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Petrogenesis, Tectonic Setting and Mineral Potentials of Dlam and Uding areas of Hong, Northeastern Nigeria

Hafizullah Abba Ahmed[1], Aminu Onuche Yusuf[1], Adeniyi Amodu[1], Usman Ahmed Umar[2]

[1]*Modibbo Adama University, Yola*

[2]*Federal University of Technology, Owerri*

ABSTRACT

The study area is located in Northeastern Nigeria. It lies between longitudes 12° 52'30" and 12°59'30" E, and latitudes 10° 07'00" and N 10° 16'00". It is about 116 km^2 in areal extent and lies in the south central of Hawal Massif. It is bounded to the west and south by the Gongola and Yola arms of the Benue Trough. Northwards, it is bounded by the Chad Quaternary Basin. The major rock units in the study area include fine to coarse grained granites, fine grained granites syenite, and quartz syenite. The rocks are characterized by a wide range in SiO_2 (58.7-73.0 wt.%,), alkaline to Calc-alkaline affinity, syn- to late orogenic signatures, metaluminousto peralkaline composition. The granitoids in the study area are categorized into alkaline and calc-alkaline suite based on their geochemical characteristics. The high K_2O and Na_2O (4.86-6.99wt.% and 4.62-6.98 wt.%. respectively) and low Y/Nb ratio of < 2 for the alkaline suites are typical of granitoid suites that are commonly considered as derivatives of mantle sources. All these data indicate that the rocks in the study area are probably formed from fractional crystallization of magmas derived from the lithospheric mantle, which emplaced the syenites, quartz syenite and alkaline granites. The calc-alkaline granite is characterized by higher SiO2 compositionand Y/N ratio >2 exhibiting crustal affinity that was probably formed by the melting of the lower crust. This study indicates that the area under study was affected by two major tectonic (magmatic), which suggest that the calc alkalic granitoids were emplaced earlier during syn-collision by partial melting of Paleoproterozoic crust. Magmatism during the second tectonic episode resulted in to the emplacement of the alkaline granitoids via fractional crystallization and crustal assimilation of lithospheric mantle melts in the late orogenic stage. These rocks exhibit dominantly NNE-SSW structural trend comparable those of othe Pan African granitoids in Nigeria. Additional trace element geochemistry, geochronology and isotopic studies are required to ascertain the origin, age and mineral potentials of the distinct rock suites found in this study area.

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***Correspondingauthor** H. A Ahmed ✉ hifzullahahmed@yahoo.com ✉ Modibbo Adama University, Yola

1. Introduction

The area is located in Northeastern Nigeria. It lies between longitudes 12° 52’30” and 12°59’30” E, and latitudes 10° 07’00” and N 10° 16’00”. It is about 116 km^2 in areal extent and lies in south central part of HawalMassif (Figs.1 and 2). It is bounded to the west and south by the Gongola and Yola Arms of the Benue Trough, Northwards, it is bounded by the Chad Quaternary Basin (Fig. 1). The major geomorphologic features in the study area are the Mandara hills (which form the highest elevation in the area of more than 850 m above sea level). The hills extend into the Republic of Cameroon. Basement complex rocks in Hawal and Adamawa Massifs are part of the extension of the Cameroon uplifts into Northeastern Nigeria. The Hawal Massif has undergone both pre- Pan African and Pan African orogeny. This has resulted into the consequent metamorphism, migmatisation and granitization of the pre-existing rocks (Rahman, 1981).

Nigeria lies in the extensive region east of the West African Craton and northwest of the Congo Craton which was affected by the Pan-African orogeny about 600±150 Ma. The Nigerian Basement Complex lies to the south of the Tuareg shield. Evidence from the eastern and northern margins of the West African Craton indicates that the Pan-African belt evolved by plate tectonics processes which involved the collision between the passive continental margin of the west African craton and the active continental margin (Pharusian belt) of the Tuareg Shield about 600 Ma ago (Burke and Dewey, 1972; Leblanc, 1976; Black et al., 1979; Caby et al., 1981). The collision at the plate margin is believed to have led to the reactivation of the internal region of the belt. The Nigerian Basement Complex lies in the reactivated part of the belt.

The review and description of the Basement Complex of Nigeria was done by several workers including Grant (1971), Oyawoye (1972), Rahaman (1976) and McCurry (1970; 1976). However, despite the works carried out by the different researchers on the geology and petrography of rocks in northern Nigeria in a regional scale, little or no work has been carried out on the petrogenesis of intrusive igneous rocks in the study area to the best of our knowledge. Therefore, the aim of this study is to classify the rocks in the study area shed more light on their origin, tectonic setting and mineral potentials.

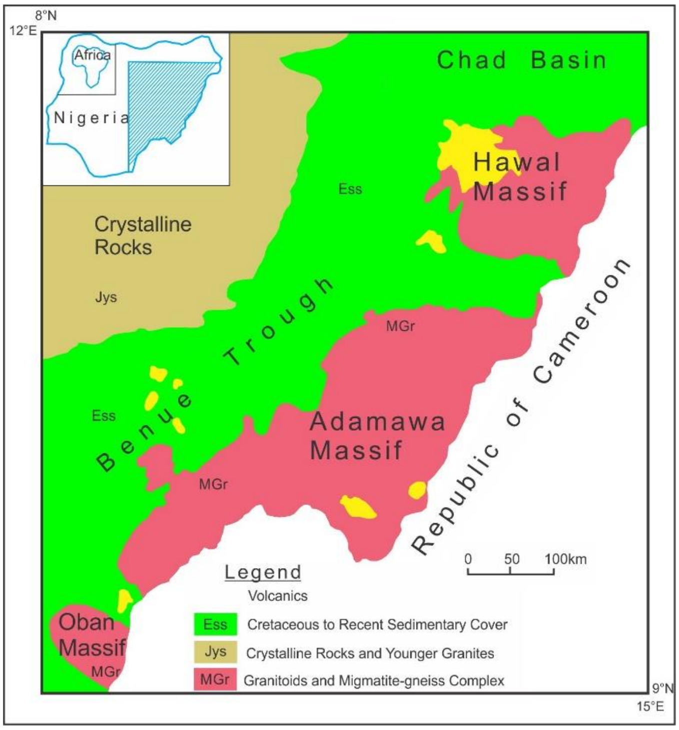

Figure 1: Regional Geological Map of Hawal Massif (Maluski et al, 1995).

