International Journal of Earth Sciences Knowledge and Applications
journal homepage: http://www.ijeska.com/index.php/ijeska
e-ISSN: 2687-5993

Research Article https://doi.org/10.5281/zenodo.15342312

Petrographical and Geochemical Studies on the Granitic Rocks Around Igarra-Ugbogbo Area, Southwestern Nigeria

Ovie Odokuma-Alonge[1], Rita Godfrey Akro[1]*
[1]Department of Geology, Faculty of Physical Sciences, University of Benin, Benin City, Edo State, Nigeria

Article history
Received 09 January 2025
Accepted 29 April 2025
Published 30 April 2025

Contact
*Rita Godfrey Akro
rita.akro@socsci.uniben.edu (RGA)

How cite
Odokuma-Alonge, O., Akro, R.G., 2025. Petrographical and Geochemical Studies on the Granitic Rocks Around Igarra-Ugbogbo Area, Southwestern Nigeria. International Journal of Earth Sciences Knowledge and Applications 7 (1), 78-90. https://doi.org/10.5281/zenodo.15342312.

Abstract
Seven samples of granitic rocks from Igarra-Ugbogbo area in Akoko-Edo Local Government Area of Southwestern Nigeria were obtained with the aim of determining their geochemical and mineralogical properties using XRF, XRD techniques and thin section. Thin section results revealed the optical properties of the minerals present and their behaviours to light. The photomicrographs reveal the presence of various minerals such as quartz, microcline, plagioclase, muscovite and biotite. Results of the geochemical analysis revealed the presence of SiO_2 (56.99-71.22wt.%), Al_2O_3 (13.55-20.76wt.%), Fe_2O_3(T)* (3.55-5.85wt.%), K_2O (0.95-7.21wt.%), Na_2O (2.82-3.98wt.%), CaO (1.88-3.03wt.%) and MgO (0.50-1.56wt.%). The abundance of these major oxides in the samples showed that samples UGB 02, UGB 03, UGB 04, UGB 05 and UGB 07 are probably from a felsic magma and UGB 01 and UGB 06 from an intermediate magma. Using Al_2O_3 classification schemes, its showed that the samples fall into the metaluminous and peraluminous field. The XrD analysis revealed the presence of quartz, alkali feldspars (microcline, orthoclase and sanidine), plagioclase feldspars (albite and anorthite), muscovite, lepidolite, petalite, amblygonite and illite. The modal composition of the quartz, alkali feldspar, plagioclase was plotted on a QAP diagram which showed that the rock falls within the granitoidal class (granite and granodiorite). The trace element plot of Rb versus (Y+Nb) reveal their tectonic setting to be from post-collision to within-plate granitoids.

Keywords
Granitoids, geochemical, alumina, minerals, magma

1. Introduction

Granites are intrusive igneous rocks that form deep within the Earth, composed of minerals like mica, quartz and feldspars. These are minerals which crystallize from magma last (Bowen, 1928). These minerals give granite its distinctive speckled appearance, with large, visible crystals of alkali feldspar called phenocryst embedded in a finer-grained matrix of quartz and mica to give a porphyritic texture. Occasionally, some ferromagnesian minerals such as biotite, hornblende, amphibole, or pyroxene may also be present. True granite is particularly rich in potassium feldspar (35 to 65% of the feldspar content) compared to plagioclase and contains a high percentage of quartz (20-60%) (Streckeisen, 1976).

The word Granitoid is a broader classification encompassing various types of granite-like rocks, sharing many similarities with true granites but exhibit differences in mineral composition, texture, or origin. Granitoids include rocks such as granodiorite, syenite, tonalite and monzonite, which have compositions intermediate between granite and other igneous rocks. These rocks often display variations in colour, grain size and mineralogy, reflecting differences in the original magma composition and geological history.An increase in plagioclase feldspar transits granite into granodiorite (with 65-90% plagioclase) and tonalite (with 90-100% plagioclase). A drop in the quartz content below 20%, becomes potassium feldspar-rich syenite or monzonite (Myers, 1997).

The formation of granites is closely associated with tectonic processes such as continental collision, subduction, and magmatic differentiation. These rocks are commonly found in mountain ranges, volcanic arcs, and continental rift zones, where intense geological activity has led to the generation and emplacement of granitic magma bodies. Granite is known for its durability, strength, and resistance to weathering, making it a popular choice for construction materials, monuments, counter-tops and decorative stones. Its high silica content and crystalline structure contribute to its hardness and ability to withstand mechanical and chemical weathering processes over long periods of time. This work focuses on the petrological characteristics and a geochemical study of one of such rocks within the Igarra-Ugbogbo Area.

2. Location of Study Area

The study area is in Igarra-Ugbogbo Area, Akoko-Edo Local Government Area located in the Northern part of Edo State. It is located between latitude N 7°17'36"- N 7°18'23" and longitude E 6°5'57"- E 6°6'53". It is surrounded by Aiyetoro Community to the north, Igue Community to the south, Uffah Community to the east and Oloma Community to the west.

3. Geological Setting

The Nigerian Basement Complex rocks consist of Migmatite-Gneiss-Quartzite Complexes dating back to the Archean to Early Proterozoic era (about 2700-2000 million years ago). Additionally, there are NE-SW trending Schist belts predominantly located in the western part of the country, and Older Granite plutons from the Late Proterozoic to Early Phanerozoic period (approximately 750-450 million years ago). It has been intruded by Mesozoic per-alkaline ring complexes and overlain by Cretaceous and younger sediments (Fig. 2).

In Nigeria, granite is a significant feature of the basement complex, often forming large outcrops that stand out above the general landscape (Akinola et al., 2021). These rocks also known as Older Granites (Falconer 1911) or Pan-African Granites, include various types such as biotite granite, hornblende biotite granite, diorite, hypersthene granite, porphyritic or porphyroblastic muscovite granite, quartz-hypersthene granite, syenite, quartz diorite, non-porphyroblastic or non-porphyritic granite, and aplite granodiorite (Oyawoye, 1964; Kröner et al. 2001). These Older Granites are evidence of significant tectono-magmatic activities during the late Precambrian period, associated with the Pan-African orogeny around 600 million years ago, and include a variety of rock types such as granodiorite, syenite, granite, tonalite, and charnockite (Truswell and Cope, 1963). They form circular to elliptical bodies in schists and more elongate bodies in the migmatite-gneiss (Rahaman 1976). The contact between the older granite and the Basement Complex is commonly gradational and a replacive contact exists between the members (Rahaman, 1988). Their formation is linked to orogenic events that resulted in widespread plutonism across Pan-African regions. Early research classified these rocks as granitoids, with compositions ranging from granite to adamellite. These granitoids are calc-alkaline, containing significant potassium and sometimes traces of normative corundum (Rahaman, 1988).

4. Local Geology

The geological setting of the region includes three main rock types: syn to late tectonic granitoids, low-grade metasediments, and a polycyclic crystalline complex of migmatites and gneisses (Odeyemi 1976). Most parts of the study area are underlain by the metasediments, referred to as the Igarra Schist Belt, which presumably overlies an older gneiss-migmatite basement, possibly of Liberian age (Odeyemi 1976).

