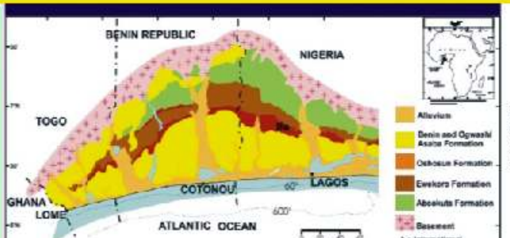
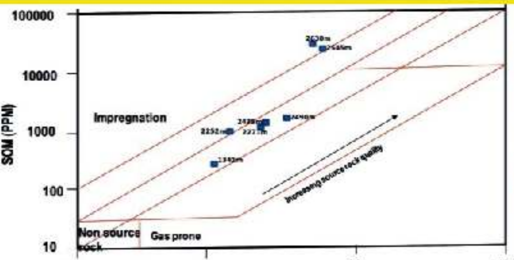
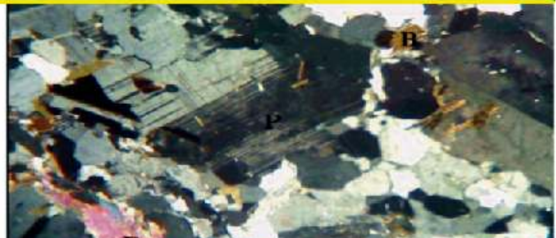
ISSN 1116-2775

Volume 55 Number 1 March 2019

JOURNAL OF MINING AND GEOLOGY







Published by the

NIGERIAN MINING & GEOSCIENCES SOCIETY

under the sponsorship of

PETROLEUM TECHNOLOGY DEVELOPMENT FUND

Journal of Mining and Geology

Publisher

Nigeria Mining and Geolsciences Society

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Subscription Rates
₦2,500.00 per copy (domestic)
US$100.00 per copy (foreign)

Information

The Nigerian Mining and Geosciences Society (NMGS) succeeded in 1977, The Nigerian Mining, Geological and Metallurgical Society (NMGMS) which was founded on 15 January, 1961, and officially inaugurated on 17 December, 1962. among its objectives, are the advancement of the study and practice of mining, geological sciences and metallurgy, and promotion of the acquisition and dissemination of scientific contributions and knowledge in the relevant fields. The Society also ensures the protection of the ethics of the respective professions, and has statutory representation in the Council of Nigerian Mining Engineers and Geoscientists (COMEG) enacted into law by the Federal Republic of Nigeria Decree No. 40 of 1990. The categories of membership are Student, Graduate, Corporate, Fellow, Institutional, Affiliate and Honourary member/Fellow, and the current strenght of ca.3500 includes Nigerian and foreign professionals and practicians working or have worked within the country.

This multi-disciplinary publication was initiated in 1963, and to 1965 titled the Journal of the Nigerian Mining Geological and Metallurgical Society. Its current title, Journal of Mining and Geology adopted from the edition of 1966, was modified between 1982 and 1987, as the Nigerian Journal of Mining and Geology. The production of the Journal is normally biannual (2 issues per volume) in March and September, and from Volume 35 No. 1 1999, has been under the aegies of the Petroleum Technology Development Fund (PTDF). The publication has international contributorship, circulation and citation. All contacts including correspondence on advertisement and back numbers, should be directed to the Editor-in-Chief.

Volume 55 **Number 1** **March 2019**

NIGERIAN MINING AND GEOSCIENCES SOCIETY

2018/2019 Council Membership

Journal of Mining and Geology Vol. 55(1) 2019. pp. 1 - 15 1116-2775

Geochemistry and Petrogenesis of Granitic Rocks in Bishini Sheet 165 SW, North-Central Nigeria

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Abstract

The geology and whole rock geochemistry of granitic rocks within Bishini sheet 165 SW, North Central Nigeria have been studied in order to determine the petrographic characteristics of the rock assemblages, their original protoliths and petrogenesis. Field mapping and laboratory work revealed that the study area is underlain by crystalline Precambrian Basement Complex which comprises of migmatite, granite, schist and granodiorite. The rocks have a major structural trend of NNE - SSW which was determined by measurement of joints and faults on them. Plagioclase, quartz and K-feldspar occur as the major minerals associated with the rocks with biotite and hornblende occurring as the major ferromagnesian mineral. A total of thirty-five (35) rock samples were collected from the study area which were described based on their field relationships. Twenty-nine (19) rock samples were later selected and analysed for major and trace elements using an X-Ray fluorescence (XRF) spectrometer. The results show that the granite contains, on average, 70.33 % SiO_2, 14.90 % Al_2O_3, 2.95 % Fe_2O_3, 1.36 % CaO, 0.52 % MgO, 3.58 % Na_2O, 4.52 % K_2O, 0.035 % MnO, and the granodiorite contains, on average, 67.06 % SiO_2, 15.81 % Al_2O_3, 2.89 % Fe_2O_3, 2.73 % CaO, 1.27 % MgO, 3.99 % Na_2O, 3.19 % K_2O, 0.08 % MnO. The negative linear trend between SiO_2 and CaO, MgO, Na_2O and Fe_2O_3 on Harker plots for the granitoids of the study area suggests that the primary mineral assemblage may have undergone changes during fractionation. Trace element analyses show that Barium (Ba) is the most abundant with an average of 42.67 ppm for migmatite, 428.67 ppm for granite, 419.5 ppm for schist and 440.62 ppm for granodiorite compared to other trace elements present in the rock samples. The depletion of Strotium (Sr) suggests plagioclase fractionation from magmatitic melt. Variation diagrams show that the granitoids are S-type granites, generally peraluminous though few samples displayed metaluminous characteristics of calc-alkaline affinity in a plate tectonic setting related to syn-to-within plate collision environment.

Keywords: *Geochemistry, Petrogenesis, Granitic rocks, Bishini Sheet 165 SW, North-Central Nigeria*

Introduction

Nigeria is situated on the West African Craton in a region of late Precambrian to Early Palaeozoic orogenesis. The Pan African Orogeny (600 ± 100 Ma), as well as other region of Africa, was accompanied by a major phase of intrusion. These intrusions gave birth to large amount of syn-to-late tectonic granites, granidiorites, adamellites and tonalities which were emplaced within the older suites of pre-existing metasediments and migmatitic gneiss. Falconer, (1911) refers to these intrusive rocks as Older Granites so as to differentiate them from the Younger Granites of North Central Nigeria. The Nigerian Basement Complex comprises of three major lithologic units; a migmatite-gneiss complex believed to be the oldest unit, a narrow north-south trending schist belt which is restricted to the western half of the country and a suite of granitic rocks (Older Granites) that intruded both the migmatite-gneiss complex and the schist belts between 650 million years and 500 million years ago during the closing stages of the Pan African cycle (Ajibade, 1982 and Akinola *et al*., 2014).

The variation in trace elements abundance and their pattern of distribution is a useful tool in tracing the evolution of granitic and basaltic rocks (Obiora and Ukaegbu, 2010). These variations in trace elements data when displayed on relevant variation diagrams serve as useful indicators of rock classification and their tectonic setting (Pearce and Cann, 1973; Pearce, 1966). The Basement Complex of North central Nigeria is perhaps the most interesting area of basement geology in northern Nigeria because of the presence of all major rock types (McCurry, 1976), thereby forming the largest mapped basement within Nigeria. This study therefore, aims as at revealing the petrogenesis of the granitic rocks in Bishini, north central Nigeria using field and geochemical data.

Regional Geologic Setting

The geology of Nigeria consists of the basement rocks that are truncated by the sedimentary rocks in almost equal proportions (Ologe *et al*, 2014) (Figure 1). The crystalline rocks are of two age groups; the Precambrian age and the Younger Granites of Jurassic age. The sedimentary sequences are Cretaceous to Quaternary in age and spread across five sedimentary basins.

The Precambrian rocks (basement complex) form a prominent topographic feature of the country and