2. Regional geology

The Nigerian Basement Complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons (Girei et al, 2020, Black, 1980). The Nigerian basement terrain was affected by the Pan-African orogeny (600 Ma) and it occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006 Girei et al, 2020). The Nigerian Pan African Basement Complex has been divided into two contrasting terranes namely the western and the eastern terranes (e.g., Ferreet al. 1997, Girei et al, 2020, Ahmed et al, 2021). The western terrain corresponds to an area west of Jos Plateau and composed of Archaean tonalites– trondhjemite–granodiorites suites which are largely overlain by the N–S trending supracrustal metasediments (e.g., McCurry 1976; Turner 1983). By contrast, the eastern terrane which corresponds to an area east of Jos Plateau is composed of high-grade metamorphic rocks comprising gneisses, migmatites, and metapelites (Ajibade et al. 1979; Ferre´ et al. 1996, 2002). Metamorphism in this region has reached upper amphibolite and granulite facies condition in places (Girei et al, 2020, Ferre´ and Caby 2007). Both the western and the eastern terranes are intruded by Neoproterozoic granitoids generally known as Older Granites to distinguish them from the Mesozoic anorogenic alkaline granitoids also known as Younger Granites.

3. Rock Types, Petrography and Geologic Structures

The major rock units in the study area include granites, syenites, quartz syenite and migmatite gneiss (Fig. 2). Most of the outcrops in the area are highly fractured and have numerous boulder sizes scattered all over, covering the lower landscape.

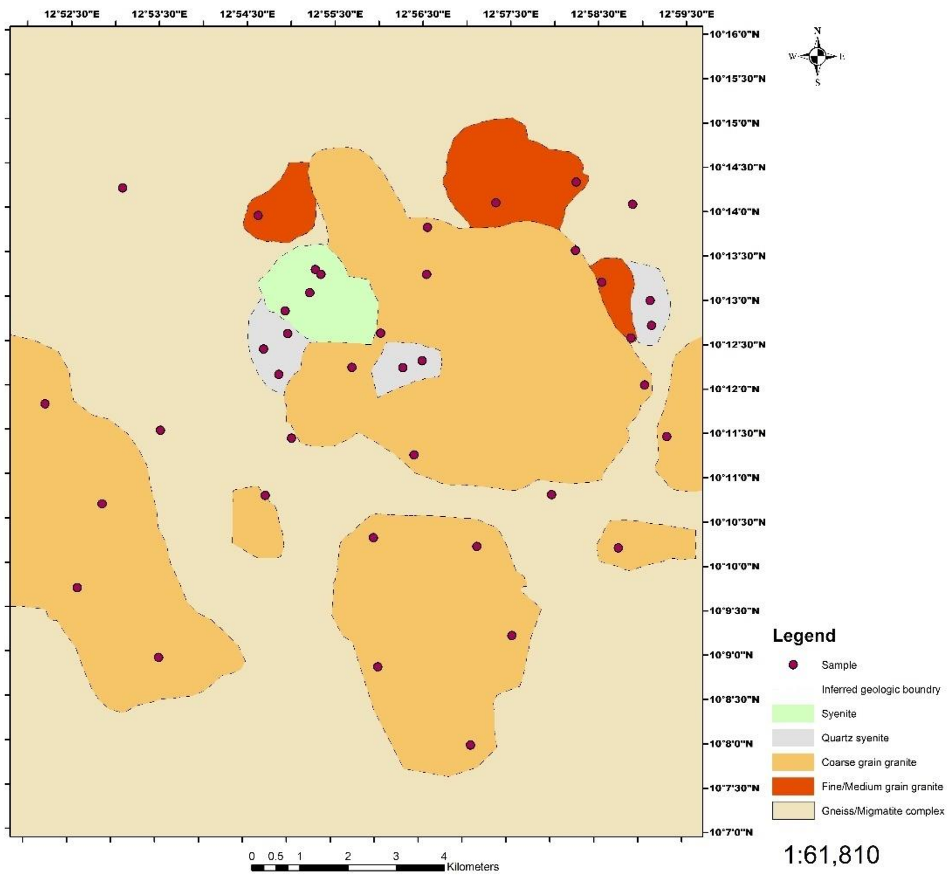

Figure 2: geologic map of Uding and Dlam areas

3.1 Granites

These occur as oval bodies positioned in the N-S direction which is in harmony with what is recognizable in other Pan-African sectors of Nigeria (Udinmwen, 2017). The granites are mainly pegmatitic and coarse grained with grain sizes up to ≥ 2cm. They range in colour from greyish to pinkish. Mineralogically, the granite is composed of quartz (Q), biotite (Bio), plagioclase (plag), feldspars (F) Fig. (3a-b). The quartz is colorless with low relief and are anhedral to euhedral in shape, and they also show wavy extinction. The Biotite in the granitic samples is generally anhedral in crystal form has weak birefringence and shows grey to white order birefringence. It has low relief, shows parallel as well as undulose extinction and is colorless under plane polarized light. The feldspars in thin-section amount to about 30% of the whole rock and they are microcline, plagioclase and orthoclase. They show perfect Carlsbad twinning.Accessory minerals are anhedral crystal grains and they make up the remaining 5% of the whole rock.

1. *3.2 Syenites*

The syenites in the study area is pinkish (Fig. 3c) and composed of about ≤ 5% quartz.They are colorless with low relief and are characterized by an anhedral toeuhedral shape, exhibiting wavy extinction. The Biotite occupies 25% of the whole rock is generally anhedral in crystal form has weak birefringence and shows grey to white order birefringence. It has low relief, shows parallel as well as undulose extinction and is colorless under plane polarized light. The feldspars in thin-section amount to about 65% (Fig. 3d) of the whole rock and they are microcline, plagioclase and orthoclase shows perfect Carlsbad twinning. Iron oxides occur in the ground mass as anhedral crystal grains and they make up the remaining 5% of the whole rock as accessory mineral in syenite.

2. *3.3 Quartz Syenite.*

The quartz syenites in the study are generally fine to medium grained sizes and greyish in colour (Fig. 3e). The quartz in thin-section amounts to abou15-20% of the whole rock, they are colorless with low relief and are anhedral to euhedral in shape, they also show wavy extinction. The biotite occupies 25% of the whole rock, it is generally anhedral in crystal form, weak birefringence and shows grey to white order birefringence. It has low relief, shows parallel as well as undulose extinction and is colorless under plane polarized light. The feldspars in thin-section amount to about 35-40% of the whole rock and they are microcline, plagioclase and Orthoclase shows perfect Carlsbad twinning. Iron oxides occur in the ground mass as anhedral crystal grains and they make up the remaining 15% of the whole rock as accessory mineral in quartz syenite (Fig 3f).