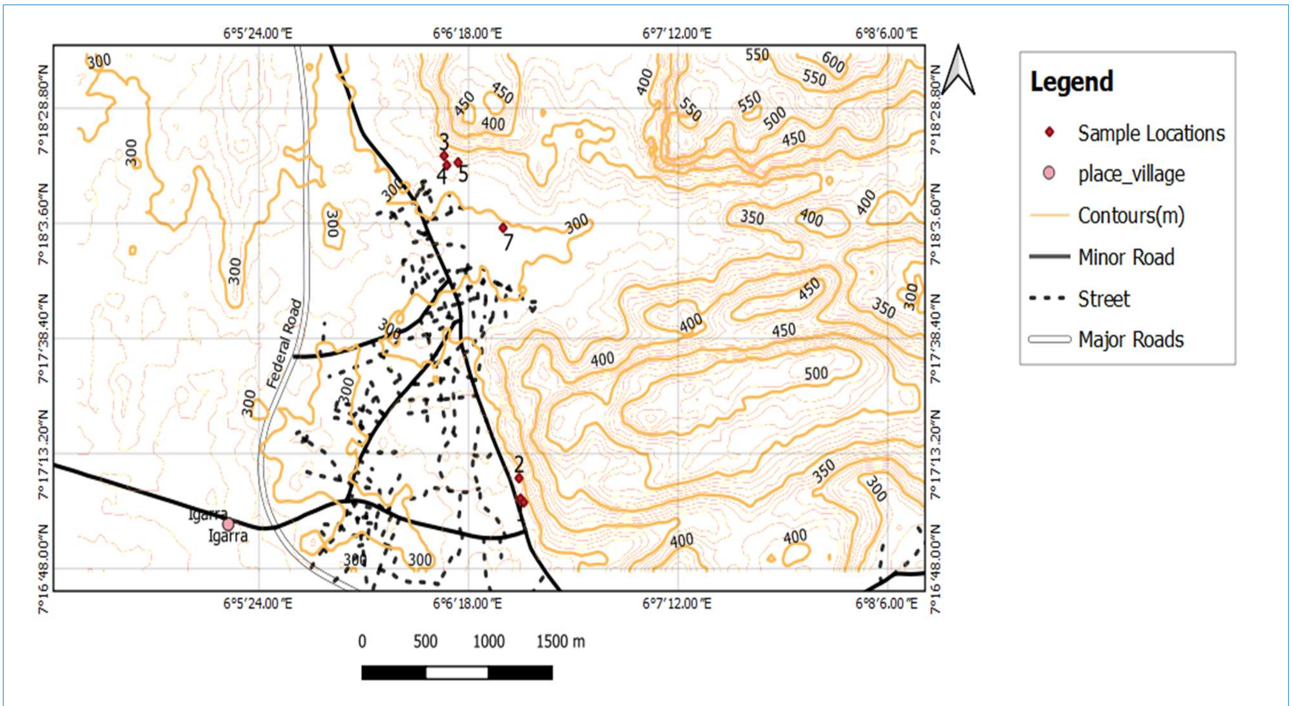


Fig. 1. Location map of study area

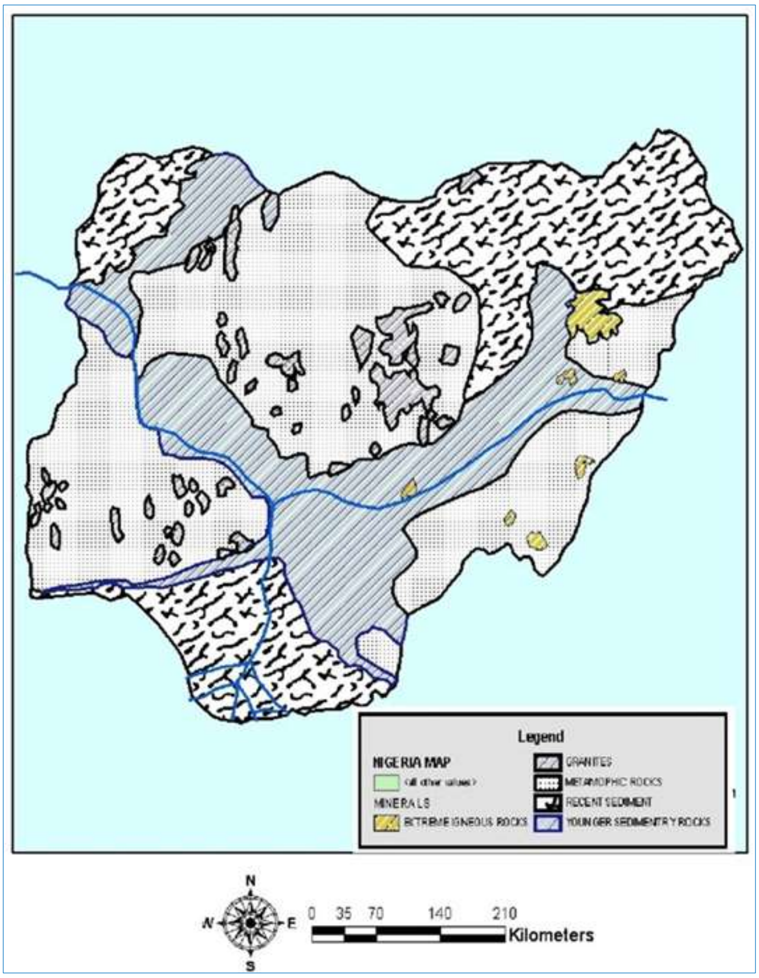


Fig. 2. Geology map of Nigeria showing study area modified after Ajibade et al. (1989)