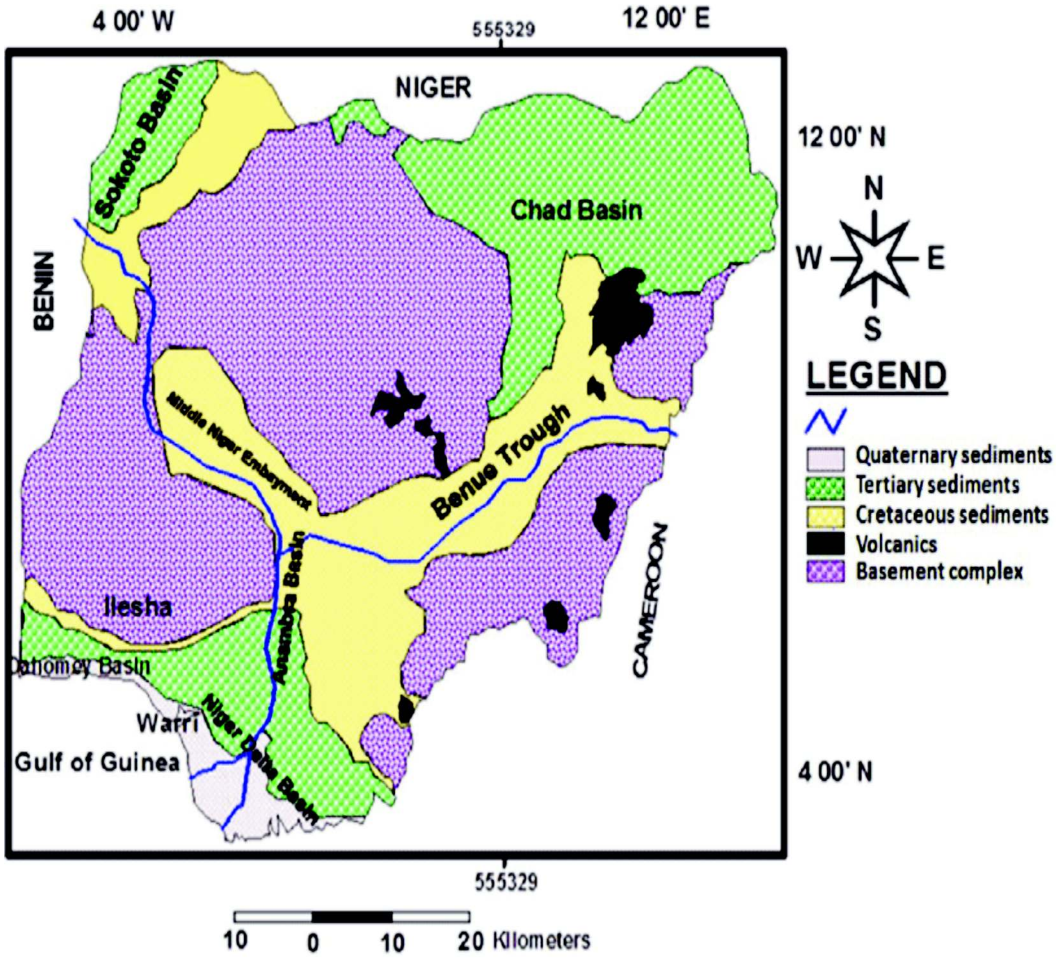

Fig. 1: Regional Geological Map of Nigeria (Ologe *et al.*, 2014)

underlie the study area, while the Younger Granites are restricted to the north central part around the Jos Plateau. The basement complex rocks fall into four lithological units: the migmatite gneiss complex, the schist belts, the Pan-African Granites (referred to as Older Granites) and the late intrusives. The migmatite gneiss complex comprise varieties of gneisses including biotite and hornblende gneisses, banded gneisses, augen gneisses, and granite gneisses with intercalations of quartzite and quartz schist. The schist belts comprise paraschists and meta-igneous rocks, schistose rocks, calcsilicates and talc-bearing rocks that occupy mainly N-S trending belts of low-grade supracrustal assemblages (Turner, 1983).

Oyawoye (1964), interpreted the schist belts as relics now preserved in synclinal keels of a once widespread cover of sedimentary rocks deposited in a single basin. However, based on the different lithological associations within the basins, Elueze (1981) believed that these belts developed in separate basins indicating that they have all undergone the same deformational histories. Some of the belts contain gold mineralization, banded iron formation (BIF) or marble. The Pan-African Granites comprise rocks of wide spectrum of compositions ranging from granite to granodiorite and charnockite with minor pegmatite and dolerite dykes that belong to the last stage of Pan-African magmatism (Truswell and Cope, 1963).

Materials and Methods

A systematic geological mapping and sampling were undertaken to ascertain the granitic rocks present in the area.Nineteen samples of granitic rocks consisting of 13 granodiorite and 6 granites were collected and analysed for their major and trace elements. The analyses were doneusing X-Ray Fluorescence Spectrometry (XRF) at the Nigerian Geological Research Laboratory of Nigerian Geological Survey Agency, Kaduna. The analytical procedure used in determining the elemental concentration involves the addition of 1g of soluble starch to 5g of each of the pulverised samples with the soluble starch acting as a binding medium. Each of these samples was thoroughly mixed by stirring to ensure homogeneity and then pressed under high pressure (6 tonnes) to produce pellets. The pellets were carefully placed in the respective measuring positions on a sample changer of the spectrometer. They were then analysed under the following condition sets as the machine was switched on. Elemental composition determination, nature of samples to be analysed as pellets (press powder), current of 14 kilovolts for major oxides and 20 kilovolts for trace elements, selected filters (kapton for major oxides and silver/aluminium-thin for trace element). The selection of these filters was guided by a given periodic table used for elemental analysis. The spectrometer was then calibrated by the machines gain control, after which the respective samples were measured by clicking the respective portions of the sample changer. The time of measurement for each sample through an air medium was a hundred seconds. Parts of the samples were used for thin sectioning in order to determine the mineralogical composition of the studied granitic samples.

Results and Discussion

Field Occurrence and Petrography

The study area is part of Bishini Sheet 165SW located within Paikoro Local Government Area, Niger State in north-central Nigeria. It lies between latitudes 9^0 30' - $9^0$45'N and longitudes 7^0 05' - $7^0$15' E on a scale of 1: 25,000 covering an area extent of approximately 502.34 km^2. The topography is relatively undulating terrain with surface elevations ranging from 420m to 565m above sea level. The study area is underlain by the basement complex rocks of North central, Nigeria .The local geology consists of the migmatite, granodiorite, granite and schist (Figure 2).

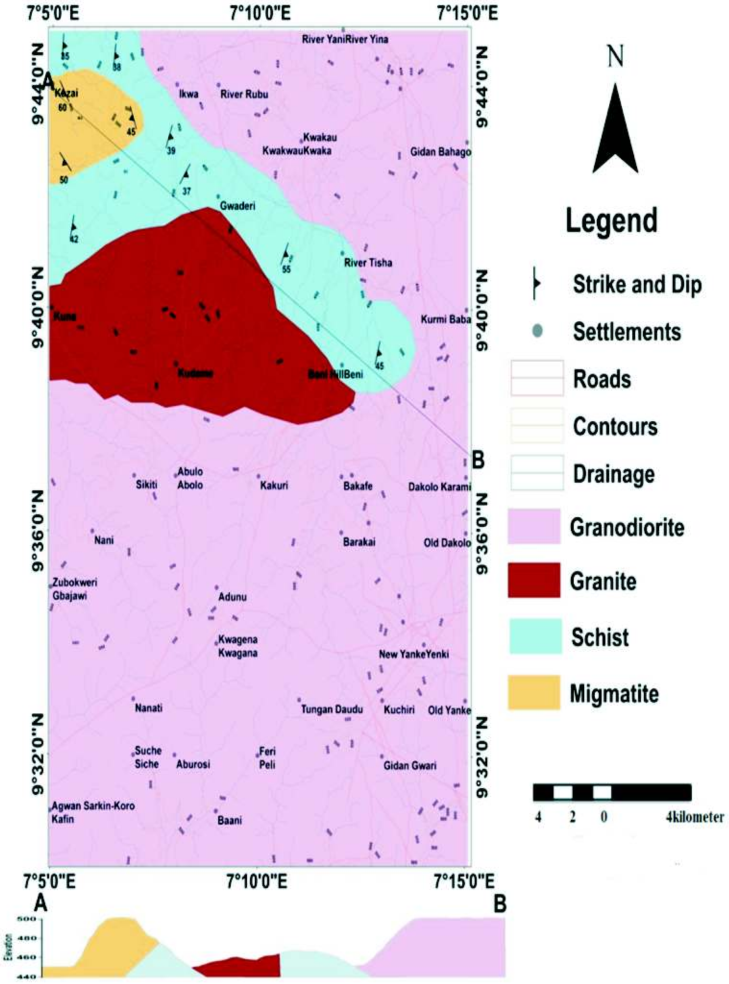

Fig. 2: Geological Map of the Study Area.

The granites occur as boulders which intrude the schist. They cover about 10% of the study area. The granite is light pink to pale red in colour (Figure 3a) and texturally medium to coarse grained (Figure 3b). It is characterised by quartzo-feldspathic veins (Figure 3c) within the range of 2 – 8cm in width. The granite is also marked with joints. At some outcrops these joints cross cut the rock vertically and/or horizontally. Faults of quartz vein (Figure 3d) were also observed on the outcrop. The faults are micro, with displacement of about 2 – 3 cm.\

