peraluminous and S-Type granite making up the broad spectrum of the rocks compositions. The characteristics of rocks that make them peraluminous are low ratio of Na_2O/ K_2O (0.44-2.64), low CaO (1.71-9.14), low MgO (0.15-3.82), and ratio of ASI < 1. [8, 9] . However, if ASI

< 1·0 where the molecular Na + K < molecular Al, then the rock becomes metaluminous, such rocks will then have excess Ca after aluminum

.Metaluminous rocks contain calcic phases such as hornblende and augite but lack either muscovite or sodic ferromagnesian phases. If ASI < 1·0 and Na + K > Al, the rock is peralkaline. In these rocks there are more alkalis than are necessary to produce feldspar, which means that some alkali, particularly Na, must be accommodated in the ferromagnesian silicates [10].

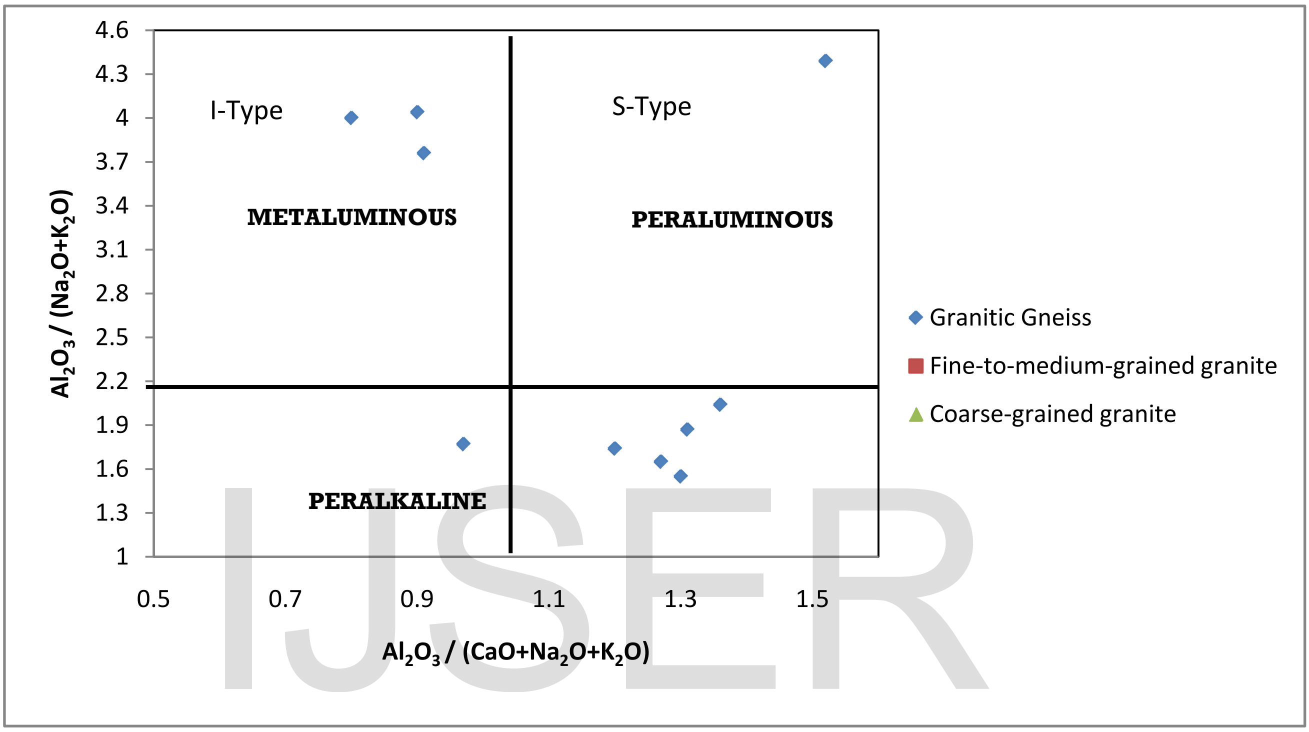


Fig.4: Plot of Al_2O_3/Na_2O+K_2O against Al_2O_3/ CaO+Na_2O+K_2O [11]

A plot of Al_2O_3/Na_2O+K_2O against Al_2O_3/ CaO+Na_2O+K_2O (Fig,4) shows the assemblage of the samples in the metaluminous and peraluminous fields with a minor in the peralkaline. The spread of the samples across these fields reflects its different magmatic sources and probably too shows a reflection of physical porphyritc texture of the rocks. [6] recognized two distinct granitoid types, the I-type metaluminuos formed from a mafic metaigneous source and the S-type peraluminuous formed from the melting of metasedimentary rocks during their geochemical classification of granitic rocks. [6] have extensively classified and studied the Cordilleran granitoids and found that most of them are magnesian and calc-alkalic or calcic where metaluminous and peraluminous types are available just like in the rocks under study (Fig 4). I-type granites are deposited in large volumes in mature island arcs, convergent margins and within Precambrian granite-greenstone terrains