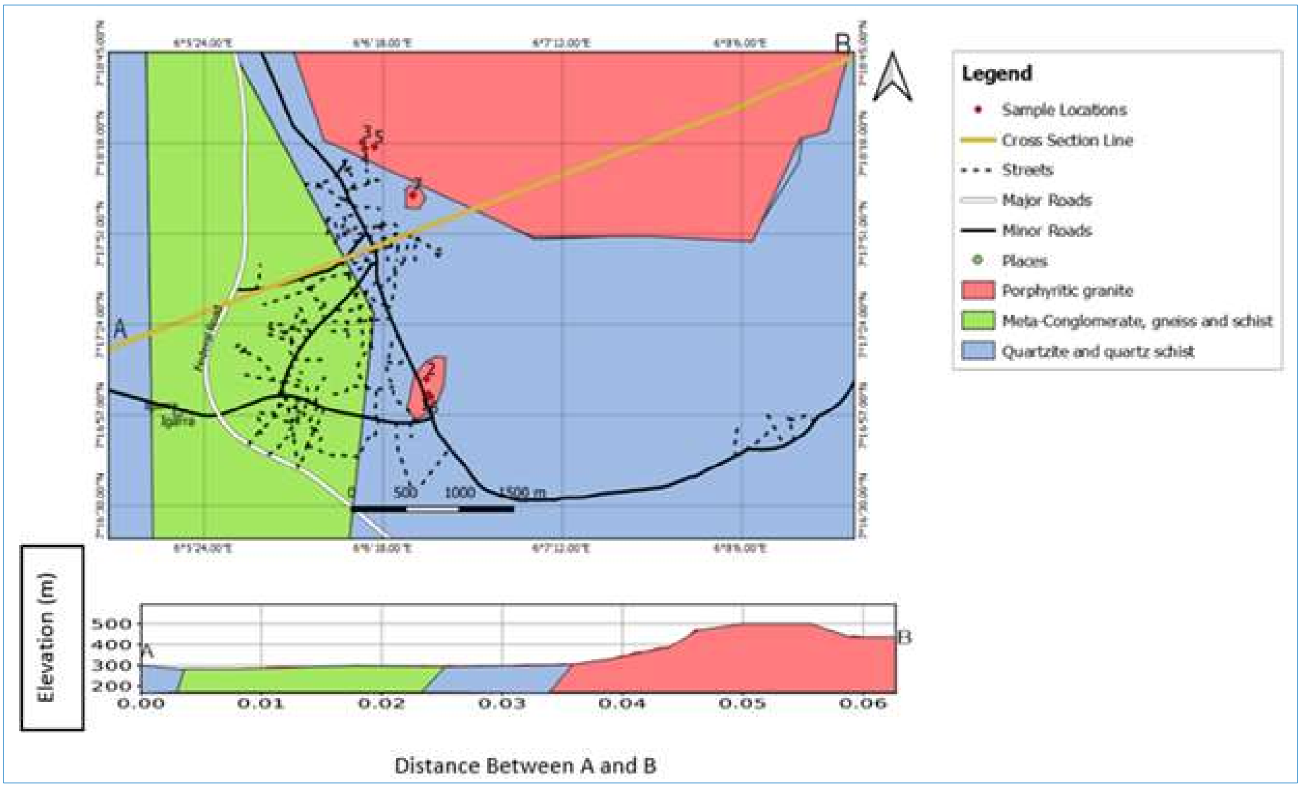


Fig. 3. Geological map of study area

The metasedimentary succession in Igarra area consists predominantly of pelitic to semi-pelitic rocks of low to medium grade metamorphism. Major rock types exposed in the area include (i) semi-pelitic phyllites; (ii) quartzbiotite schist; (iii) mica schist; (iv) calc-silicate gneiss and marble; and (v) meta-conglomerate; all of which have been deformed in at least two episodes (Odeyemi 1988). These are considered to be part of the schist belts of Nigeria and occupy a N-S trending belt (Rahaman 1976).

The migmatite-gneiss complex, containing ancient metasedimentary relics, evolved during the Liberian orogeny (Odeyemi 1988). The migmatite-gneiss complex rocks are the oldest, with the metasediments lying unconformably on top and being younger. These granites occur as part of the Igarra Pluton occupying high elevations. . The granitoids, which include various types such as porphyritic biotite granites and granodiorites which are discordant with the non-metamorphosed syenite dyke (Odeyemi 1988; Rahaman1988; Ajibade et al., 1989). They are part of the Older Granites associated with the Pan-African orogeny. The Older Granites are the youngest, formed during the waning phase of the Pan-African orogeny. A geology map of the study area is shown in Fig. 3.

5. Materials and Methods

This research employed both field and laboratory techniques. In the field, detailed geological mapping was carried out. Each outcrop was plotted on a base map using GPS, and a hand lens was used to examine mineral compositions in hand specimens. Structural data were measured with compass-clinometer and tape measure, and fresh samples were collected using a geological hammer. Key features were documented with a digital camera, and all observations and measurements were recorded in a field notebook. The collected samples were labeled, packaged, and transported to the laboratory in sample bags. In the laboratory, the seven granitic rock samples were selected for petrographic analysis. Thin sections of these rocks were prepared according to the method outlined by Rowland (1953).

Fig. 4. Granitic rock samples collected

These slides were then examined using a petrological microscope (model NP-107B) under both plane-polarized light (PPL) and crossed polarized light (XPL), with transmitted light used to capture photomicrographs of the thin sections. The samples were sent to Rolab Research and Diagnostics Laboratory, Ibadan for geochemical analysis using X-ray Fluorescence-MODEL: TEFA ORTEC automatic X-ray F. The samples were also sent to the laboratory at the National Steel Raw Materials Exploration Agency (NSRMEA), Kaduna for mineralogical analysis using Rigaku Miniflex Benchtop 600 XRD Machine. The results were interpreted using geochemical data, binary plots and discrimination diagrams for mineralogical classification and petrogenesis.

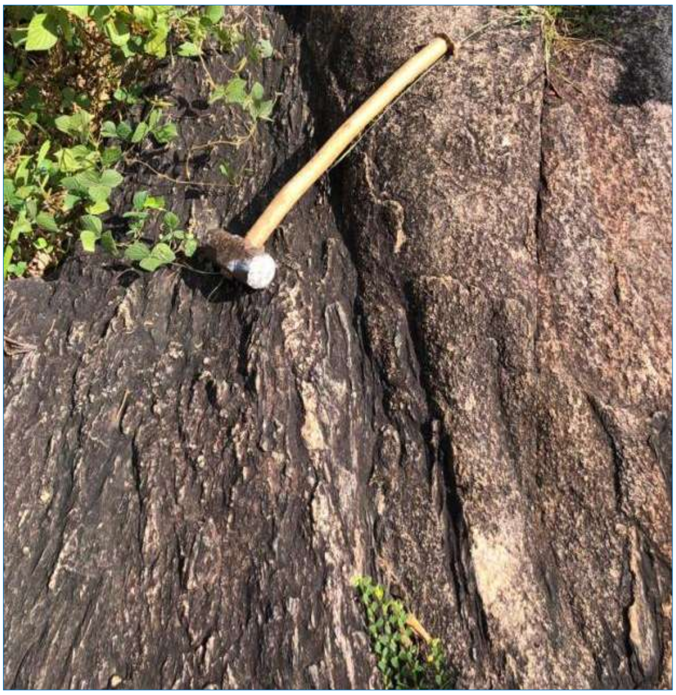


Fig. 5: Contact between quartz biotite schist and the granite body

Fig. 6. Xenolith of Schist occurring in the granite body

4. Results and Discussions

4.1. Field Observation

The samples were obtained from the Igarra Pluton which is composed mainly of granitic rocks. The pluton covers a large part of the sampled area. The pluton intrudes the metaconglomerate and quartz-mica schist. The highest elevation of outcrops measured was 340m for UGB 03 and the lowest being 301m for UGB 06. The minerals that can be identified directly by the naked eye were quartz, alkali feldspar (microcline), muscovite and biotite. The samples collected show two types of colour indices: leucocratic (UGB 03, UGB 04, UGB 05 and UGB 07) and mesotypic (UGB 01, UGB 02 and UGB 06). The rock samples containing more biotite about 10% are classified as mesotypic and that with light-coloured minerals such as quartz, alkali feldspar and muscovite with about 5% of biotite are classified as leucocratic. The rocks show a random fabric with random interlocking texture of the individual minerals. The texture of samples collected is porphyritic with phenocryst of alkali feldspar in a groundmass of quartz, muscovite and biotite (Fig. 4). They are coarse-grained with an increase in grain size moving up the Igarra Pluton and with a decrease in biotite. Outcrops close to the contact between the metaconglomerate and quartz biotite schist (Fig. 5) are characterized by xenoliths of these rocks (Fig. 6). Field classification identified the samples tentatively as porphyritic biotite granites.

6.2. Petrographical Characteristics of the Granitic Rocks

The photomicrographs reveal that the granitic rocks in the study contain quartz, microcline, plagioclase, muscovite, biotite and opaque minerals. The properties of these minerals under plane polarized light (PPL) and crossed polarized light (XPL) are listed as follows (Figs. 7-13):

Quartz: Quartz is colourless under PPL and has low relief. It shows no pleochroism. There is no cleavage. Quartz under XPL it shows Order I interference colour.