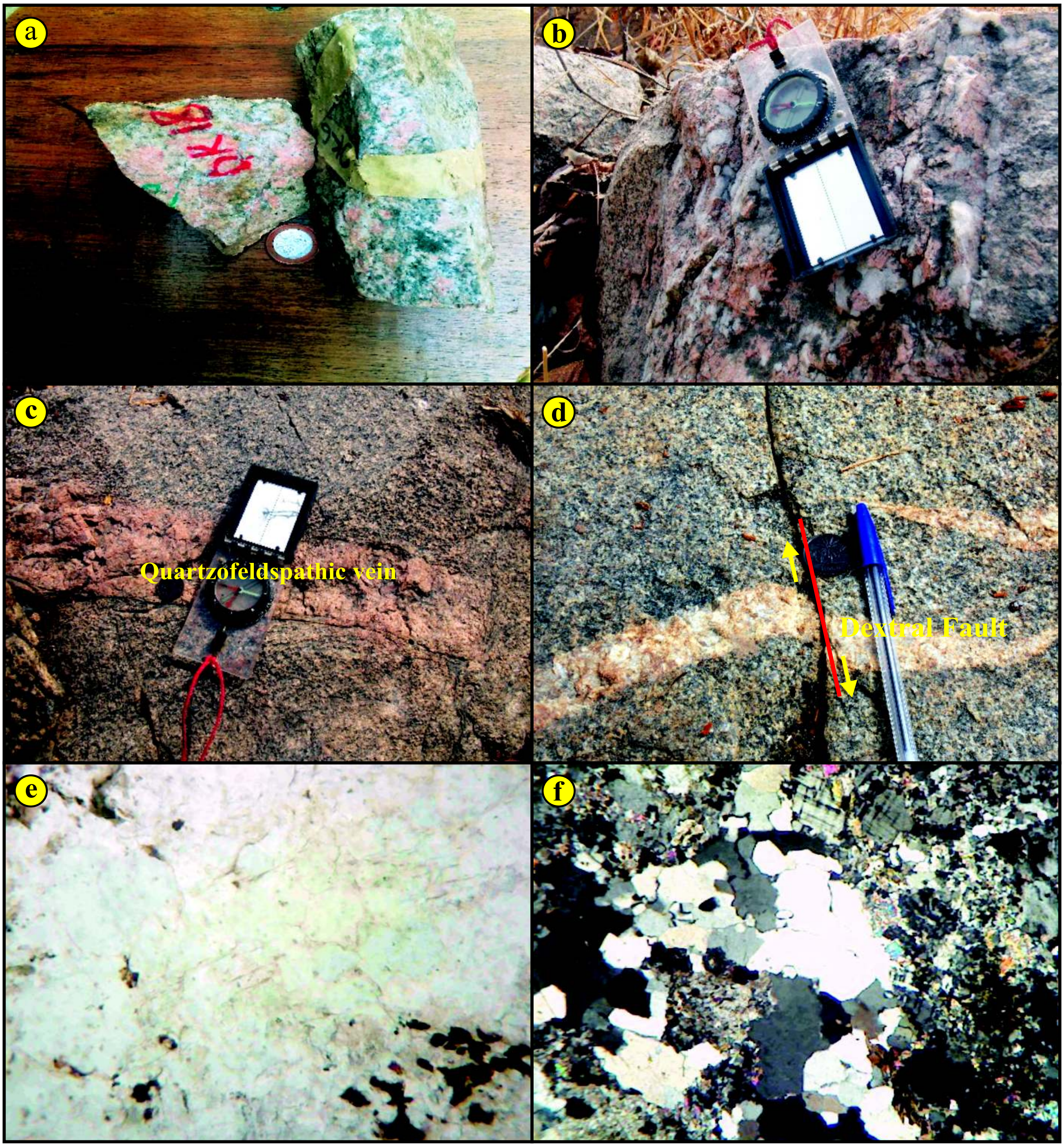

Fig. 3: (a) Hand specimen of granite from the area. (b) Textural appearance of granite. (c) Granite with quartzo feldspathic vein (d) Granite with dextral fault. (e) Photomicrograph of granite under plane polarised light (PPL). (f) Photomicrograph of granite under crossed polarised light (XPL)

The dominant minerals in granite are quartz, feldspar and muscovite. The accessory minerals include chlorite, sericte, zircon, apatite and epidote. The chlorite might have been formed from the retrograde reaction of biotite while the epidote and sericite were formed from late stages of plagioclase alteration.The quartz occur as a colourless mineral (Figure 3f). The dominant feldspar in the rock is microcline. Under crossed polarised light (XPL) it is typified by a subhedral to euhedral crystals of microcline which exhibits a cross – hatched twinning (Figure 3f). The muscovite appear in shades of bright interference colour under XPL. The biotite is characterised by its anhedral shape and pleochroic nature (Figure 3f). Biotite shows a good cleavage and interference colour from brown to green.

The granodiorite occur as sub-elliptical and elongated bodies which constitute hills covering about 75% of the study area. These rocks are well exposed around Patta, Kurmin Baba, Beni and along the banks of River Dinya as rugged topography rising up to about 120m above the surrounding flat land. The granodiorite appear dark in colour and texturally medium to coarse grained (Figures 4a and b). The rock is marked by quartz veins of about few millimetres to 9cm. It is also characterised by set of joints (Figure 4c), fault and doleritic intrusion (Figures 4b and d).

Essential minerals in granodiorite are plagioclase, quartz, biotite, muscovite and hornblende. These rocks have large plagioclase crystals, biotite, and little amount of quartz giving the rock its phaneritic texture. Under the microscope the plagioclase is about 78 % making it the most abundant mineral. This relatively high abundance of plagioclase is the major characteristics that differentiate a granodiorite from granite. Plagioclase is easily distinguished from other minerals due to its characteristic albite twinning (Figure 4 e and f). The quartz appear colourless under PPL with a low relief. Biotite is characterisedby its anhedral shape, pleochroic nature and a high relief. It shows an interference of colour from green, pink and brown (Figure 4f) with a good cleavage.

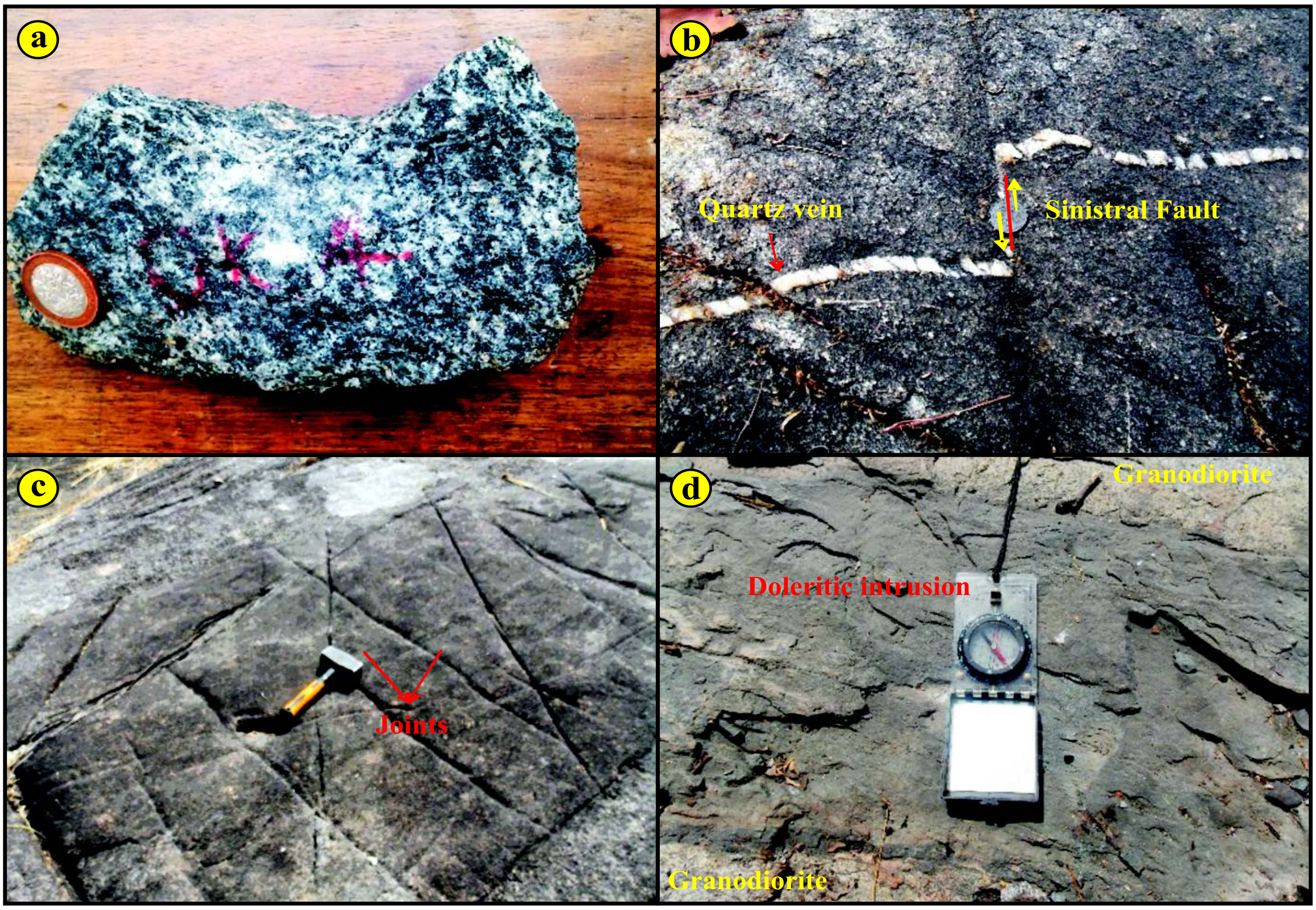

Fig. 4: (a) Hand specimen of Granodiorite. (b) Granodiorite with sinistral fault. (c) Joint sets on granodiorite. (d) Doleritic intrusion on granodiorite