ISSN 2229-5518

3.0 Geochemical Classifications of the rocks

The rocks under study can be classified as calcic, alkalic and calc-alkalic based on the crossplots of Na_2O+K_2O versus SiO_2 (Fig 5) [12] . Calcalkaline magma contains relatively large amounts of calcium (CaO) in relation to alkalis (Na_2O and K_2O). Calc-alkali is applied to igneous rocks in which the dominant feldspar is calcium-rich the converse of which is alkali but other definitions are put forward by [13,14] . Calcalkaline has also become synonymous in many geologists' minds variously with: (i) medium-K (as opposed to low-K = tholeiitic, or high-K = shoshonitic/alkalic) volcanic rock series [15] (ii) derivative from high-Al basalt rather than 'low-Al = tholeiitic' [15] ; (iii) 'hypersthenic' as opposed to 'pigeonitic' rock series (associated with low-K tholeiitic parental basalts.

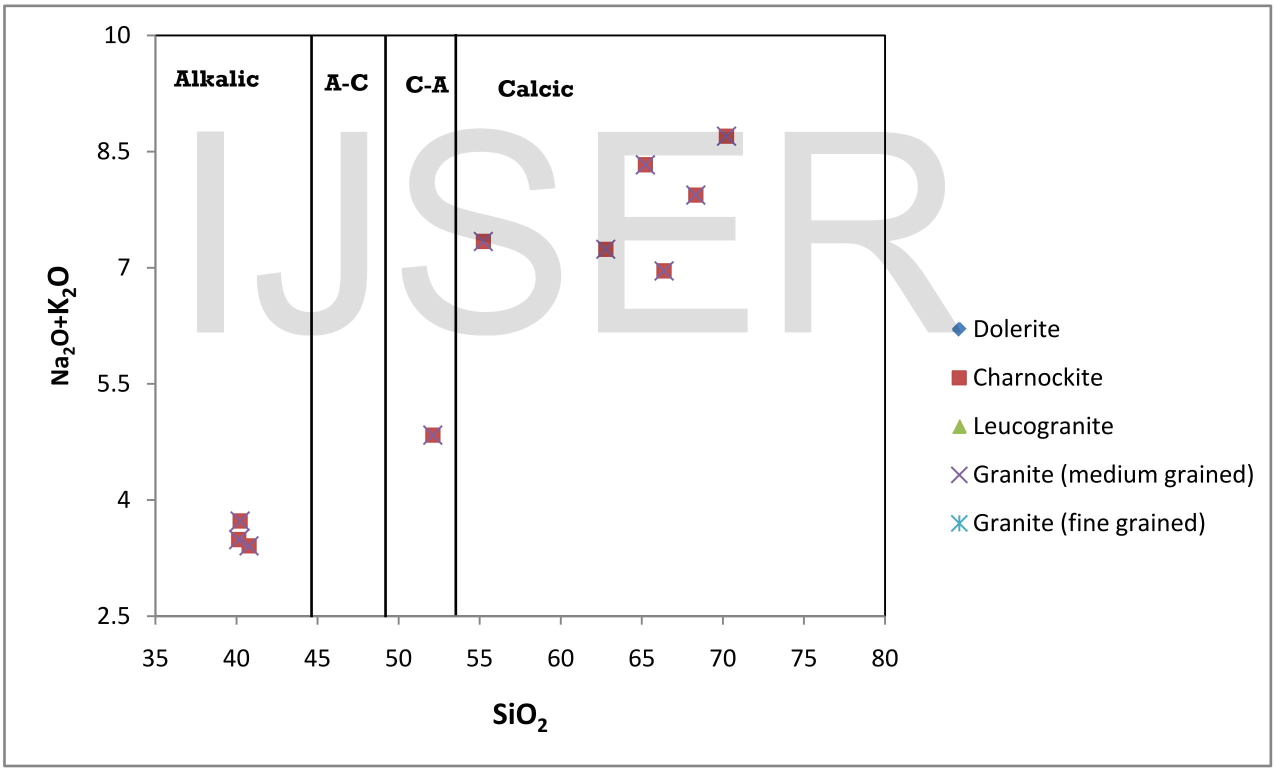


Fig5: Classification of rocks of the study area based on NaO_2+K_2O against SiO_2 plot [12] .

A plot of Na_2O+ K_2O-CaO versus SiO_2 of [16] shows that the fine to medium grained granite gneiss plotted in the alkalic- calcic and calcic fields as well as in the boundary between the calc-alkalic and alkalic calcic fields (Fig 5).The terms used by [12] alkalic,

ISSN 2229-5518

alkali-calcic, calc-alkalic and calcic) were applied to suites of rocks, not individual samples, and were based on arbitrary divisions drawn on a combined plot of total alkalis (wt % $Na_2O + K_2O$) and lime (wt % CaO) vs silica (SiO_2) (Fig 6).