Microcline: Microcline under PPL is colourless and has low relief. It has an anhedral to euhedral crystal form. It has perfect cleavage with no pleochroism. Microcline under XPL is anisotropic, it shows an Order I birefringence (gray and white) with a cross-hatched twinning.

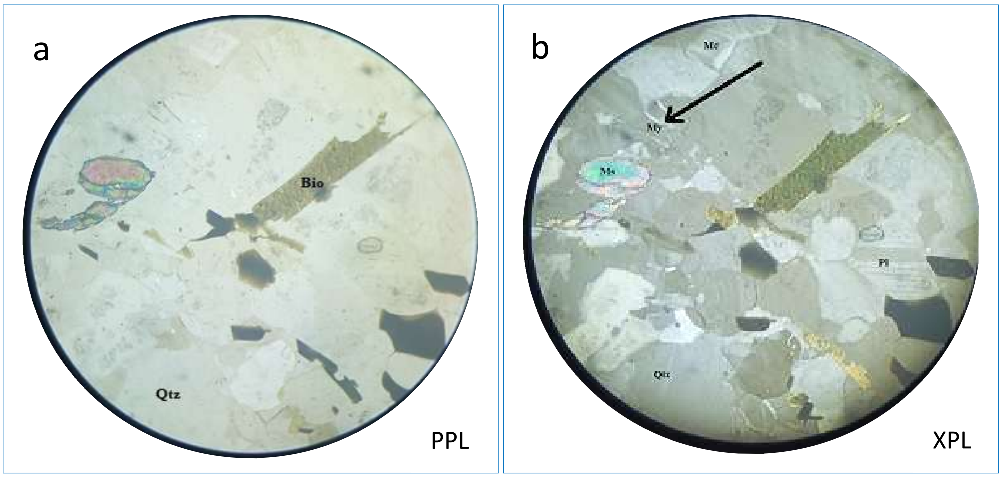


Fig. 7a and b: Photomicrograph of UGB 01 showing the repeated twinning of plagioclase, brown colour and relief of biotite and vermicular texture of myrmekite, X40.(Qtz=Quartz, Mc= Microcline, Ms=Muscovite, Bio= Biotite, My= Myrmekite)

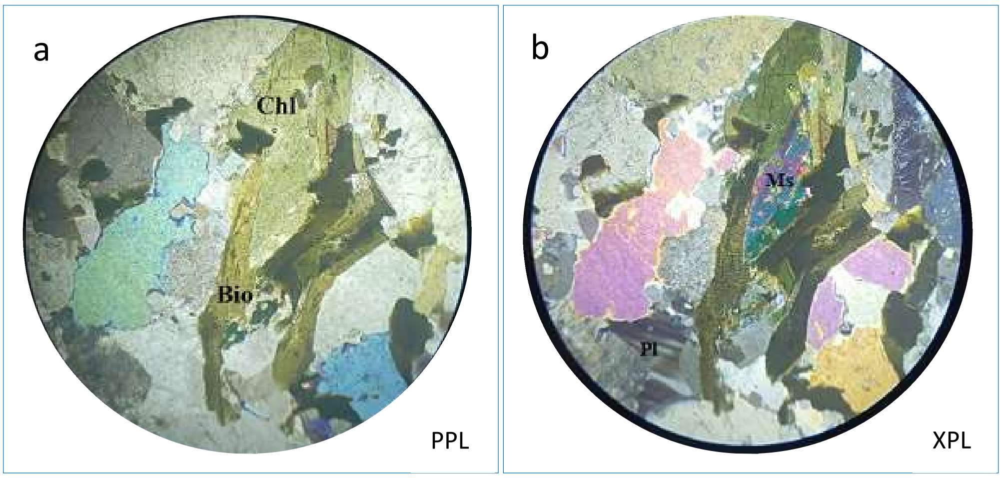


Fig. 8a and b: Photomicrograph of UGB 02 showing flaky habit of muscovite and alteration of biotite to chlorite, X40.(Qtz=Quartz,Mc= Microcline, Ms=Muscovite, Bio= Biotite, Chl = Chorite)

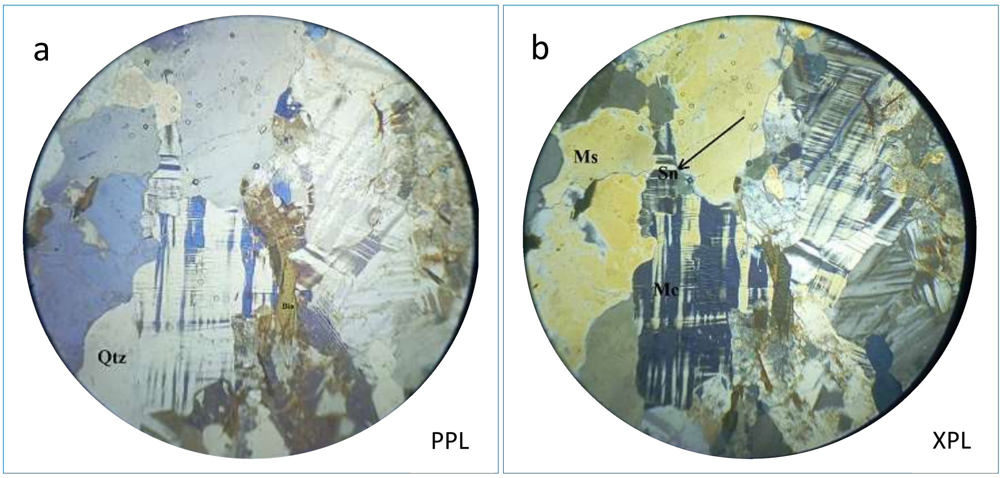


Fig. 9a and b: Photomicrograph of UGB 03 showing large grains of microcline showing their cross-hatched twinning and flaky habit of muscovite, X40.(Qtz=Quartz, Mc= Microcline, Ms=Muscovite)

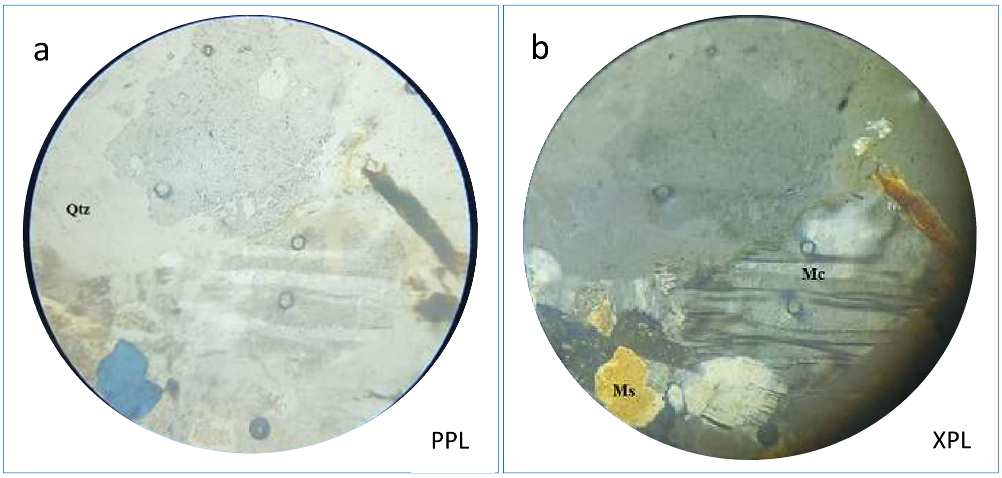


Fig. 10a and b: Photomicrograph of UGB 04 showing perthitic inter-growth in microcline, X40.(Qtz=Quartz, Mc= Microcline, Ms=Muscovite)