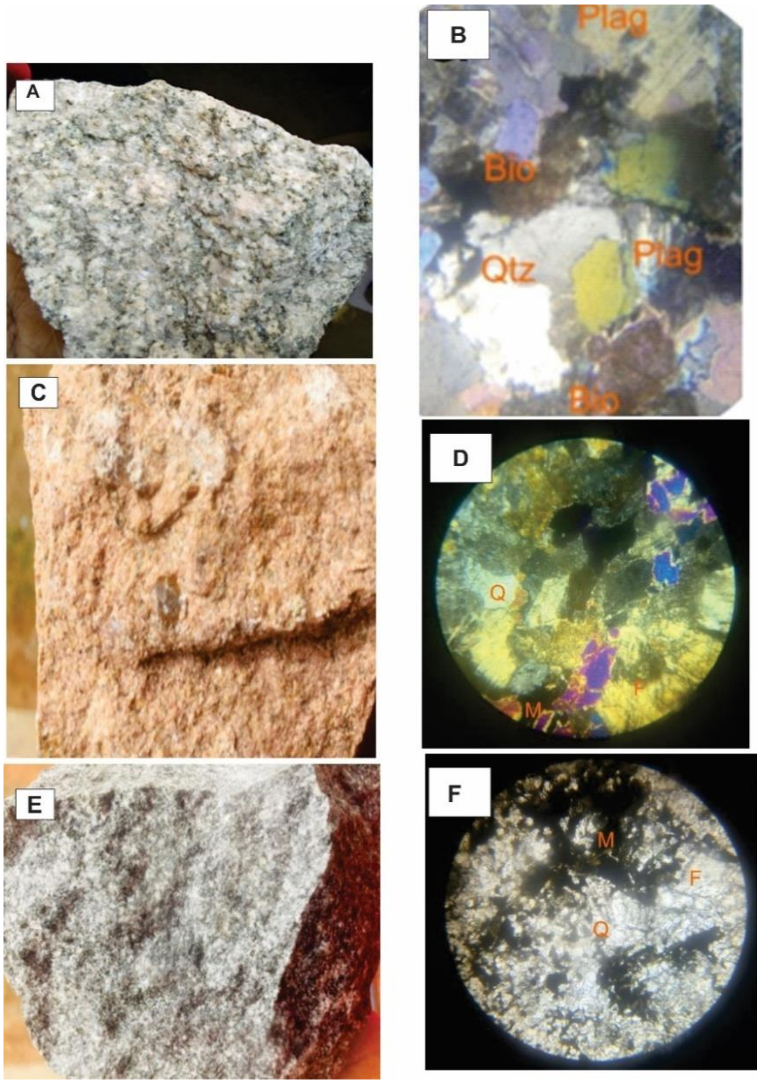

Fig. 3. Hand specimens and photomicrograph of samples

3.4 GEOLOGICAL STRUCTURES

Different structures were observed during the field mapping. These structures include; Joints, veins, fractures and fault (Fig. 4e-f).Joints are widespread over the mapped area. The veins are generally quartz, pegmatitic and aplitic (Fig. 4a-b). Extensive jointing occurs at NE and SW of the study area (Figs. 4 and 5). Joints and fractures are widespread in the study area (Fig. 4c-d), exhibiting dominant NE-SW structural trend (Tables 1 and 2; Figs. 5 and 6).

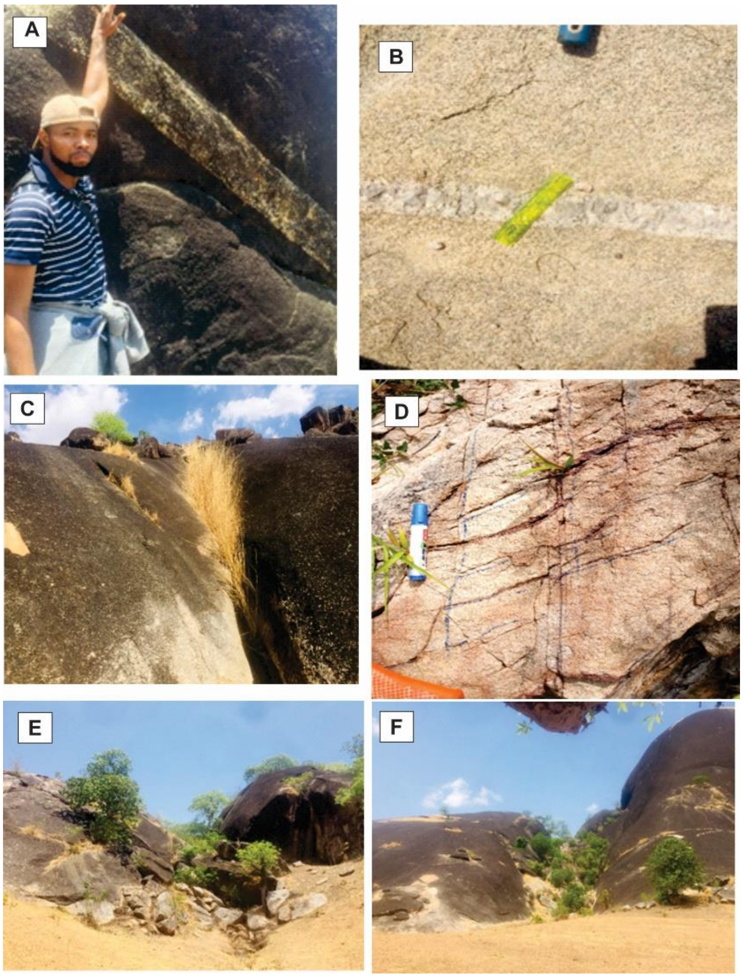

Figure 4a-b: Quartz vein exposed at Muzigba hill, 4c-d: Fractures exposed at Golare, 4e-f: Front and back view of fault at the study area.

Table 1: Statistical Presentation of Joint Readings in the Study Area.

Joint readings in degree	**Class interval**	**Frequency of occurrences**
8, 9, 5, 6, 6, 8, 7,5,4,10,7,9	0-10	12
13,14,17,18,12,15,19,20	11-20	8
25,30,24,29	21-30	4
31,32,33,35,40,40,37,38	31-40	8
41,44,43,50,48,49,50,41	41-50	8
51,60,58,55	51-60	4
67,62,64,65,70,70	61-70	6
79,80	71-80	2
90,90,82,84,86,89	81-90	6
96,97,100	91-100	3
TOTAL		**61**