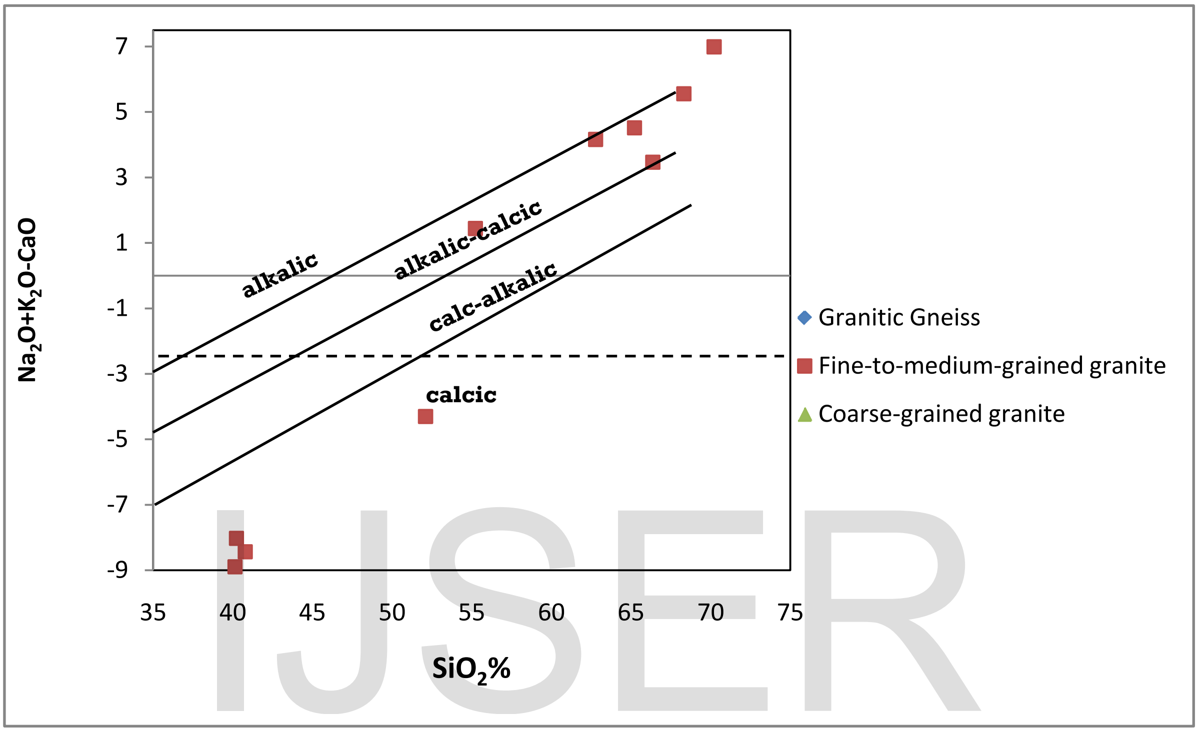
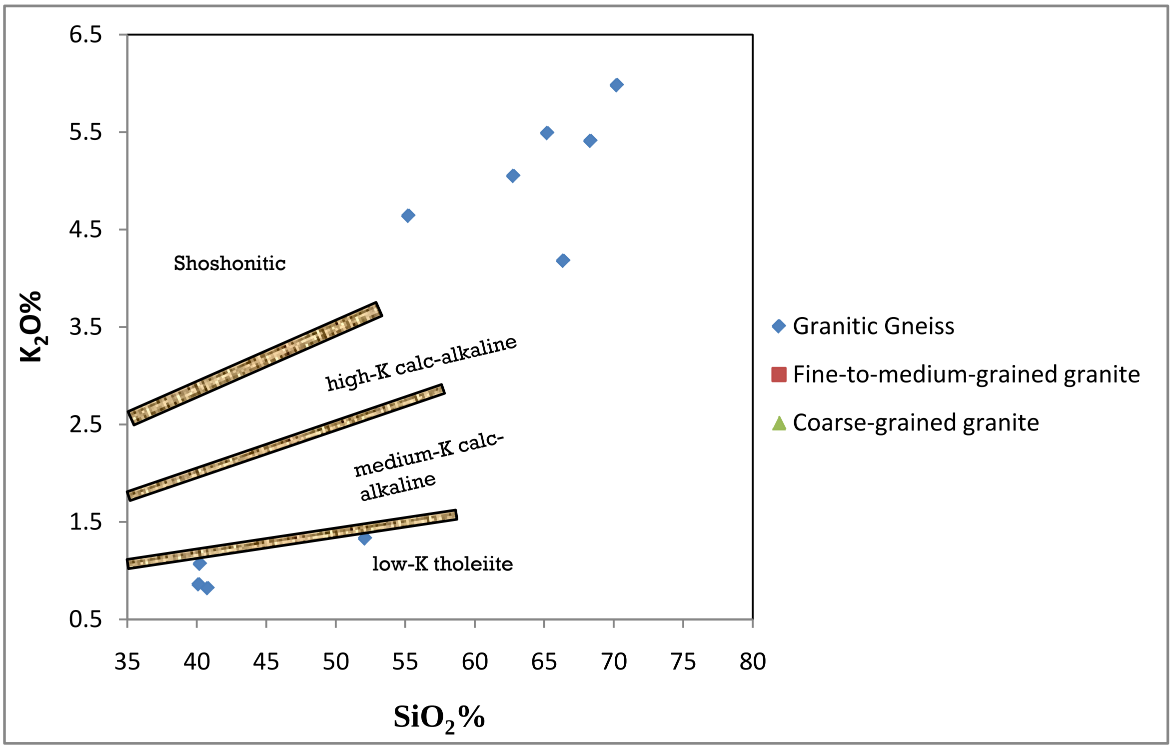