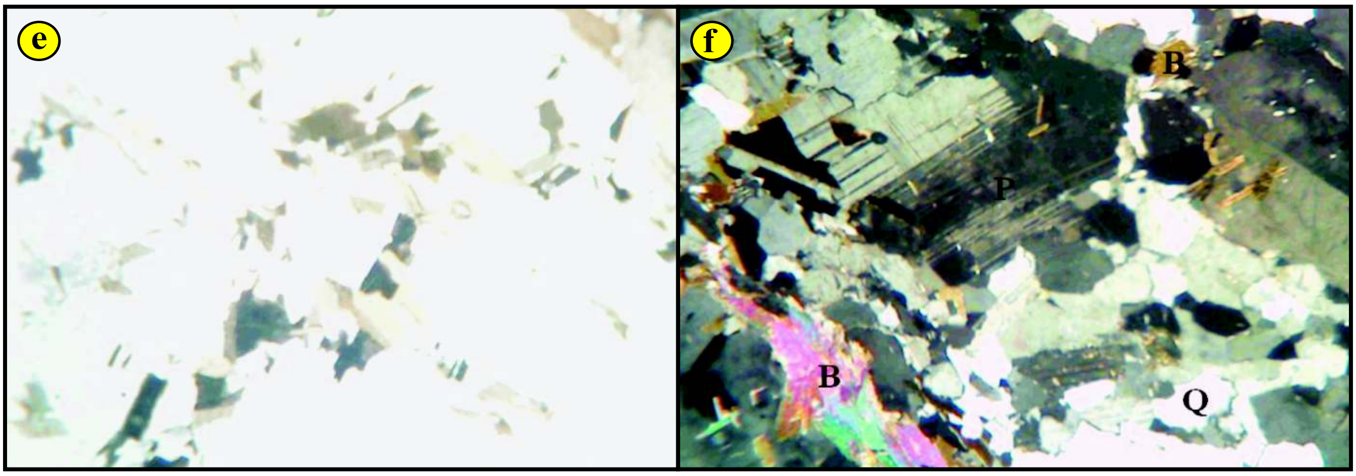

Fig. 4: (e) Photomicrograph of granodiorite under Plane Polarised Light [PPL].
(f) Photomicrograph of granodiorite under Crossed Polarised Light (XPL)

Geochemistry

Results of the geochemical analysis of granite rock samples are presented in Tables 1 and 2. The granites are characterised by high concentration of SiO_2 wt. % and a range of 68.74 - 73.15 wt. %. This range is within that of acidic rocks and this is supported by low contents of MnO (0.52 wt. %) and TiO (0.39 wt. %). The concentration of Al_2O_3 ranges from 13.76 - 16.41 wt % with an average of14.90 wt. %. The samples have average total alkali content (Na_2O + K_2O) content of 4.10 wt. % with K_2O greater than Na_2O content which is similar to the composition of granitic rocks fromObudu plateau in south west (Ukwang and Ekwueme, 2009) as contained in Table 1.

Trace element concentrations are generally high with an exception of Ba, Co and Zn having concentrations below their average crustal abundance (Table 2). In the spider plot (Figure 5) it is observed that Ba, Sr, P and Ti exhibit negative anomalies which are similar to that of pink and leucocratic granite indicating either the retention of plagioclase and accessory minerals in the source during partial melting or their separation during fractionation (Singh and Vallinayagam, 2012).

Table 1: Major oxide concentration (wt %) of granites in the study area

Sample ID	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	Cr_2O_5	LOI	Total
OK 2	69.68	16.41	2.48	1.48	0.57	4.36	4.3	0.04	0.52	0.09	0.03	1.02	100.98
OK 5	69.94	14.73	3.97	1.21	0.93	3.77	4.11	0.04	0.38	0.14	0.05	0.68	99.95
OK 6	68.74	15.23	3.04	1.38	0.66	3.42	4.18	0.03	0.56	0.17	0.06	0.58	98.05
OK 7	70.51	14.67	2.91	1.18	0.12	3.54	4.65	0.04	0.39	0.12	0.052	0.54	98.722
OK 18	73.15	13.76	2.44	1.24	0.42	2.92	4.98	0.02	0.1	0.03	0.043	0.98	100.083
OK 24	69.94	14.62	2.87	1.65	0.42	3.52	4.87	0.04	0.39	0.11	0.038	1.04	99.508
Average	70.33	14.90	2.95	1.36	0.52	3.58	4.52	0.035	0.39	0.11	0.046	0.81	99.55
AGR	71.16	14.79	1.65	1.89	0.63	3.65	4.54	0.06	0.51	0.15	-	0.49	99.52

AGR- Average major oxide concentration of Obudu plateau granites after (Ukwang and Ekwueme, 2009)

A number of discrimination diagrams are plotted below using the concentration of major oxides in order to classify the granite samples. On the TAS diagram (Figure 6) after Cox *et al.* (1979) the granite samples plot in the field of granite. On the AFM diagram (Figure 7) after Irvine and Baragar (1971) the samples plot around the calc-alkaline series.

On the Harker plots most of the major oxides correlate with SiO_2 (Figure 8 a-h). Of interest is the positive correlation of K_2O with SiO_2 and the display of a negative linear trend by Al_2O_3, CaO and TiO_2 (Figure 8). MgO, Na_2O, FeO_t and P_2O_5 do not show any obvious variation trend with SiO_2. The linear trend observed on the Harker plot (8a, b e and f) suggest that despite the

Table 2: Trace element concentration (ppm) of granites in the study area

Sample ID	Ba	Co	Cs	Ga	Hf	Nb	Rb	Sr	Th
OK2	671	6.4	16	19	4.1	12	221	546	15.2
OK5	497	5.9	12	22	3.8	8	198	291	19.4
OK6	391	6.6	16	21	5.1	16	211	157.2	22.4
OK7	321	5.9	18	17	3.4	13	281	172.4	27.6
OK18	229	4.2	10	19	4	22	178	98.2	28.5
OK24	463	4.1	14	23	4.6	6	139	229.1	31.1
Average	428.67	5.52	14.33	20.17	236.98	24.03	204.6	236.98	24.03
AVC*	550	10	3.7	17	5.8	25	112	350	10.7

Sample ID	U	Zr	Y	La	Sm	Tb	Pb	Zn	Ni
OK 2	3.4	217.2	30	39	3.5	0.45	6.9	60	80
OK 5	6.8	199.5	19.3	47	3.2	0.45	4.8	46	89.3
OK 6	7.8	235.7	32.1	26.3	2.2	0.34	8.5	59	59.8
OK 7	7.4	171.3	22.4	33.7	4.2	0.56	11.7	38	121.6
OK 18	7.5	118	39.3	37.3	5.2	0.63	12.3	22	89.2
OK 24	10.5	199.8	34	60.3	1.4	0.69	8.8	56	101
Average	7.23	190.25	29.52	40.6	3.28	0.52	8.83	46.83	90.15
AVC*	2.8	190	22	30	4.5	0.64	20	71	20

AVC* - Average crustal abundance after Taylor and McLennan (1985)

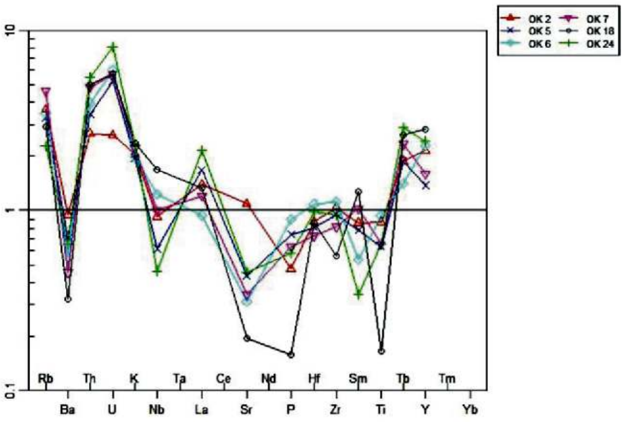

Fig. 5: Spider plot for granite samples of study area

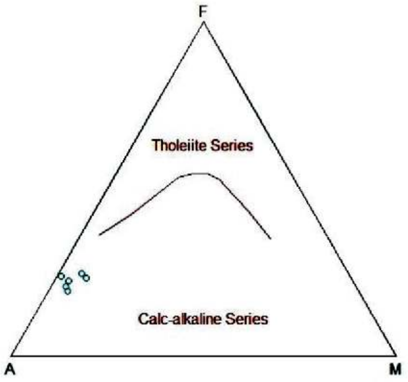

Fig. 7: AFM diagram of granite samples (after Irvine and Baraga, 1971)

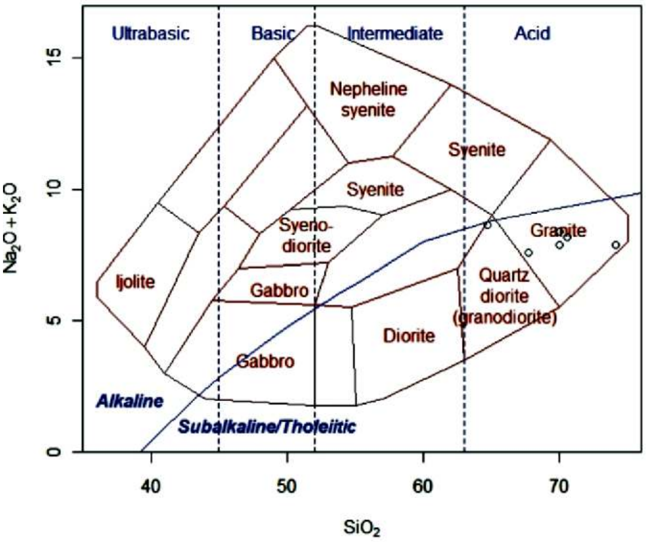

Fig. 6: TAS diagram of granite samples (after Cox *et al.*, 1979)

difference in the spatial location of the granite they are genetically related and their mode of formation can be explained by fractional crystallization.