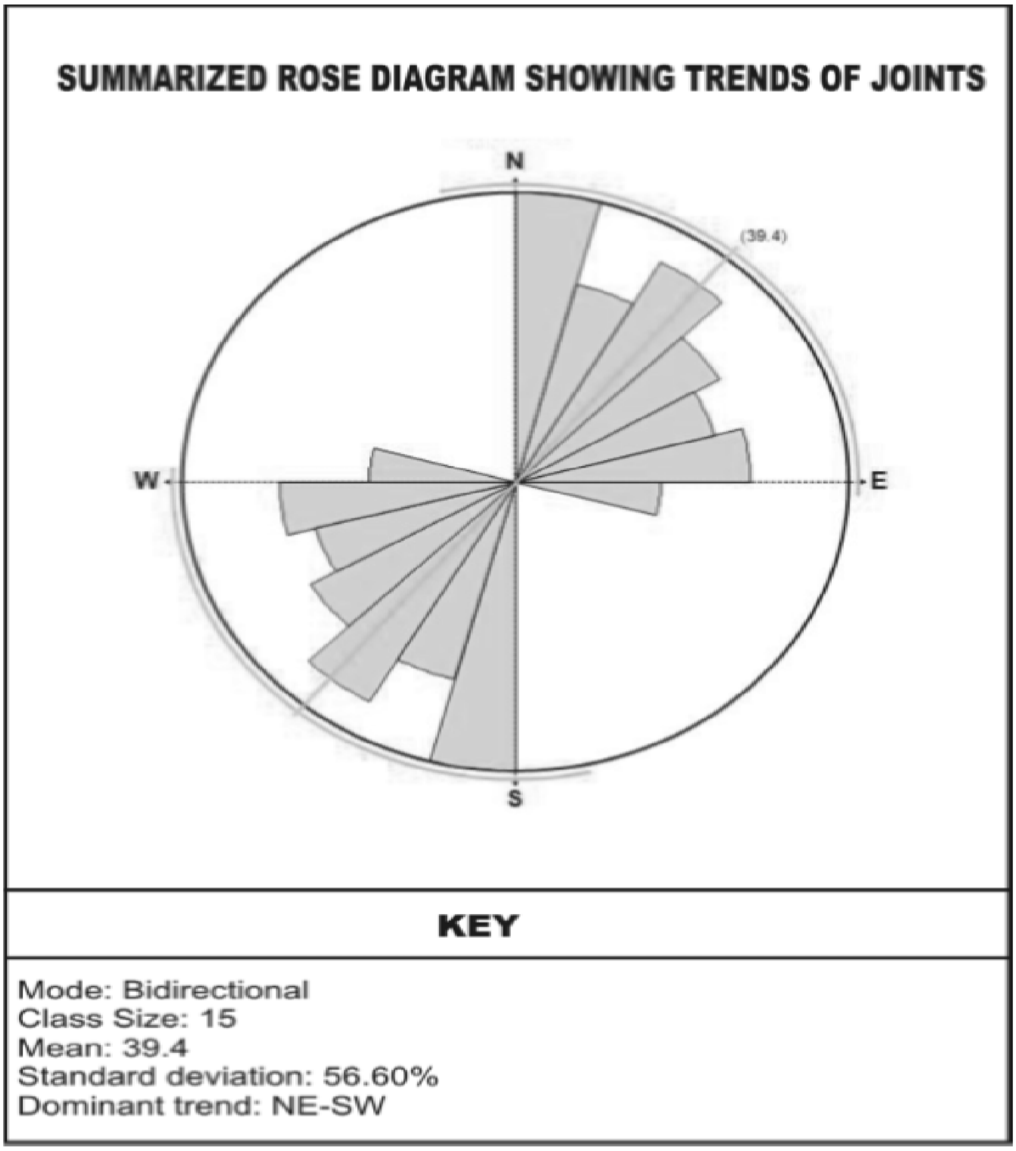

Figure 5: Rose diagram for joints on the granites in the study area.

Table 2: Statistical Presentation of Dyke and Veins Readings in the Study Area.

Veins readings in degree	**Class interval**	**Frequency of occurrences**
0	0-20	
034,40,36,40	21-40	4
50,50,44,52,50,53,55,50,60,55,50,60,60	41-60	13
78,76,75	61-80	3
0	81-100	0
TOTAL		**20**