Fig 6: A plot of Na_2O+ K_2O-CaO versus SiO_2 [16] .



ISSN 2229-5518

Fig.7: Plot of K_2O versus SiO_2 [17] .

The diagram of K_2O versus SiO_2 in Fig 7 shows the plots of the samples in the Low -k tholeiite shoshonitic field and in the high K-calc alkaline. [18] suggested that granitic rocks with shoshonitic chemical characteristics must have the following conditions; high total alkalies ($Na_2O + K_2O > 5\%$), high K_2O/Na_2O, Low TiO_2 and high but variable Al_2O_3 among other conditions.[18,19] suggested that rocks with shoshonitic characteristicstend to be associated with calc-alkaline island-arc subduction volcanism, but theK-rich shoshonites are generally younger and above deeper, steeper parts or the Benioff zone. In some places, shoshonitic and high-K calc-alkaline magmatism are associated with an enriched hydrothermal gold and copper-gold mineralization. Calcalkaline has also become synonymous with medium-K as opposed to low-K tholeiitic, or high-K shoshonitic/alkalic volcanic rock series [15] . Calcalkaline is derived from high-Al basalt rather than 'low-Al tholeiitic [13] .

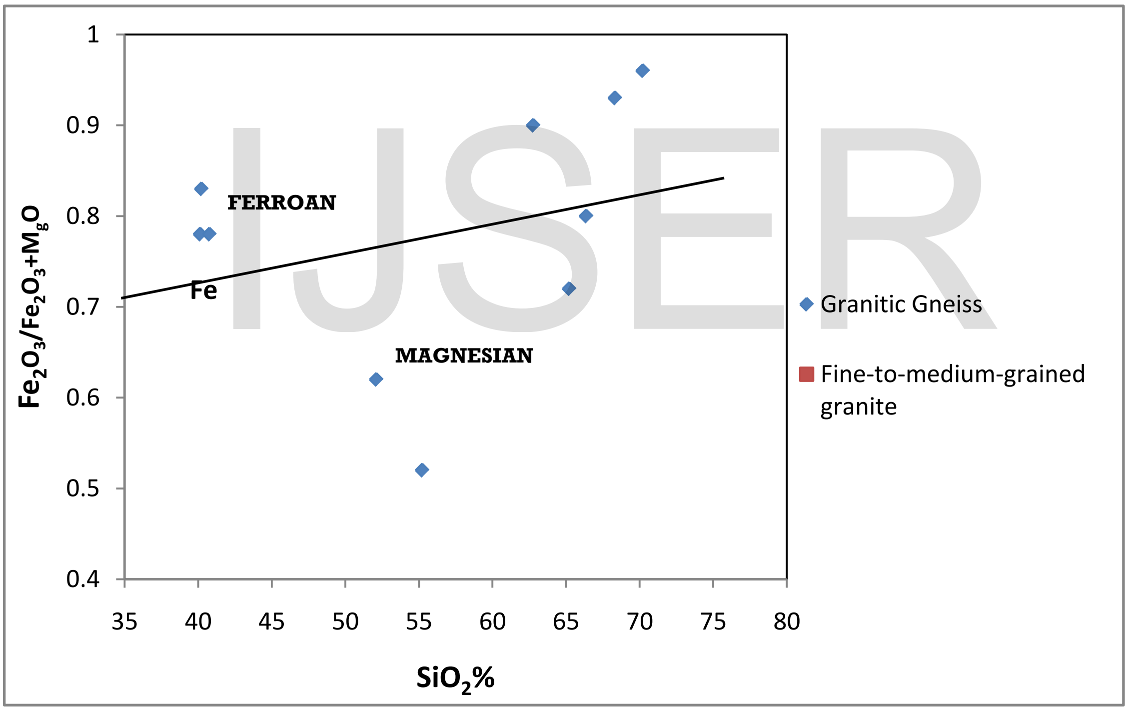


Fig 8: Fe_2O_3+ MgO against SiO_2 [20] .