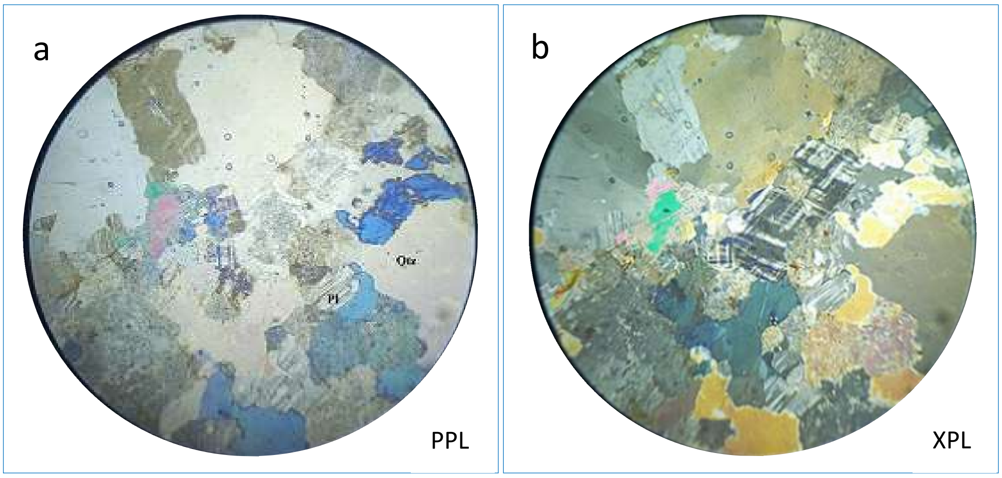


Fig. 11a and b: Photomicrograph of UGB 05 showing the cross- hatched twinning in microcline, X40. (Qtz=Quartz, Mc= Microcline, Ms=Muscovite)

Plagioclase: Plagioclase is with an anhedral crystal form characterized by a one-direction cleavage with no pleochroism. Plagioclase under XPL, it shows an Order I birefringence (gray and white) with an inclined extinction. The Myrmekite observed in Fig. 7 indicates late-magmatic to post-magmatic changes, especially in the replacement of k-feldspar to plagioclase possibly influenced by fluid or deformation in the area.

Muscovite: Muscovite under PPL is colourless and shows a moderate relief. It has a one-direction perfect basal cleavage and shows very weak to no pleochroism. It occurs as shapeless flakes with irregular outlines. Muscovite under XPL it shows an Order I-II birefringence at the basal section.

Biotite: Biotite under PPL is brown with a high relief and euhedral crystal form. It has perfect basal cleavage in one direction and pleochroism from from light to dark brown. Biotite under XPL showa Order I birefringence with an interference colours of brownt o purple.

Opaque Minerals: They appear black under PPL and XPL

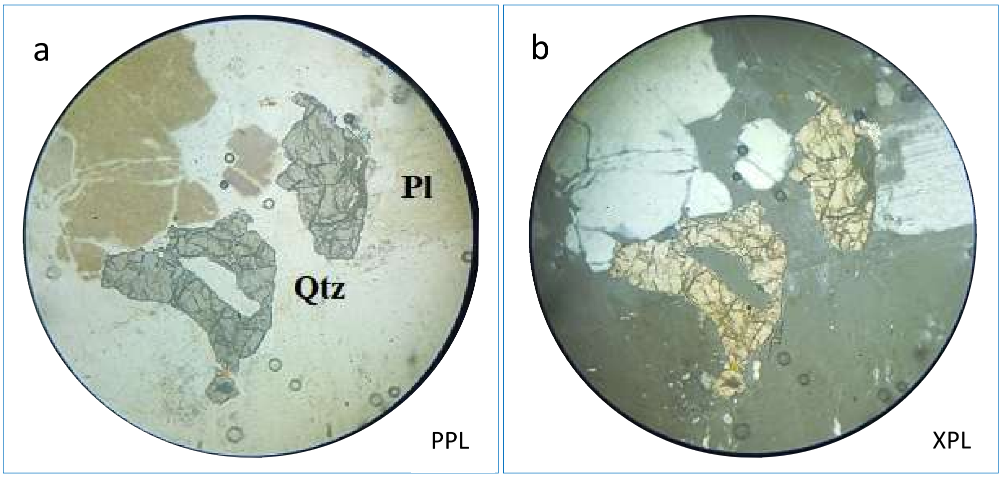


Fig. 12a and b: Photomicrograph of UGB 06 showing the low relief of quartz and repeated twinning in plagioclase, X100. (Qtz=Quartz, Pl=Plagioclase)

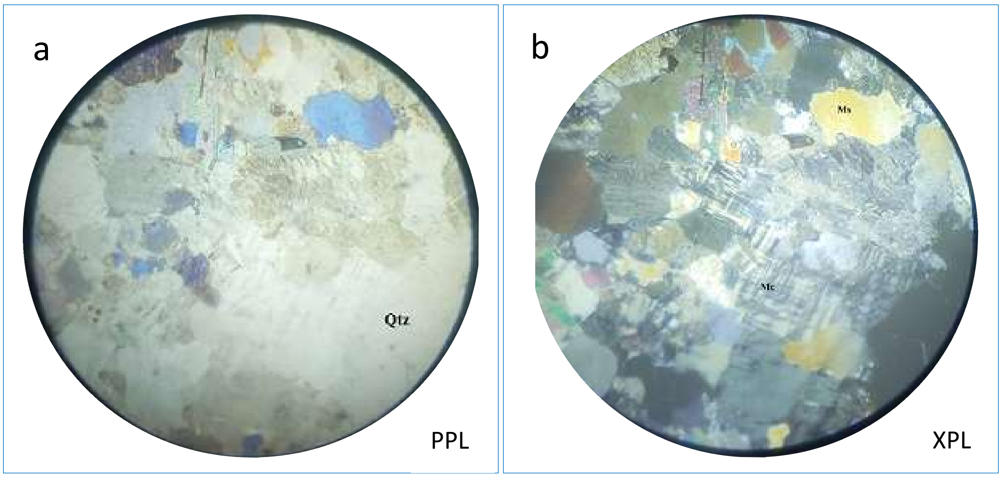


Fig. 13a and b**:** Photomicrograph of UGB 07 showing large grains of microcline and sub-rounded quartz crystal, X40. (Qtz=Quartz, Mc= Microcline, Ms=Muscovite)