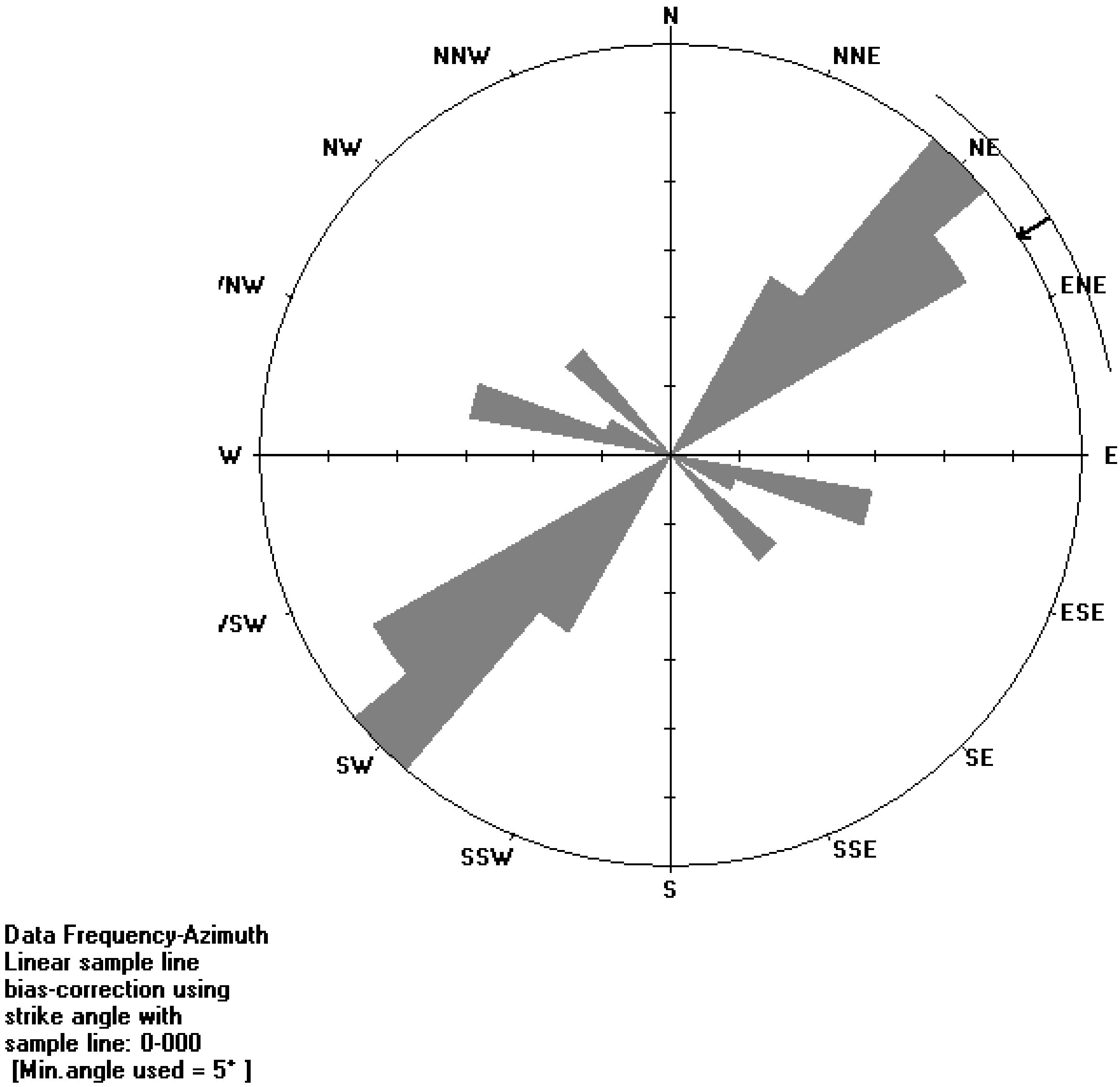

Figure 6: Rose diagram for dykes and veins on the granites in the study area

4. MATERIALS AND METHODS

The quantitative and qualitative determination of elements in the seventeen (17) representative rock samples was done using an X-Ray Fluorescence Spectrometry (XRF) model Rigaku NEX DE 1233. The analysis was carried out at Gombe state University. The result of the analysis of the major and minor elements determined is presented in Table 3. The samples of mappable lithologic units were pulverized to fusible fineness in a tungsten carbide mill at the National steel raw material exploration agency the samples were, approximately 100-200 mesh, and then about 5g of each sample was weighed into 32 mm sample cups with a polypropylene X-ray film of 4μm thickness and were hydraulically pressed. Sample heights were measured in millimetres and sample cups were capped. The EDXRF analysis was performed using a Rigaku NEX DE EDXRF spectrometer equipped with a fifteen-place sample changer, with spin function using slow and steady spinning mode.EDXRF measurements were carried out under helium (He) atmosphere using a palladium (Pd) X-ray tube at a voltage of 60 kV and current of 10μA, with 10 mm beam spot size, and silicon (Si) drift detector comprised of Peltier electronic circuit cooling system. Standardless calibration was employed using Fundamental Parameters (FP) methods software (Rigaku RPF-SQX) to allow for elemental quantification of completely unknown. The software can automatically estimate elemental concentration and provide appropriate corrections. Rigaku NEX DE EDXRF spectrometric analysis can be employed to measure a wide range of elements with varied atomic numbers, from sodium (11) through uranium (92), while providing elemental detection limits from low parts-per-million (ppm) to high weight percent (%wt.). The analytical uncertainties were generally within 0.1-1% (RSD).

5. RESULTS

Major and trace elements data are presented in Table 3. Silica (SiO_2) content in the granitoids ranges from 58.7 wt.% to 71.10 wt.%. The granitoids are typically alkaline as shown on (Al_2O_3+CaO)/(FeOT +Na_2O+K_2O) vs. 100(MgO+FeOT +TiO_2)/ SiO_2 discrimination diagram (Fig. 7a), except samples ST6 and ST7, which are calc alkalic. The alkaline rocks are generally peralkaline, while the calc-alkalic granites (samples ST6 and ST7) are peraluminous and metaluminous respectively (Fig. 7b). The alkaline suites range in composition from syenite, quartz syenites to granites (Fig. 7c). Similarly, on the 10 000×Al/Ga vs. Y and Na_2O+K_2O discrimination diagram proposed by Whalen et al. (1987), most of the granitoids plot within the field of I & S type granite, while some show diagnostic features of A-type granite and plot within the A-type field (Figs. 8a and 8b). The potassium content in the granitoids is high (K_2O=4.98 wt.%–6.99 wt.%) and increases with an increase in silica contents.

Table 3: Major and Trace element composition of Rock samples from Dlam and Uding areas of the study

Sample	DL1	DL2	DL3	DL4	DL5	DL6	DL7	DL8	DL9	DL10	ST2	ST3	ST5	ST8	ST9	ST6	ST7
Rock	Syenite	Syenite	Quartz syenite	Syenite	Quartz syenite	Granite	Granite	Quartz syenite	Granite	Quartz syenite	SYENITE	Granite	Quartz syenite	Quartz syenite	Quartz syenite	Granite	Granite
SiO_2	70.9	61.5	71.8	58.7	69.3	71.1	71.1	68.3	73	70.2	70.9	71.1	69.3	71.1	69.85	70.5	69.7
TiO_2	0.114	0.705	0.0909	1.54	0.288	0.459	0.268	0.552	0.27	0.278	0.11	0.46	0.29	0.27	0.55	0.71	0.54
Al_2O_3	13.4	15	13	13.8	13.5	11.6	12.6	12.5	11.8	12.9	13.4	11.6	13.5	12.6	12.5	15	13.8
Fe_2O_3	1.46	4.8	1.63	6.66	1.79	0.0948	2.86	4.24	2.07	2.42	1.26	0.09	1.79	2.86	2.24	2.8	1.66
MnO	0.105	0.124	0.0715	0.116	0.095	0.0948	0.086	0.115	0.0948	0.11	0.11	0.09	0.1	0.09	0.12	0.12	0.12
MgO	0.103	2.53	0.36	2.66	0.799	0.252	0.135	0.349	0.166	0.39	0.1	0.25	0.8	0.14	0.35	0.53	1.66
CaO	1.35	3.13	0.944	4.97	1.99	1.64	1.2	2.26	1.89	1.6	1.35	1.64	1.99	1.2	2.26	1.13	1.97
Na_2O	6.98	6.23	5.35	5.2	5.68	4.62	5.28	5.1	5.43	5.73	6.92	4.62	5.68	5.28	5.1	4.23	4.2
K_2O	5.52	5.17	6.99	4.98	6.04	6.31	6.09	6.05	4.86	6.01	5.52	6.31	6.04	6.09	6.05	4.17	4.98
P_2O_5	0.43	0.474	0.225	0.906	0.226	0.147	0.128	0.229	0.14	0.153	0.12	0.15	0.23	0.13	0.23	0.47	0.91
S	253	251	225	315	219	252	238	264	234	268	99.67	96.32	99.71	99.75	99.25	99.66	99.53
Cl	152	257	167	631	175	288	201	422	173	183	12.44	10.93	11.72	11.37	11.15	8.4	9.18
V	N.D	278	N.D	410	221	145	N.D	154	87	N.D	253	252	219	238	264	251	315
Cr	N.D	43	N.D	52	37	56	N.D	41	41	N.D	152	288	175	201	422	257	631
Ni	N.D	24	4	16	15	11	6	13	12	N.D	N.D	145	221	N.D	154	278	140
Zn	10	74	19	112	20	58	42	61	28	36	N.D	56	37	N.D	41	43	52
As	4	1	8	N.D	3	4	2	3	3	6	N.D	11	15	6	13	24	16
Rb	173	172	233	136	123	146	160	140	94	187	10	58	20	42	15	74	112
Sr	32	320	26	250	303	82	69	89	93	80	4	4	3	2	61	1	N.D
Y	1	4	41	18	6	20	19	33	12	5	173	146	123	160	140	172	N.D
Zr	68	396	84	799	156	330	334	450	211	230	32	82	303	69	89	320	136
Ba	53	919	91	743	1210	547	339	590	512	223	1	20	6	19	33	4	250
Ce	36	88	26	254	32	208	221	231	99	98	68	330	156	334	450	396	18
La	0	60	0	152	10	108	133	145	60	57	53	547	1210	339	590	919	799
Pb	5	11	6	8	9	7	6	8	6	0	36	208	32	221	231	88	743
Ga	12	19	16	18	12	16	13	19	16	12	N.D	108	10	133	145	60	254
Nb	8	3	39	22	3	31	9	26	13	12	5	7	9	6	8	11	152
Tm	30	86	0	93	34	68	0	59	41	0	12	16	12	13	19	19	8
Ag	6	0	0	6	0	0	5	4	0	6	8	31	3	9	26	3	18