The plot of Fe_2O_3+ MgO against SiO_2 [20,21] shows the distinct trend that distinguished iron-rich and magnesian-rich fields. The samples converged in the iron -enriched field as well as in the magnesian field termed 'ferroan' and 'magnesian' respectively (Fig. 8) .Rocks which have Fe-number < 0·5 have molecularly more abundant Mg than Fe and such are called magnesian rocks. In the case of the rock under study, six samples and four samples are Fe-rich and Mg -rich respectively (Fig 8). The compositional ranges of the magnesian and ferroan granitoids are virtual mirror images of each other. The magnesian granitoids are most commonly calcic and calc-alkalic; [22] but there are some magnesian alkali–calcic and alkalic granitoids. Magnesian alkalic rocks are syenites, quartz syenites and nepheline syenites, and are not granites in the real sense of it. In ferroan rocks, calcic rocks are unknown, and calc-alkalic rocks are rare but alkali–calcic and alkalic rocks are abundant. [23] suggested that most of the ferroan rocks are metaluminous, (alkali–calcic) while some occur as peraluminous types (calc-alkalic), [22]. In the magnesian granitoids, peraluminous compositions are most common among calc-alkalic rocks, though they are also represented in alkali–calcic granitoids and calcic granitoids, where they occur as cordierite-bearing tonalites. [24,25].The magnesian rocks range in composition from tonalite through granodiorite to granite from calcic to alkali calcic and rarely alkalic. They fall in either metaluminous or peraluminous group and they typically form in arcs and post-collisional environments [26]. He also pointed out that much of the continental crust is composed of magnesian granitoids, where magmas derived by partial melting of continental crust inherited magnesian character. In the case of ferroan, the rocks range from fayalite granite (or rhyolite), through alkali granite to nepheline syenite (or phonolite). Ferroan rocks are mostly alkalic, while some are alkali calcic [27] or calc-alkalic [28] .Most ferroan rocks are metaluminous or peralkaline. The rocks under study have the attributes of magnesian and ferroan and some are metaluminous, peraluminous and peralkaline.

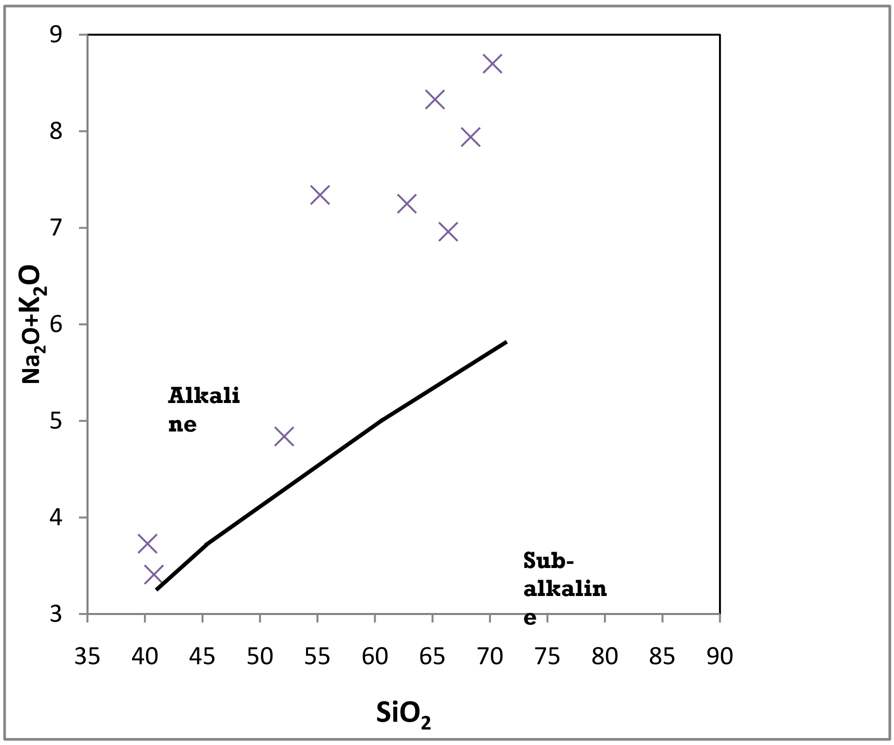


Fig 9: Plot of the total alkalis Na_2O+K_2O against SiO_2 [14].

The plot of the total alkalis Na_2O+K_2O against SiO_2 [14] in Fig 9 indicates that the rock samples have affinity for alkaline. On the plot of Na_2O+ Na_2O against SiO_2 , the samples fall in the fields of Granite, quartz monzonite ,gabbroic diorite as well as a minor fall in the granodiorite (Fig 10). Quartz monzonite is an intrusive, felsic igneous rock that contains almost equal proportion of orthoclase and plagioclase feldspar and exhibiting a light coloured phaneritic to porphyritic granitic rock.