6.3 Results from Geochemical Analysis

The geochemical analytical results (Table 1) show that all the granitic rocks are siliceous with SiO_2 value ranging from 56.99-71.22wt%. The samples UGB 02, UGB 03, UGB 04, UGB 05 and UGB 07 show the highest concentration of SiO_2 with values 68.18wt.%, 66.42wt.%, 70.89wt.%, 71.22wt.% and 70.32wt.% respectively, which indicates that the magma that gave rise to these rocks was most likely felsic. UGB 01 and UGB 06 show the lowest concentration of SiO_2 with values 62.17wt.% and 56.99wt.% respectively, which indicates the magma that gave rise to these rocks were probably of intermediate composition. The average value for SiO_2 (Table 2) is 66.59wt.% which is slightly lower than average and SiO_2 in Idanre Granite Batholith with an average of 69.03wt.% (Akinola et al., 2021) and the granitoids from around Fiditi with an average of 69.98wt.% (Isibor et al., 2020) both from the basement complex of southwestern Nigeria; the granites in Gwada an average of 71.20wt.% (Sambo et al., 2020) and the Saigbe Granites with an average of 71.30wt.% (Omanayin et al., 2022) both from basement complex of northcentral Nigeria; the granitic rock from Michika Area with an average of 70.58wt.% (Obiefuna et al., 2018) from the basement complex of northeastern Nigeria. However, when compared to the granitoidal rock from Ojirami-Ogbo with an average of 58.26wt.% (Odokuma-Alonge et al., 2019) and the granitic rocks in Ogun with an average of 64.29wt.% (Olayinka et al., 2023) both from the basement complex of southwestern Nigeria it is higher.

High alumina indicates the presence of alumina rich minerals such as muscovite and biotite. On the molecular

$Al_2O_3/(Na_2O+K_2O)$ versus $Al_2O_3/(CaO+Na_2O+K_2O)$ diagram (Fig. 14) after Maniar and Piccoli (1989) shows that the granitic rocks fall into the metaluminous and peraluminous field.

Table 1. The composition of major oxides (wt.%) and trace elements (ppm) from granitic rocks in study area

No	Element Oxides	UGB 01	UGB 02	UGB03	UGB04	UGB 05	UGB 06	UGB 07
1	SiO_2	62.17	68.13	66.42	70.89	71.22	56.99	70.32
2	Al_2O_3	18.35	15.25	15.67	13.17	15.55	20.76	13.55
3	Fe_2O_3(T)*	4.02	3.55	5.85	3.65	3.95	4.65	3.85
4	TiO_2	0.76	0.48	0.19	0.08	0.97	0.98	0.98
5	CaO	0.98	1.88	2.70	3.00	3.03	2.89	1.92
6	P_2O_5	0.73	0.13	0.16	0.22	0.08	0.93	0.73
7	K_2O	6.00	6.21	4.20	3.14	0.95	5.91	7.21
8	MnO	0.91	0.01	0.06	0.08	0.22	0.91	0.71
9	MgO	1.59	0.50	0.74	0.12	0.56	1.50	1.50
10	Na_2O	3.98	3.22	3.02	2.44	2.99	3.67	2.82
11	LOI	0.42	0.56	0.80	0.27	0.20	0.50	0.86
	Total	**99.91**	**99.92**	**99.81**	**97.06**	**99.72**	**99.69**	**104.45**
				TRACE ELEMENTS (ppm)				
12	Ba	132	432	115	161	343	265	102
13	Rb	45	95	120	84	120	122	100
14	Cs	8	4	18	34	12	11	14
15	Y	2	22	7	10	8	2	2
16	U	4	8	5	2	12	8	7
17	Th	31	21	8	12	18	29	10
18	Nb	45	5	53	102	215	50	98
19	Sc	6	4	21	32	10	14	8
20	La	3	8	35	15	25	8	4
21	Sr	122	110	121	310	175	160	123
22	Ta	2	9	3	8	5	9	22

Table 2. Average of major oxides in study area

No	Major Element Oxides	Range (wt.%)	Average (wt.%)
1	SiO_2	56.99-71.22	66.59
2	Al_2O_3	13.55-20.76	16.04
3	Fe_2O_3(T)*	3.55-5.85	4.22
4	TiO_2	0.08-0.98	0.63
5	CaO	1.88-3.03	2.34
6	P_2O_5	0.22-0.73	0.43
7	K_2O	0.95-7.21	4.80
8	MnO	0.01-091	0.41
9	MgO	0.50-1.56	0.93
10	Na_2O	2.82-3.98	3.16

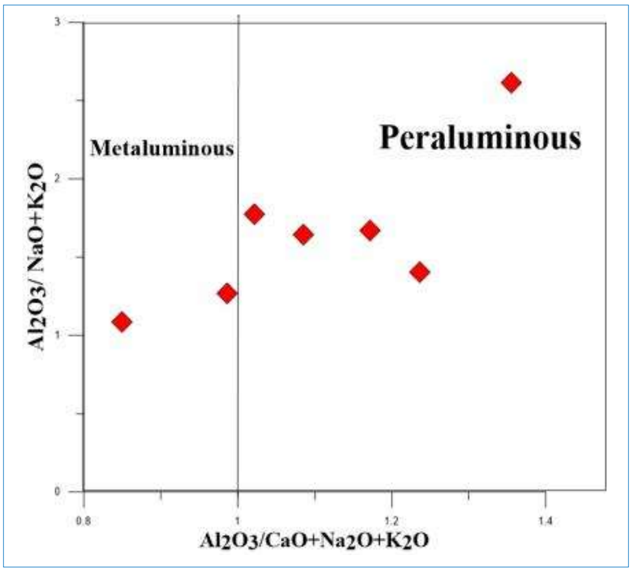


Fig. 14. Molecular $Al_2O_3/(Na_2O+K_2O)$ versus molecular $Al_2O_3/(CaO+Na_2O+K_2O)$ diagram after Maniar and Piccoli (1989)

Major elements Harker plots (Figs. 15 a–h) demonstrate an overall positive correlation with increasing SiO_2 values except Al_2O_3 (Fig. 5a) which exhibits a negative pattern. The value for K_2O is significantly higher than that of Na_2O. This is probably due to the contribution of minerals such as k-feldspar (microcline and orthoclase) and muscovite. This is the case for all samples except UGB 05 which has more Na_2O which mostly due to the presence of albite and amblygonite (Table 3). The substantial amount of Fe_2O_3 is due to iron (III). The ferric nature of the granite is due to the limited H_2O and low oxygen during partial melting of the progenitors and crystallization of anhydrous silicates (Okonkwo et al., 2013). The presence of Fe_2O_3 and MgO indicates contribution of ferromagnessian minerals such as biotite and hornblende.

MgO and CaO as well as MnO show a positive trend with SiO_2. The indicates possible assimilation from carbonate minerals that occur in the metaconglomerate present in the study area.

Geochemical features of granitic rock determine whether it is ‘I’ or ‘S’ type. Figure 6 show a plot of molar porpotions of $Al_2O_3/CaO+Na_2O+K_2O$ versus SiO_2 which revealed that all the sample fall within the S-type granitoids. The S-type granitoids are products of anatexis of meta-sedimentary or supra-crustal rock (Chappell and White, 1992).