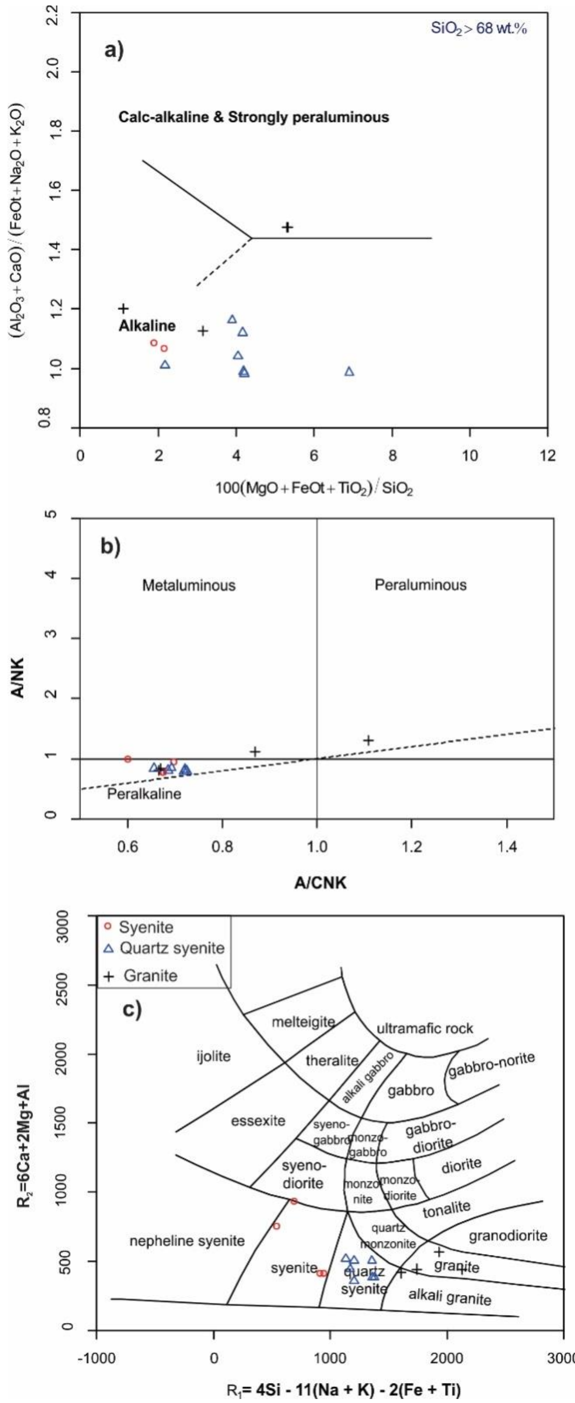

Fig. 7: (a) $(Al_2O_3+CaO)/(FeOT+Na_2O+K_2O)$ vs. $100(MgO+FeOT+TiO_2)/SiO_2$ discrimination diagram (Sylvester, 1989), (b) A/CNK versus A/NK diagram (after Shand, 1943) and (c) R1-R2 discrimination diagram for studied alkaline granitoids (De La Roche et al., 1980).

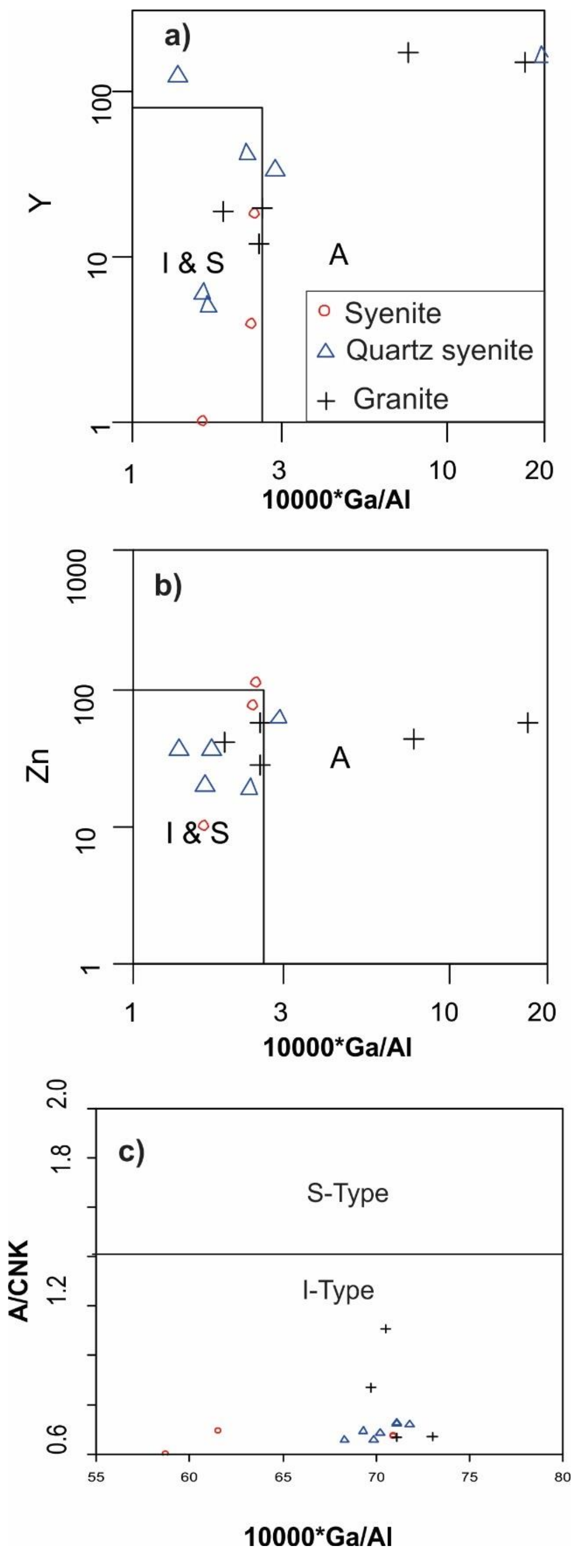

*Fig. 8 (a) Plot of Y vs. 100000*Ga/Al to distinguish between A, I andS type granite,after Whalen et al, 1987. (b) Zn vs. 100000*Ga/Al to distinguish between A, I andS type graniteafter Whalen et al, 1987. and (c) A/CNK vs. SiO_2 after Chappel and White, 1974*