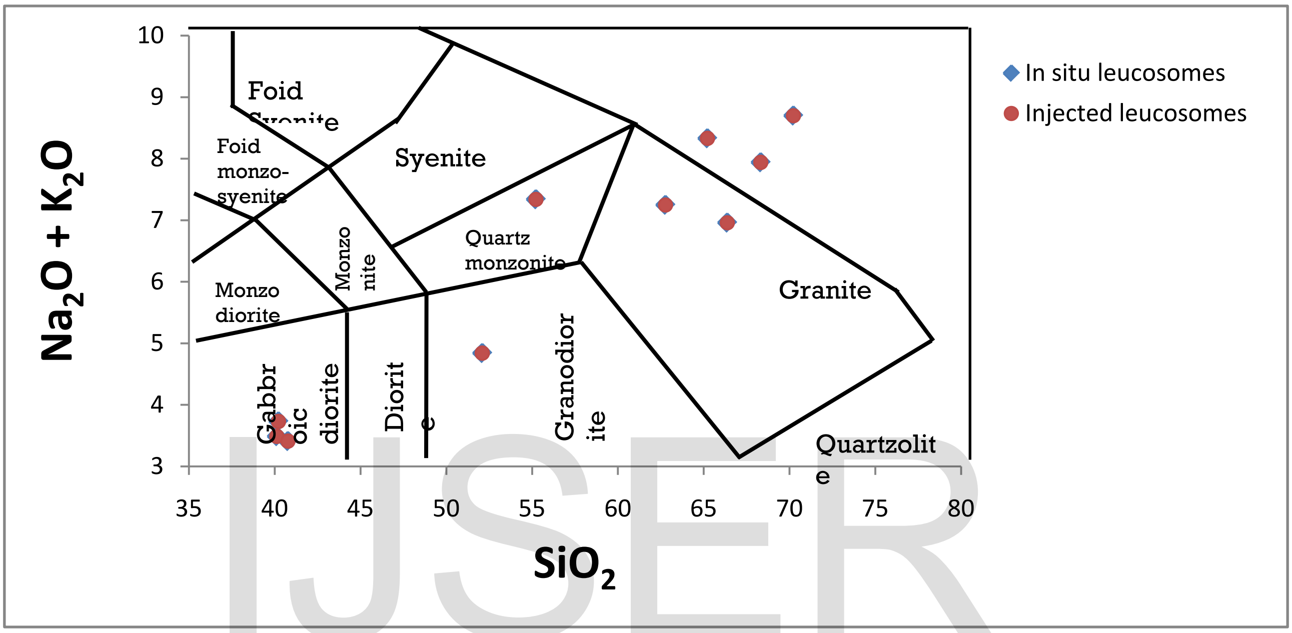


Fig.10 : Plot of Na_2O+ Na_2O against SiO_2

4.0 Provenance and Tectonic Setting

[30] proposed three tectonic settings, the passive margin (PM), active continental margin (ACM), and oceanic island arc (OIA) and the three are plotted using K_2O/Na_2O against SiO_2 diagram (Fig 11).