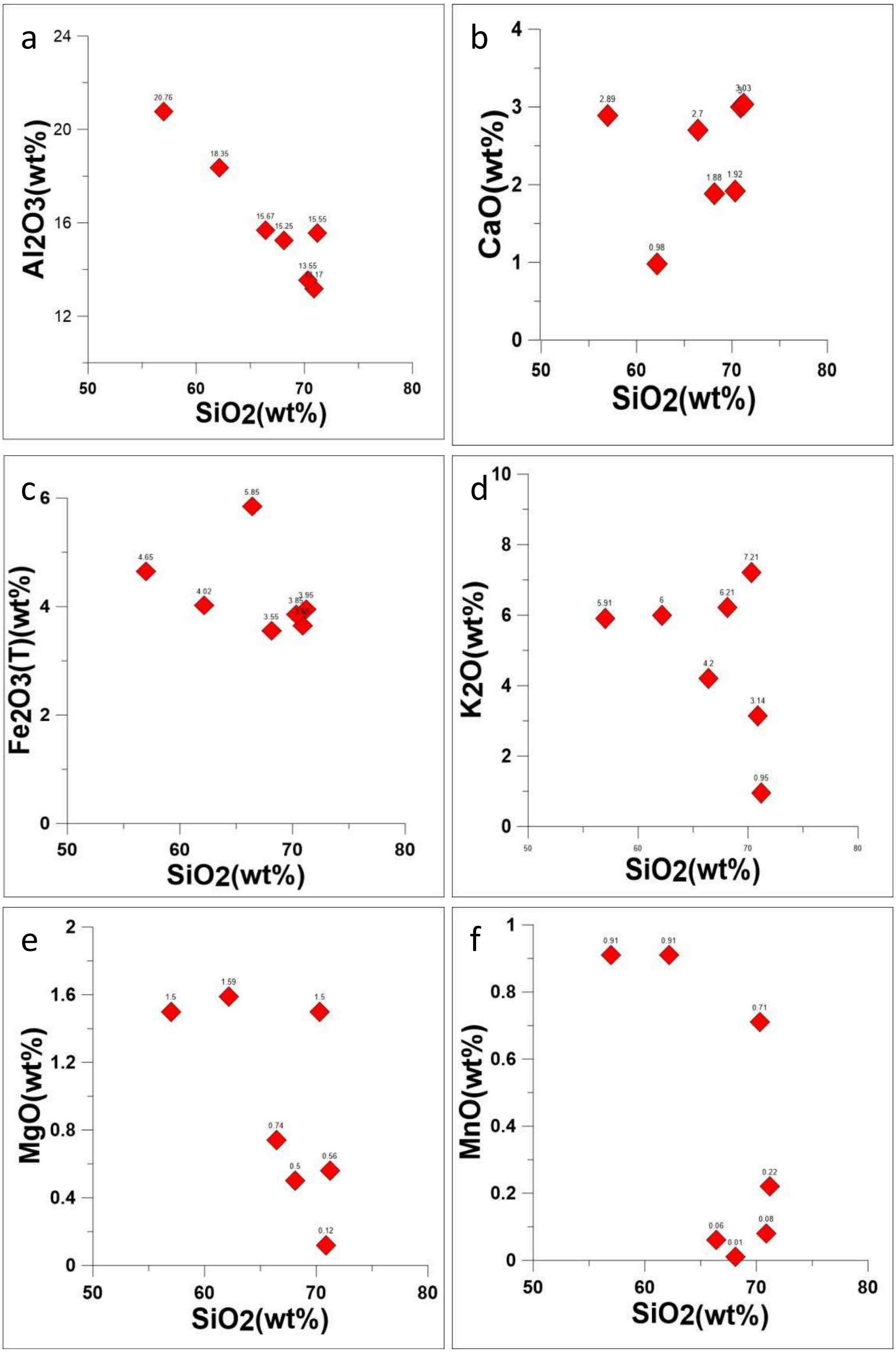
6.3.1. Tectonic Setting

Trace elements have been used to identify the tectonic setting., so discriminating against the tectonic setting can be done by a binary plot of Rb versus (Y+Nb). Fig. 7 is a plot of Rb versus (Y+Nb) of granitoids (after Pearce et al., 1984) which revealed their tectonic setting to fall under post-collisional to within-plate granitoids.

6.4. Results from Mineralogical Analysis

The XRD analysis results (Table 3) showed that the rocks are enriched in the minerals; quartz, alkali feldspar (microcline, orthoclase and sanidine) and plagioclase feldspar albite and anorthite).The modal composition for these minerals were recalculated to 100% and represented in Table 4.

These values were used to plot QAP diagrams in Fig. 8. The QAP diagram shows that UGB 01, UGB 02, UGB 03,UGB 04, UGB 05 and UGB 07 plot within the granite field and UGB 06 plots within the granodiorite field. The presence of illite in UGB 06 and UGB 07 signifies the alteration of the feldspars through the action of hydrothermal fluids. Lithium-rich minerals such as amblygonite, petalite and lepidolite identified in UGB 01, UGB 02 and UGB 03 indicate a late-stage magmatism for these granitic rocks.



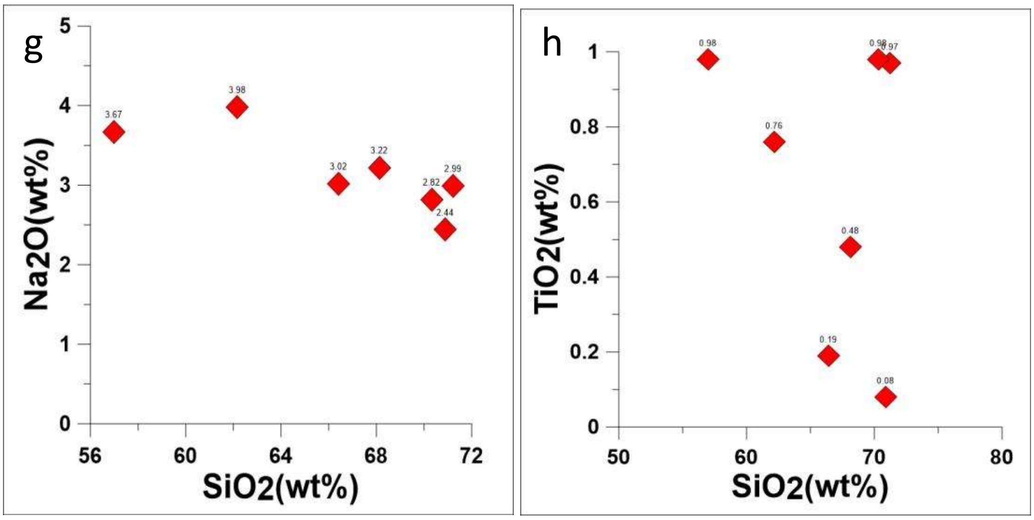


Fig. 15 a–h: Harker variation plot of the major oxide's composition of granitic rocks in Igarra-Ugbogbo Area

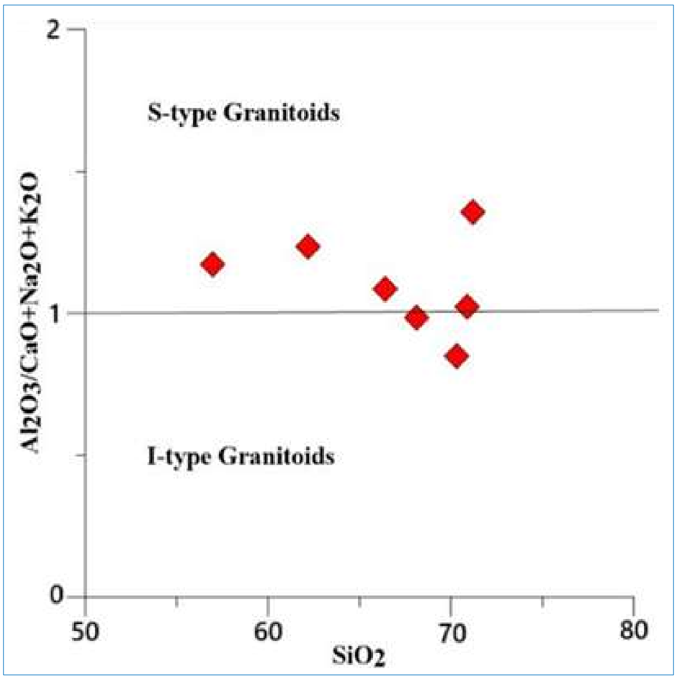


Fig. 16. Molecular $Al_2O_3/CaO+Na_2O+K_2O$ versus SiO_2 plot for the Granitic rocks in the Study Area (after White and Chappell, 1977)