The granite samples fall within the ferroan field on the FeO_t+MgO against SiO_2 plot (Figure 9a) after Frost *et al.* (2001) while on the A/NK against ASI diagram (Figure 9b) after Frost *et al.* (2001) the samples plot on

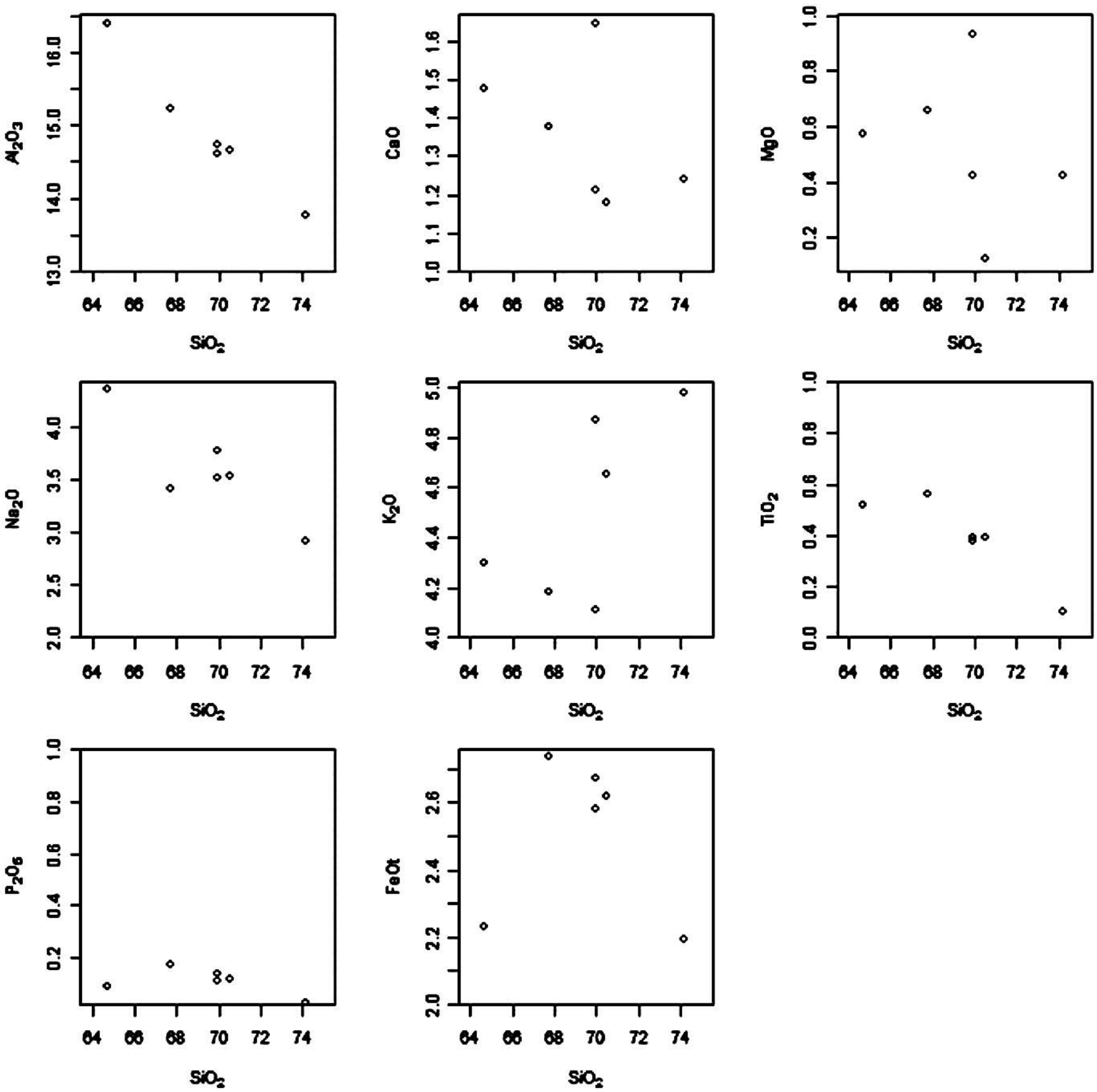

Fig. 8(a-h): Harker variation plots for granite samples of the study area

the peraluminous field. A Na_2O+K_2O-CaO against SiO_2diagram (Figure 9c) after Frost *et al.* (2001) was also plotted for the sample in which they fall majorly on akali-calcic field. The high content of SiO_2in the range of 68.74 - 73.15 wt%, and an average concentration of FeO and MgO suggest a ferroan rock. This is also confirmed in the petrogenetic plot of FeO_t+MgO against SiO_2. The ferroan granites (Fe-enriched) are closely associated with conditions of limited availability of H_2O and low oxygen fugacity during partial melting of their source rocks (Frost *et al.*, 2001).

Peraluminous granites are mainly S-type granites which is supported by Figure (9b) are generated by partial melting of sedimentary protolith White and Chapell (1977). On the K_2O/Al_2O_3 versus Al_2O_3/ (Na_2 + K_2O + CaO) plot (Figure 10) the granites plots on the S-type granite field suggesting its derivation from partial melting of metasedimentary source rock (White and Chappell, 1977).

The granites from the study area plot predominantly on the arc field of Rb-(Y+Nb) discrimination diagram of

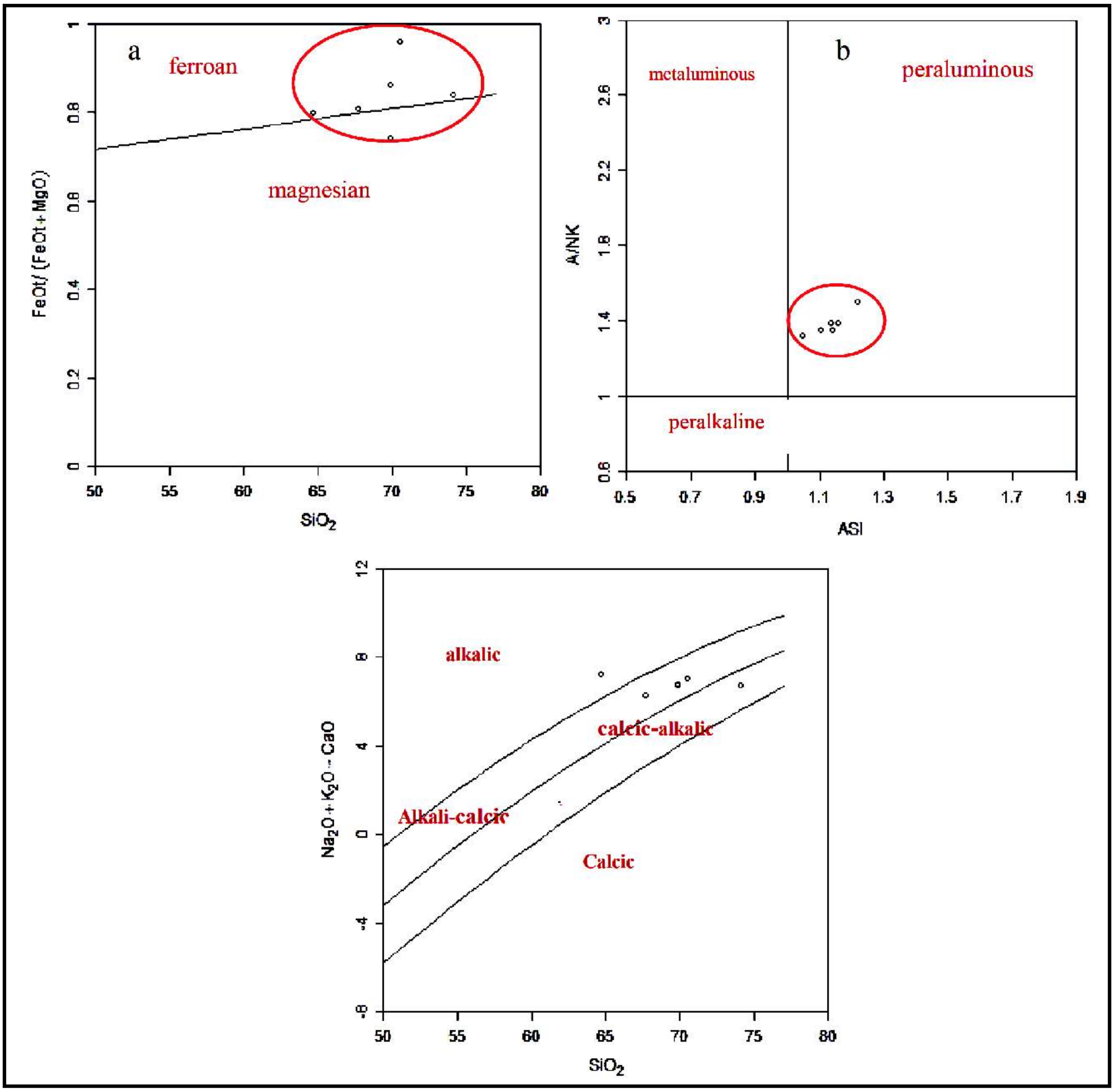

Fig. 9: (a & b): FeOt+MgO against SiO$_2$ & A/NK against ASI plot for granite samples of study area (after Frost *et al.,* 2001) and (C) Na$_2$O+K$_2$O-CaO against SiO$_2$ diagram for granite sample of study area (after Frost *et al.,* 2001)

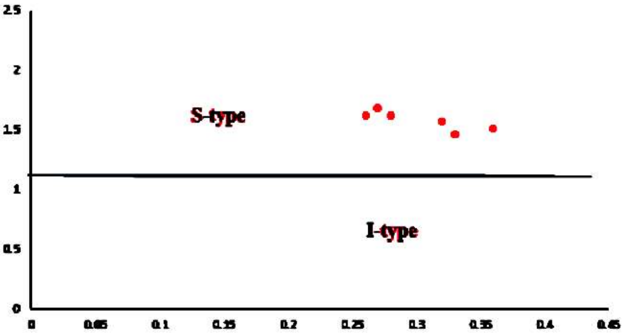

Fig. 10: K$_2$O/Al$_2$O$_3$ versus Al$_2$O$_3$/ (Na$_2$O+ K$_2$O + CaO) plot for granite samples of study area (after White and Chapell, 1977)

Pearce *et al*, (1984) (Figure 11). On the the R_1-R_2 plot (Figure 12) after Bowden *et al*. (1984) all the samples plot in the syn-collisional field with only one sample plotting in the late orogenic field.Syn-collisional is synonymous to Volcanic arc granites (VAG) in the scheme of Pearce *et al.* (1984) and this setting are likened to the process of crustal thickening usually by the under thrusting of crustal "slice" beneath another (Batchelor and Bowden, 1985). Hence, the granite samples can be said to have resulted from crustal thickening.