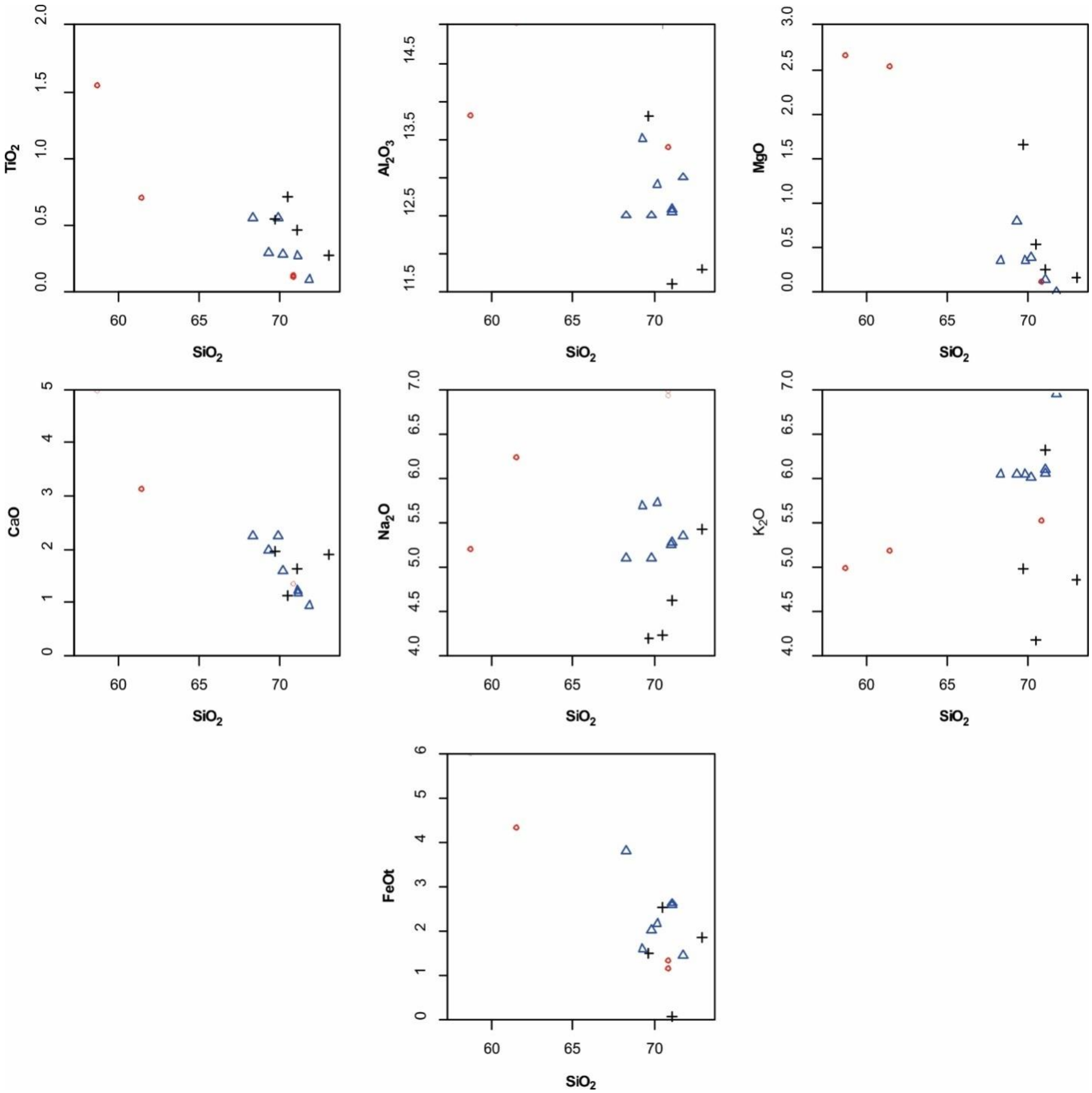

Fig. 9: Harker variation diagrams of SiO_2 against the major elements.

6. DISCUSSION

Most of the oxides (except K_2O) show decrease in their contents with increasing silica (Fig. 9). This indicates the removal of the high temperature minerals and plagioclase in the course of crystallization via fractionation.Geochemical results of the analyzed samples indicate that they belong to alkaline and calc-alkalic series (Fig. 7a). In the plots of Y and Zn versus10000*Ga/Al, the granitoids in Hong area belongs to I and S types granites (Fig. 8a and b). Further discrimination using A/CNK vs SiO2 plot (Fig. 12b), further supports that they are indeed I-type granites (Fig. 8c).

The geochemical characteristics of the syenites and granites such as their high K_2O

and Na_2O (Table 3) and low Y/Nb ratio <2 are typical of granitoids that arecommonly considered as mantle derivatives (Bonin, 2007; Eby, 1992, 1990, Ahmed et al, 2018).But experiment carried out by (Litvinovsky et al. 2000) has revealed that syenitic magmas cannot form through melting of sialic crustal material even at pressures as high as 15 to 25 kbar. According to Litvinovsky et al. (2015), peralkaline granites and syenites characterized by high K_2O and Na_2O are generally derived from K-rich basaltic or andesitic magmas with negligible crustal input. The SiO_2composition of some syenitic rocks in this study (58.7wt.%-61.5wt. %) falls within the andesitic range. Higher SiO_2 compositions could be as a result of bulk assimilation (Heinonen et al, 2021) during magma ascent. Transpressive movement along shear zones probably caused asthenosphere upwelling that emplaced the alkaline syenite, quartz syenite and alkali granite following extensive fractional crystallization (Fig. 9) and crustal contamination. Bute et al, 2019 reported that rocks from the Hawal Massif are characterized by ƐHf(t) values ranging from +3 to -9.03 and TC DM ages range from 1.3 to 2.1 Ga, signifying mixing of juvenile mafic melts with the older continental crust at different stages of the Pan-African Orogeny.

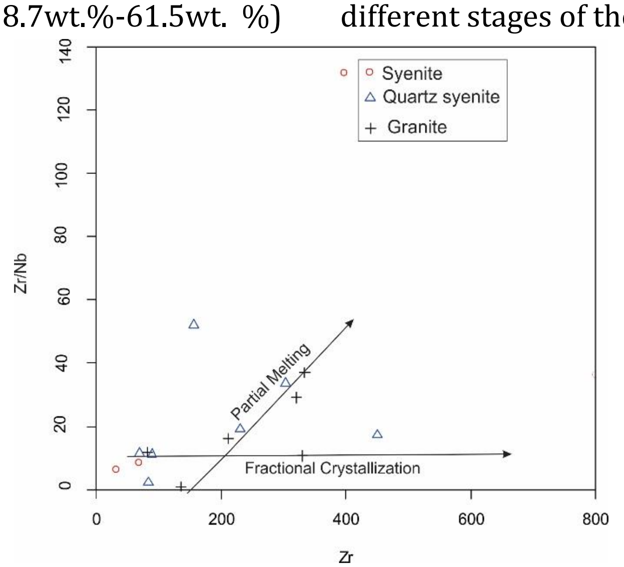

Fig. 9: Zr/Nb vs. Zr diagram for granitoids of the study area from (Ahmed et al, 2021)

On the other hand, the calc-alkalic granite in the study area, which are metaluminous to peraluminous in composition with Y/Nb >2 (e.g., sample DL7) exhibits crustal affinity. They were probably emplaced by partial melting (Fig. 9)of the lower crust facilitated by asthenosphericupwellingduring the syn-collisional tectonics.