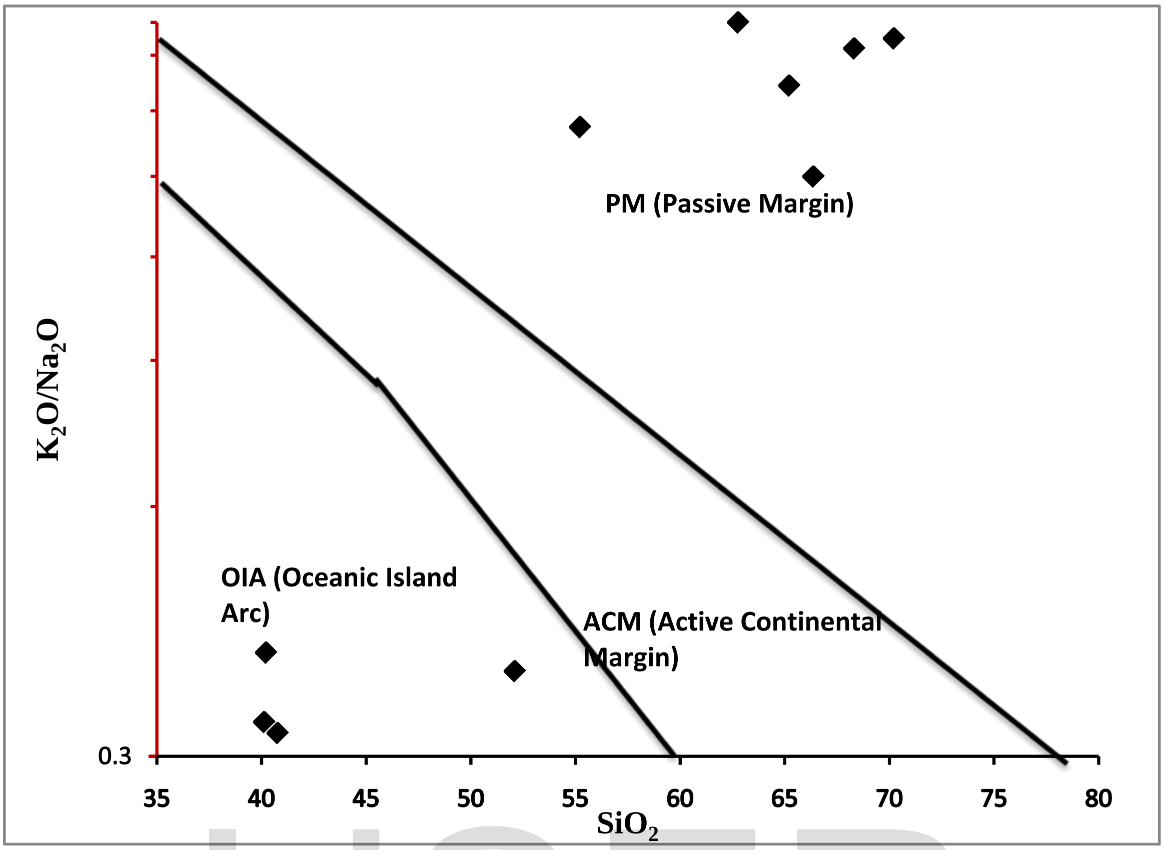


Fig 11: Plot of K_2O/Na_2O versus SiO_2 [29] .

Fig 11 shows the samples that plotted on the passive and oceanic fields. The passive margin is described as a margin or transition between oceanic and continental lithosphere and which in real sense is not an active plate margin. Passive margins are seen at every ocean and continent margins that are not marked by a strike-slip fault or a subduction zone. They are areas of petroleum reservoirs of economic importance and they define the regions around the Atlantic , Arctic , and western Indian Oceans .

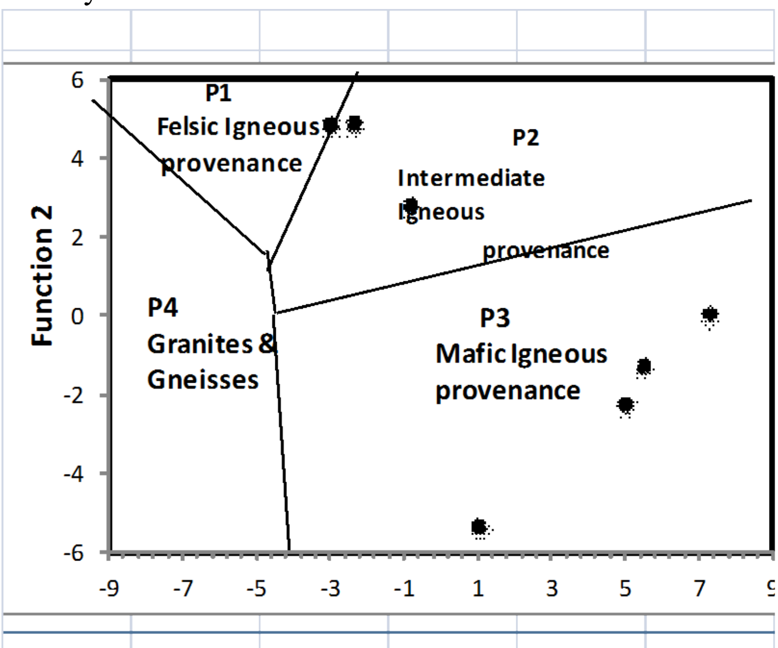


Fig. 12: The Discriminant Function plot with major elements for provenance signatures [31] .

The discriminant function plot with major elements proposed by [31] defined four distinct rock provenances notably mafic igneous provenance; intermediate igneous provenance; felsic igneous provenance; and quartzose sedimentary provenance. The plots of the rocks from Orin Ekiti fall majorly in the mafic igneous provenance, intermediate igneous provenance and felsic igneous provenance fields demonstrating that they are derived from diversed or mixed sources. The plot of the discriminant functions is based on the oxides of Ti, Al, Fe, Ca, Na, and K and this is aimed at differentiating the provenances as shown in Fig.12 .The plot is done on discriminant function 1 and 2 ratios for the raw plot.

5.0 Conclusion.

Orin Ekiti is underlain by crystalline rocks of the basement complex of Southwest Nigeria. These rocks range from Pan African granite, charnockite, quartz monzonite, migmatite gneiss to diorites. The geochemical analysis shows an unusually low SiO_2 contents (40.13-40.77%) in the charnockites (the first three rock samples near the clay deposit) and moderate contents (52.10-70.22%) for the remaining samples thus corresponding to approximately basic (40-52.10 wt %) and acid (> 66 wt %) compositions respectively. The Al_2O_3 content varies between 12.96 and 21.26 Wt % thus reflecting relatively a calc- alkaline affinity just as CaO ranges from 1.71 to 12.38. The rocks are classified as calc-alkalic, alkalic- calcic, and calcic. The rocks have characteristically low ratio of Na_2O/ K_2O (0.44-2.64), low CaO (1.71-9.14), low MgO (0.15-3.82), and ratio of ASI > 1.1 [9,10] that characterized them as S-type peraluminous . However, some have ASI < 1·1 and therefore are the I-type metaluminous as well as peralkaline. The rocks under study have the attributes of both the magnesian and ferroan. The samples fall majorly in the mafic igneous provenance, intermediate igneous provenance and felsic igneous provenance fields demonstrating that they are derived from diversed or mixed sources in the passive margin and oceanic island arc fields.