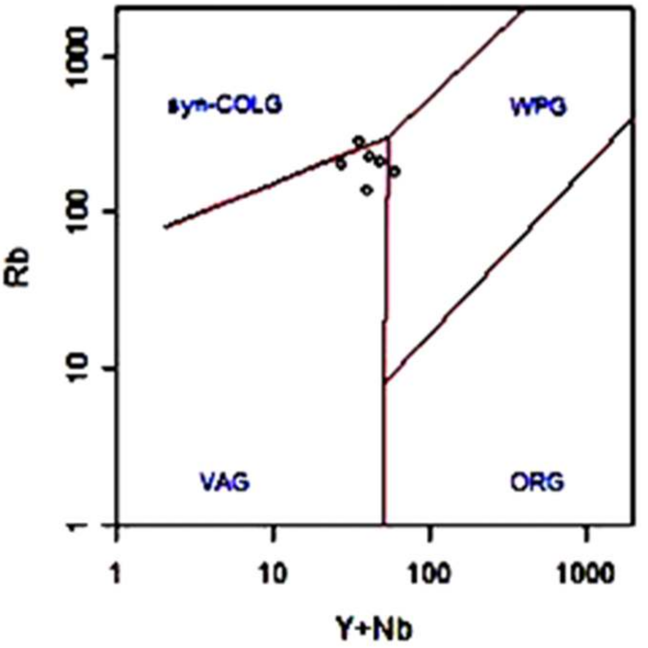

Fig. 11: Rb-(Y+Nb) discrimination diagram for granite samples of study area (after Pearce et al, 1984).

Syn-COLG= Syn-collision granites;
VAG= Volcanic arc granites,
WPG= within plate granite;
ORG= Ocean ridge granites (Symbols as shown in Figure 11).

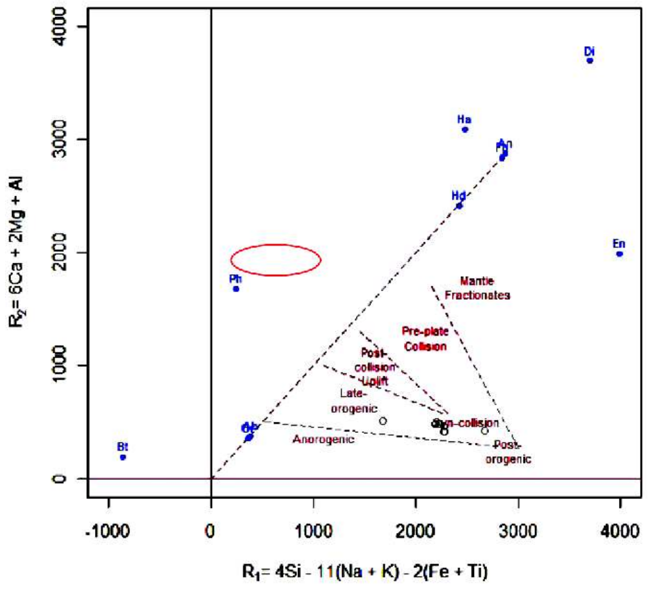

Fig. 12: R_1 versus R_2 tectonic discrimination plot for granites samples of in study area (after Bowden *et al.*, 1984)

The granodiorite has a lower concentration of SiO_2 and K_2O but a higher concentration of Al_2O_3, CaO, and Na_2O when compared with the granites from the study area. It was also compared with granodiorite from Anderan area south west Nigeria and it was observed to be relatively similar (Table 3).

Table 3: Major oxide concentration (wt%) of granodiorite in study area

Sample ID	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	Cr_2O_5	LOI	Total
OK 1	66.85	15.82	0.89	3.77	2.02	4.12	2.98	0.07	0.38	0.29	0.82	1.3	99.31
OK 3	68.64	16.51	0.62	3.52	1.99	3.69	2.34	0.09	0.31	0.19	1.01	0.96	99.87
OK 4	66.94	15.2	2.05	3.86	1.87	4.79	2.45	0.06	0.61	0.52	0.76	0.62	99.73
OK 9	65.36	16.59	3.31	4.7	1.68	4.18	2.74	0.01	0.07	0.24	0.69	0.52	100.09
OK 11	71.09	15.65	0.97	0.38	0.7	3.96	4.97	0.04	0.09	0.01	1.08	1.09	100.03
OK 13	67.78	15.23	4.49	2.98	0.76	3.36	2.02	0.02	0.1	0.49	1.37	1.03	99.63
OK 14	68.99	15.05	3.7	2.53	0.72	4.62	2.83	0.02	0.09	0.38	0.72	0.41	100.06
OK 15	65.97	16.37	3.46	2.33	1.34	4.18	3.76	0.073	0.12	0.28	1.07	0.98	99.933
OK 16	68.69	17.51	1.05	0.62	1.04	3.48	5.22	0.02	0.08	0.03	0.86	1.04	99.64
OK 17	65.68	16.15	4.41	2.48	1.4	4.28	2.24	0.08	0.16	0.3	1.01	0.91	99.1
OK 19	67.75	15.01	4.2	3.66	1.15	3.79	2.32	0.12	0.02	0.48	0.82	0.62	99.94
OK 21	68.29	14.58	4.71	2.12	0.82	3.54	3.89	0.42	0.07	0.33	0.73	0.49	99.99
OK 23	66.82	15.89	3.81	2.53	1.01	3.91	3.67	0.03	0.3	0.31	0.65	1.02	99.95
Average	67.60	15.81	2.89	2.73	1.27	3.99	3.19	0.08	0.18	0.29	0.89	0.85	99.75
AGN*	66.62	16.33	4.17	3.99	1.24	4.01	2.17	0.04	0.59	0.23	-	0.56	99.95

AGN*- Average major oxide concentration in granodiorite (after Okonkwo and Folorunso, 2013)

The granodiorite has concentrations high in Rb, La, Ce, Zr but a low Ba concentration (Table 4). In the normalized multi-element spider diagram (NMORB of Sun and McDonough, 1989; Figure 12), the granodiorite rocks display enrichment in LILE compared to the HFSE as well as negative anomalies of Nb, P, Ba and Ti in most samples confirming an arc – related origin and this strongly suggest that the rocks are product of subduction (Ryerson *et al.*, 1987).

Table 4: Trace element concentration (ppm) of granodiorite within the study area

Sample ID	Ba	Co	Cs	Ga	Hf	Nb	Rb	Sr	Ta	Th
OK1	352	8.9	8.2	21	3.5	15	201	218	0.34	16.5
OK3	621	4.3	4.5	13.2	5.2	14	100	402	0.6	14.5
OK4	469	6.1	1.7	12.4	7.5	8.4	175	254	0.6	18.6
OK9	503	4.6	4.5	14	0.9	6.5	70	201	1.7	10.1
OK11	518	4.1	3.2	15.1	2	4.9	97.5	92.4	0.37	8.3
OK13	301	3.7	4.8	14.7	3.1	9.5	73.9	201.4	0.7	5.9
OK14	482	3.9	2.3	16	2.6	5.7	122	276	0.3	16.3
OK15	605	4.5	1.7	11	7.8	10	110	471.3	0.7	15.3
OK16	473	3.8	2.1	18.9	3	8.4	169.3	71.5	0.39	17.7
OK17	300	3.6	2.1	12	0.31	2.4	101.1	240.2	0.1	9.4
OK19	250	2.6	4.8	13	1.7	0.8	129	337.4	0.1	12.7
OK21	508	5.5	2.3	18	5.8	13	142.1	253.6	0.6	28
OK23	346	2	1.3	13	3.3	7	190.3	180	0.2	17.9
Average	440.62	4.43	3.35	14.79	3.62	8.12	129.32	246.06	0.52	14.71
AVC*	550	10	3.7	17	5.8	25	112	350	2.2	10.7

AVC* - Average crustal abundance after Taylor and McLennan (1985)