On R1-R2 tectonic discrimination plots of (Batchelor and Bowden 1985; Fig.10), the calc-alkalic granite fall within the syn collision, whereas the alkaline granite, quartz syenite and syenite occupy the region around late tectonic event.Zircon U-Pb geochronology by (Bute et al, 2020b) revealed two major tectonic (magmatic) episodes (627 ± 4 Ma and ca. 580 Ma) in the Hawal Massif. This is in conformity with this study, which suggests that the calc alkalic granitoids were emplaced earlier during syn-collision. Magmatism during the second tectonic episode resulted in to the emplacement of alkaline granitoids in the late orogenic stage.These alkaline rocks are probably coeval with the ca. 580 Ma quartz monzodiorite in the western part of the Hawal Massif reported by (Bute et. al 2020b).

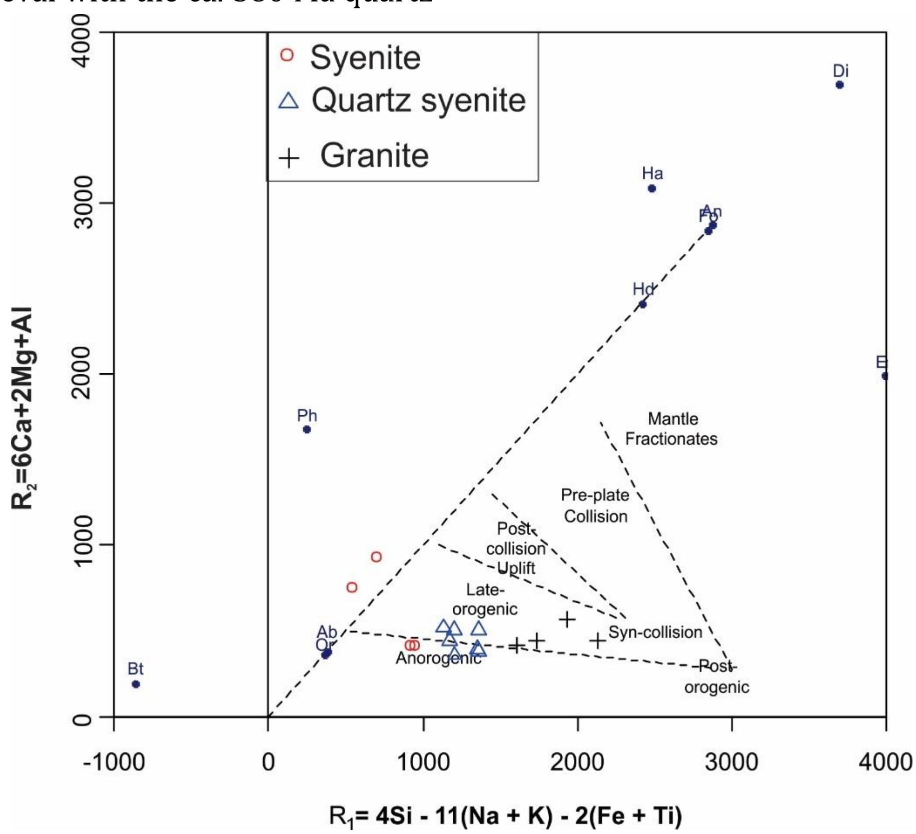

Fig. 10: R1-R2 tectonic discrimination plots after (Batchelor and Bowden 1985)

7. Mineralization potentials.

An anomalously high concentration of Barium Ba concentration (up to 1210 ppm) was detected in Dlam area of the study area. This high value is far above the (90 ppm) universal crustal abundance of Ba in the earth crust. Hence, an indication of Baryte enrichment in the area. Although no industrial baryte deposit has been discoveredin the whole Hong area yet, but the high barium concentrations in mostof the rock samples indicate their mineralizationpotentials. Kwache and Ntekim, (2015), Studied the Geology of Dumne Area in Southeastern Hawal Massif, and reported baryte mineralization in Dumne area, occurring along fault zone emplaced within granites and gneisses. Hence, further structural and geochemical studies is recommended to locate baryte mineralization in the study area and possible extension of Dumne mineralization.

8. Conclusion

The studied rocks in Dlam and Uding areas of Hong are granitic in nature comprising of fine grained to coarse grainedgranites, syenite andquartz syenite. The rocks are characterized by a wide range in SiO_2, alkaline to Calc-alkaline affinity, syn- to late orogenic stage signatures andmetaluminous to peralkaline composition. Based on petrologic and geochemical features, the granitoids are I-type, generated in a syn-collision to late orogenic tectonic setting and emplaced by processesof partial melting fractional crystallization/assimilation. From the combined lines of evidence obtained from the field investigations,geochemical analysis and literature review, the following conclusions can be drawn:

1. Dlamand Udingareas in Hong, northeastern Nigeria is underlain by the Precambrian (Paleoproterozoic) Basement complex rocks similar to other basement rocks in Nigeria.

2. The area was subjected to at least two tectonic episodes during the Pan-African orogeny, which involved syn-collision and late orogenic activities that gave rise to the emplacement of Pan-African granitoids in the area.

3. These granitoids include granite, syenite and quartz syenite. The granites range from calc-alkaline (metaluminous and peraluminous) to alkaline (alkali granite), while the syenite and quartz syenite are generally peralkaline.

4. The graniteswere first emplaced by the partial meltingof the lower crust facilitated by asthenosphericupwelling during the syn-collisional tectonics.

5. Later transpressive movement along shear zones probably caused asthenosphere upwelling that resulted to the emplacement of the alkaline syenite, quartz syenite and alkali granite from the lithospheric mantle following extensive fractional crystallization and crustal contamination

6. These rocks exhibit dominantly NNE-SSW structural trend comparable to those of other Pan African granitoids in Nigeria.
7. Anomalous concentration of Ba is found in Dlam area worthy of follow up.

9. Recommendation

Major elements and limited number of trace elements were analyzed in this research work, so it is therefore recommended that a more detailed geochemical work,isotopes and dating analyses be carried out in the study area. That will further provide more information on genetic relationship of the granitoids, their tectonic history and mineralization potentials.

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