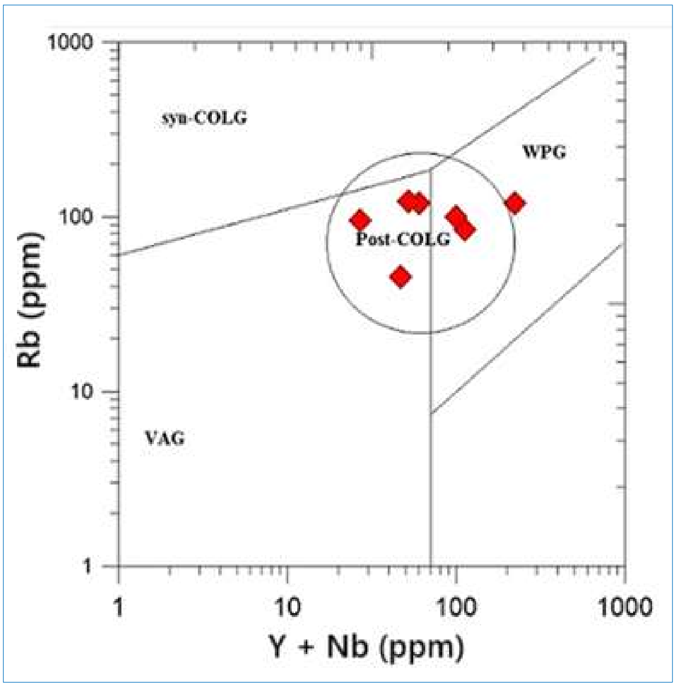


Fig. 17. Rb versus Y +Nb Plot (after Pearce et al., 1984)

Table 3. Modal composition of minerals in the study area

Minerals	Formula	Percentage Abundance Within the Sample						
		UGB01	UGB02	UGB03	UGB04	UGB05	UGB06	UGB07
Quartz	SiO_2	37.00	46.00	25.00	26.30	34.00	41.00	36.40
Microcline	$KAlSi_3O_8$	-	-	25.00	-	-	-	-
Orthoclase	$KAlSi_3O_8$	21.00	31.00	16.00	25.00	28.00	19.00	18.20
Sanidine	$KAlSi_3O_8$	-	-	18.00	-	-	-	-
Albite	$NaAlSi_3O_8$	35.00	12.70	11.70	18.00	26.00	34.00	10.00
Anorthite	$CaAl_2Si_2O_8$	-	-	-	16.00	11.00	-	10.80
Muscovite	$K_2Al_4[Si_6Al_2O_{22}](OH,F)_4$	0.70	0.60	4.40	13.00	2.00	6.00	23.30
Lepidolite	$K_2(Li.Al)_{5\text{-}6}Si_{6\text{-}7}Al_{2\text{-}1}O_{20}](OH,F)_4$	5.00	10.00	-	-	-	-	-
Petalite	$LiAlSi_4O_{10}$	0.80	-	-	-	-	-	-
Amblygonite	$(Li,Na)AlPO_4(OH,F)$	-	-	-	2.00	-	-	-
Illite	$K_{1\text{-}1.5}Al_4[Si_{7\text{-}6.5}Al_{1\text{-}1.5}O_{20}](OH)_4$	-	-	-	-	-	0.01	1.00

Table 4. The relative abundance of felsic minerals in the granitic rock samples

Sample No	Quartz	Alkali feldspar	Plagioclase	Results
UGB 01	39.78	22.58	37.63	Granite
UGB 02	51.28	34.56	14.16	Granite
UGB 03	26.10	61.65	12.23	Granite
UGB 04	30.83	29.31	39.86	Granite
UGB 05	34.34	28.28	37.37	Granite
UGB 06	43.61	20.21	36.17	Granodiorite
UGB 07	48.28	24.14	27.59	Granite

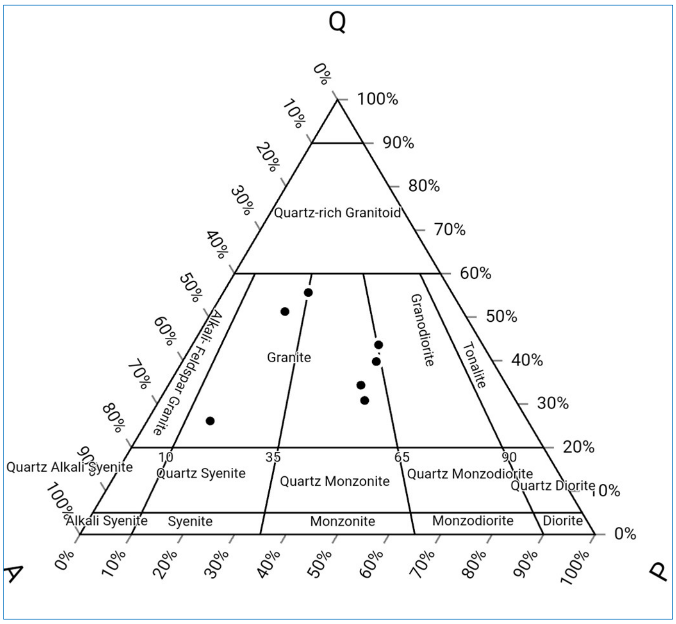


Fig. 18. QAP diagram showing samples plot

7. Conclusion

Field observation reveals the granitic rock having coarse grains with a porphyritic texture. The amount of biotite observed in each sample in the field range from about 5% (UGB 03, UGB 04, UGB 05 and UGB 07) to 10% (UGB 01, UGB 02 and UGB 06), therefore, the tentative name given for these samples are porphyritic biotite granites. Further mineralogical analysis showed that UGB 06 falls within the granodiorites. Photomicrographs show that the rocks are enriched in quartz, alkali feldspar (microcline) and muscovite. The concentration of SiO_2 in the rocks indicates a probable acidic magma for UGB 02, UGB 03, UGB 04, UGB 05 and UGB 07 to intermediate for UGB 01 and UGB 06, respectively. The rocks fall into metaluminous and peraluminous showing high contents of Al_2O_3. They fall within the granitoidal field and have quartz greater than 20%, alkali and plagioclase feldspars between 35-65%. The high content of Al_2O_3 indicates that they are S-type granitoids which were likely formed through partial melting assimilation of materials from pelitic metasedimentary sequence in the study area or from magma already undergoing magmatic differentiation. From the Rb versus (Y+Nb) the samples fall within the post-collision (post-COLG) to within-plate granitoids (WPG).

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