Sample ID	U	V	Zr	Y	La	Sm	Tb	Yb	Pb	Zn	Ni
OK1	2.8	61	90	33	34	4.4	0.46	0.85	13	70	45
OK3	0.8	85	120	34	39	5.6	0.61	0.34	15	80	30
OK4	1.5	46	134	12	37.5	5.7	0.32	0.92	22	102	43
OK9	2.3	70	231	11	34	1.55	0.21	1.33	10	122	55
OK11	9.3	8	45.9	9.97	32.5	0.69	0.12	0.37	11.2	17	118.2
OK13	1.3	61	192	6.6	41	1.43	0.34	0.75	8	108	39
OK14	1.6	86	89	3.7	31	3.4	0.31	0.21	7.6	98	63
OK15	2.8	92	263	17.5	38	6.1	0.38	0.45	11	87	71
OK16	6.9	8	79.3	47.9	33.5	0.87	0.26	4.7	18.2	19	121
OK17	0.7	37	109	16	19	2.08	0.41	0.12	22	70	65
OK19	1	29	53	10	17	1.65	0.14	0.22	13	15	68
OK21	1.2	48	178	18.3	42	1.8	0.34	0.17	15	86	58
OK23	1.3	32	192	17	30	3.4	0.29	0.33	9.9	101	50
Average	2.58	51	136.63	18.23	32.96	2.97	0.32	0.83	13.53	75	63.55
AVC*	2.8	60	190	22	30	4.5	0.64	2.2	20	71	20

AVC* - Average crustal abundance after Taylor and McLennan (1985)

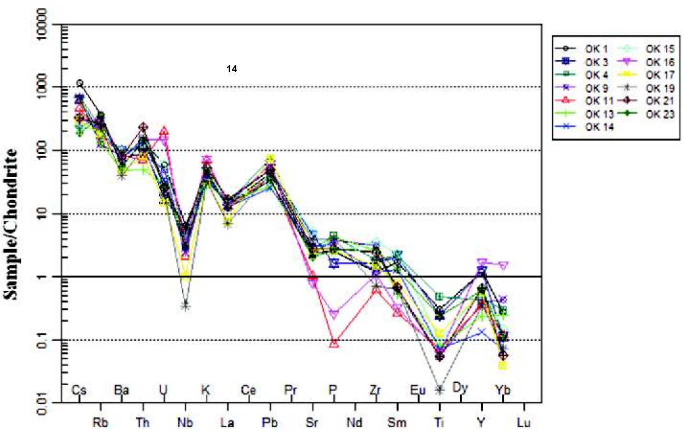

Fig. 11: Spider diagram of trace elements normalized to average crust of granodiorite in the study area after (Sun and McDonough, 1989)

Harker variation plot (Figure 12) was used to establish the evolution of granodiorite samples of the study area geochemically. Al_2O_3, CaO, MgO, Na_2O, TiO_2, and FeO_t exhibit inverse trend with SiO_2whereas variation in K_2O and $P_2O_5$with SiO_2 are not well defined. Generally the strong inverse variation between $SiO_2$and CaO, MgO, Na_2O and FeO_t suggest that the primary mineralogical assemblages of the rocks may have undergone significant changes during fractionation (Ugbe*et al.*, 2016). On the SiO_2 against Na_2O+K_2O plot (Figure 13) after Cox *et al.* (1979) the granodiorites plot majorly in the field of quartz diorite (or granodiorites).On the molecular A/CNK against A/NK diagram (Figure 14) after Shand, (1943) the granodiorite plot on within the fields of metaluminous and peraluminous. The peraluminous to metaluminous nature of this rock unit reflects an evolution that involves the contamination of mantle derived magma by the continental crust (Ustöamer, 1999). FeOt/(FeOt+MgO) plot (Figure 15) after Frost *et al* (2001) the granodiorite samples plot on both the magnesian and ferroan fields. On the AFM diagram (Figure 16) after Irvine and Baragar, (1971) the rocks plot in the calc-alkaline series. Also on the tectonic discrimination diagram (Figure 17) after Pearce *et al.* (1984) the granodiorites plot within the arc-collision granite portion.

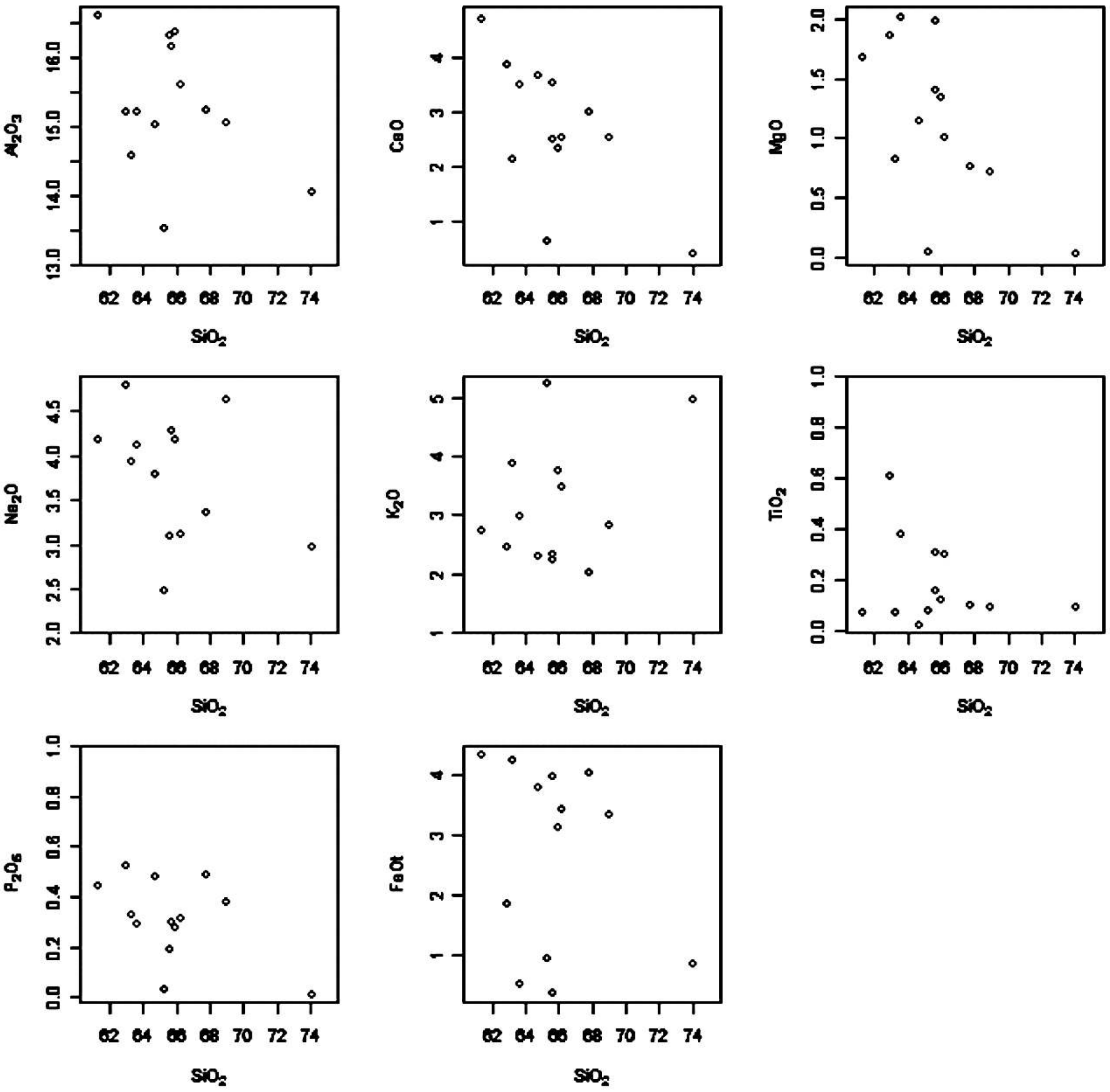

Fig. 12(a-h): Harker variation plots for granodiorite samples of the study area

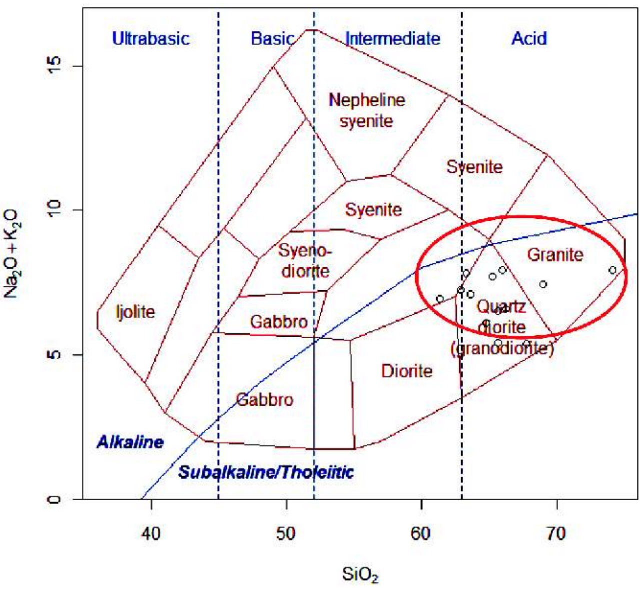

Fig. 13: TAS diagram for granodiorites of study area (Cox *et al.*, 1979)