References

[1] Miller C.F., Wooden J.F., Bennett V.C., Wright J.E., Solomon G.C., Hurst R.W. 1990. Rang batholith, southeastern California; isotopic constraints. In: Anderson, J. L. (ed.). The Nature and Origin of Cordilleran Magmatism. Geological Society of America, Memoir 174, 99–109.

[2] Collins, B. W. (1996). Lachlan fold belt granitoids; products of three-component mixing. In: Brown, M., Candela, P. A., Peck, D. L., Stephens, W. E., Walker, R. J. & Zen, E-an

(eds) Third Hutton Symposium on the Origin of Granites and Related Rocks. Geological Society of America, Special Papers 315, 171–181.

[3] Hyndman, D. W. (1984). A petrographic and chemical section through the northern Idaho batholith. Journal of Geology 92, 83–102.

[4] Ague, J. J. & Brimhall, G. H. (1988). Regional variations in bulk chemistry, mineralogy, and the compositions of mafic and accessory minerals in the batholiths of California. Geological Society of America Bulletin 100, 891–911.

[5] Barbarin B. 1990. Granitoids: main petrogenetic classification in relation to origin and tectonic setting. Geological Journal. 25: 227-238.

[6] Chappell BW, White AJR. 1974. Two contrasting granite types. Pacific Geology, 8: 173-174

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

[8] 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.

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

[10] Zen E. 1988. Phase relations of peraluminous granitic rocks and their petrogenetic implications. Annual Review of Earth and Planetary Sciences 16, 21–52.

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

[12] Peacock M.A. 1931. Classification of igneous rock series. Journal of Geology 39, 54–57.

[13] Wilkinson, J. F. G. (1968). The petrography of basaltic rocks: In: Hess, H. H. & Poldervaart, A. A. (eds) Basalts: The Poldervaart Treatise on Rocks of Basaltic Composition, 2. New York: Interscience, pp. 163–214.

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

[15] Rollinson, H. R. 1993). Using Geochemical Data: Evaluation, Presentation, Interpretation. Harlow: Longman.

[16] 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.

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

[18] Morrison, G.1980.Characteristics and tectonic settings of Shoshonite rock association. Lithos,18, 97-108.

[19] Muller, D and Groves, D.I. 2016. Potassic igneous rocks and associated gold-copper mineralization. (4th ed.) Mineral Resources Review. Springer-Verlag, Heideberg, p.311.

[20] 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. Journalof Petrology 42, 2033-2048.

[21] Miyashiro, A. (1970). Volcanic rock series in island arcs and active continental margins. American Journal of Science 274, 321–355.

[22] King, P.L., White, A.J. R., Chappell, B.W. and Allen, C.M.(1997).Characteristics and origin of aluminous A-Type granites from the Lachlan fold belt, southeastern Australia. Journal of Petrology.38, 371-391.

[23] Anderson, J.I and Thomas, W.M. (1985). Proterozoic anorogenc two mica granites: Silver Plume and St Vrain batholiths of Colorado. Geology 13, 177-180.

[24] Shimura, T., Komatsu, M. and Iiyama, J.T.(1992). Genesis of the lower crustal garnet-orthopyroxene tonalites (S.Type) of the Hidaka metamorphic belt, northern Japan. Transactions ofnthe Royal Society of Edinburg. Earth Sciences. 83, 259-268.

[25] Johnson, K., Barnes, C.G and Miller, C.A. (1997). Petrology, geochemistry and genesis of high -AL tonalite and trondhyjemites of the Cornucopia stock, Blue Mountains, northeastern Oregon.Journal of Petrology.38, 1585-1611.

[26] Osbourn, E. F. (1959). Role of oxygen pressure in the crystallization and differentiation of basaltic magma. American Journal of Science 257,609^647.

[27] 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.

[28] King, P. L., Chappell, B.W., Allen, C. M. & White, A. J. R. (2001). Are A-type granites the high-temperature felsic granites? Evidence from fractionated granites of theWangrah Suite. AustralianJournal of Earth Sciences 38,501^514.

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

[30] Roser B.P., Korsch R.J. 1986. Determination of tectonic setting of sandstone-mudstone suites using SiO2 content and K2O/Na2O ratio. J. Geol. Vol. 94: 635-650.

[31] Roser, B. P. and Korsch, R. J. (1988) Provenance signature of sandstone-mudstone suite determined using discriminant function analysis of major element data. Chem. Geol, Vol. 67:119-139.

ISSN 2229-5518