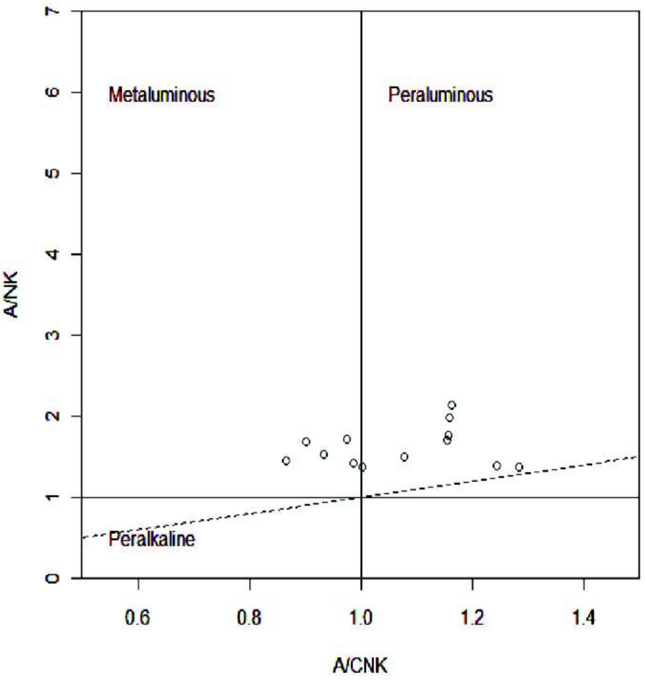

Fig. 14: A/CNK vs A/NK diagram for granodiorites of study area (afterShand, 1943)

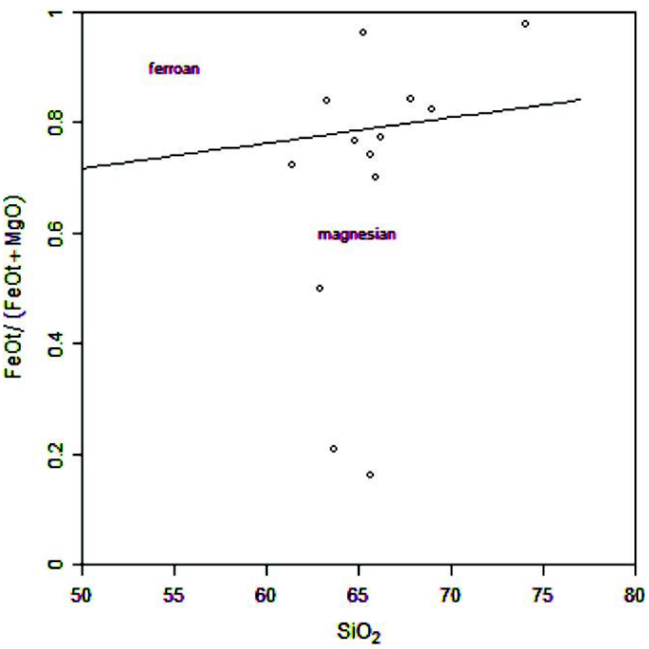

Fig. 15: SiO_2 against FeOt/(FeOt+MgO) plot of granodiorites in study area (after Frost *et al.*, 2001)

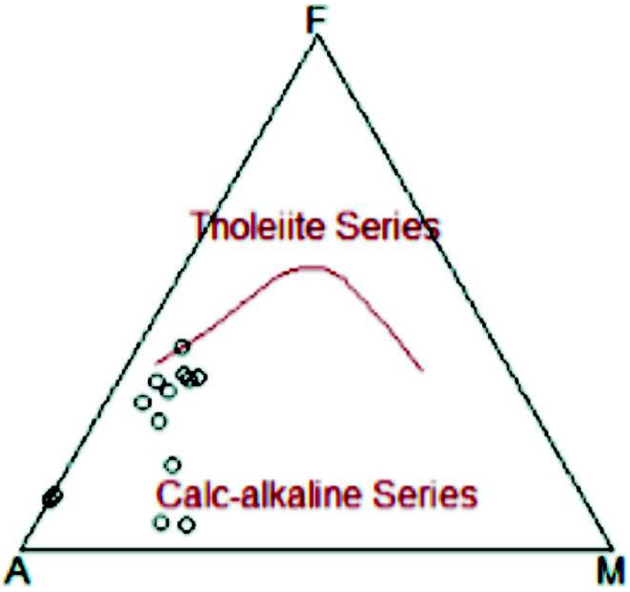

Fig. 16: AFM plot of granodiorites in study area (after Irvine and Baragar, 1971)

Conclusion

Systematic field investigation and petrographic studies of rocks from the study area reveals four petrologic units which are migmatite, granite, schist and granodiorite. These rocks have undergone intense deformational processes indicated by the presence of geologic structures such as joint sets, ptygmatic and similar folds and also sinistral and dextral faults.

Petrogenetic study of rocks from the study area shows that the granitoids are generally calc – alkaline and

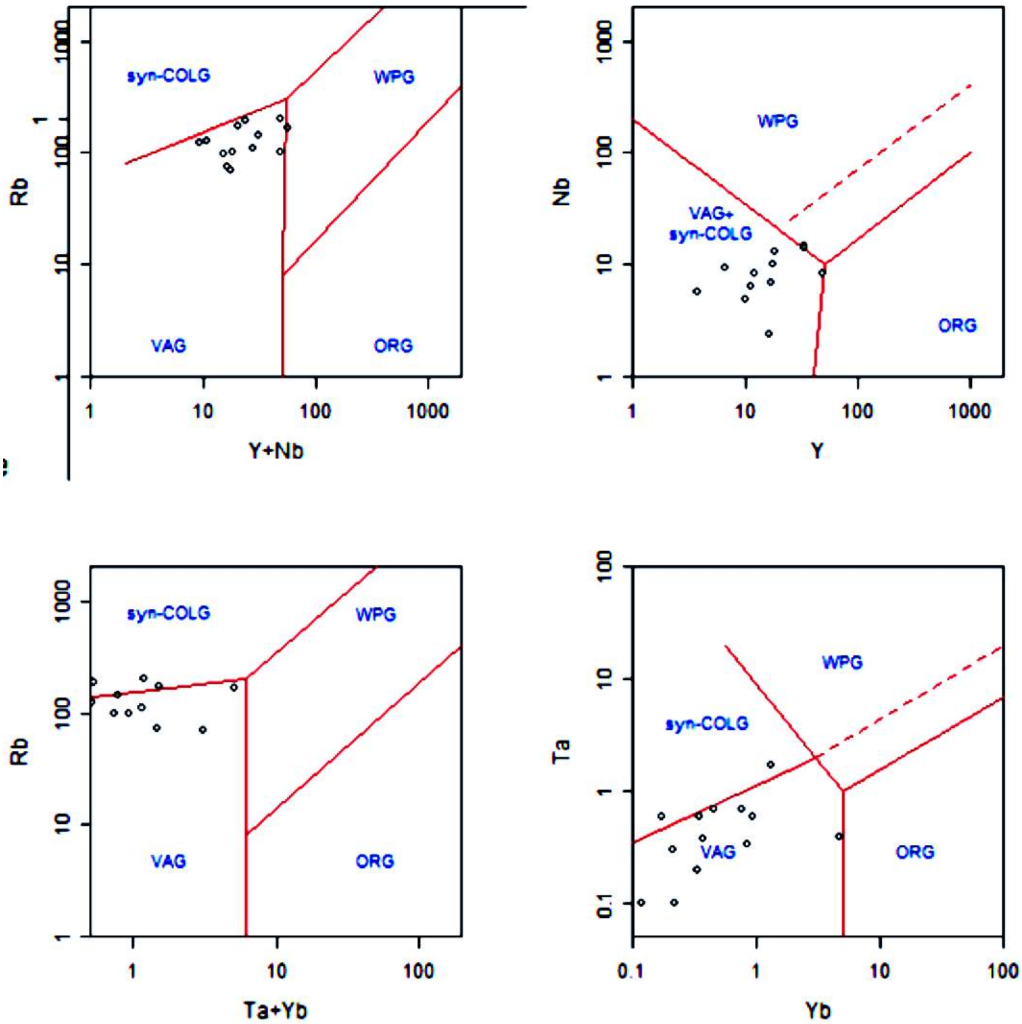

Fig. 17: Tectonic discrimination diagram of granodiorites in study area after Pearce *et al*. (1984)

peraluminous to metaluminous. They display an inverse linear trend on Harker plots suggesting that their primary mineralogical assemblages must have undergone significant changes during fractionation. Based on petrogenetic study, the granitoids in the study area were generated from a syn – to – within plate collision related tectonic setting and are genetically related to a common source by fractional crystallization.

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NIGERIAN MINING AND GEOSCIENCES SOCIETY

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Journal of Mining and Geology Volume 55 No. 1 2019

Articles

JOURNAL OF MINING AND GEOLOGY BI-ANNUAL CONTENTS

Volume 55 Number 1 March, 2019

Note to Contributors

Abstracting / indexing coverage in EMBASE, Geobase, Scopus. Geological Abstracts, Geologie Africaine/Africam Geology,
National Inquiry Services Centre (NISC) - AJOL
And National Universities Commission (NUC) - NVLP

Nigerian Mining and Geosciences Society website **www.nmgsweb.org**

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P.O. Box 9899. Garki Area 10, Abuja, ***Tel.:*** 234-9-3142216

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1. **Geological Map of Dahomey Basin (Modified after Billman, 1976)**
2. **Cross plot of soluble organic matter (SOM) versus total organic carbon (TOC), revealing increasing maturity of samples from PML-1 well. (Devised by Hunt, 1979 and modified after Le Tran and Philippe, 1993)**
3. **Photomicrograph of granodiorite under Crossed Polarised Light (XPL)**