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Petrogenesis and Tectonic Setting of the Basement Rocks around Irruan Area, Bamenda Massif, SE Nigeria

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Abstract The basement rocks around Irruan in southern Obudu Plateau, southeastern Nigeria were studied using field mapping and geochemical data. Both igneous (granodiorite and biotite granite) and metamorphic rocks (granite gneiss, banded gneiss and migmatite gneiss) were mapped in the area. The rocks are generally quartzofeldspathic and range from alkali-calcic to calc-alkali. Fairly strong negative correlation exists between Al_2O_3 and Na_2O with SiO_2 as well as between Al_2O_3 and Fe_2O_3. The magma source for the Irruan granitoids is continental as indicated by the high SiO_2 content (≥70.11 wt.% except the biotite granite that records 61.10 wt.% of SiO_2) and discriminant plots for the area. A sedimentary protholith has been interpreted for the gneissic rocks. Magmatism in the area commenced during the later stages of the Pan-African orogeny and continued much into the post-orogenic period, leaving behind, imprints of syn-collosional and post-orgenic tectonic settings.

Keywords: *petrogenesis, tectonic setting, magmatism, syn-collisional, Obudu Plateau, Bamenda massif*

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1. Introduction

The Basement Complex rocks of southeastern Nigeria has attracted less research interests compared to their southwestern and northwestern counterparts [1,2,3]. More so, most of the existing research on the Obudu Plateau [4,5,6] seem to be concentrated on the north of the plateau with the area of the present seemingly lacking in detailed and comprehensive studies till date. And as pointed out by [7], most of the existing researches on the basement rocks of the Irruan area are largely regional in scale.

Based on geochronological data, similarities have been established between the basement rocks of southeastern Nigeria and those of western Cameroun [8,9]. However, rocks of both peraluminous and metaluminous characteristics have been reported for the Cameroun Volcanic Line (east of the study e.g. [10,11]), and the Nigerian segment of the Bamenda massif [1,12,13]. There is therefore, the need to carry out a correlation study of the rocks of the Irruan area with a view to establishing their true petrogenetic attributes and tectonic setting.

This paper seeks to ascertain the petrogenesis and tectonic environment of the basement rocks of the Irruan area using field mapping and geochemical data. These data enable the inference on the aforementioned geological aspects of the rocks of the study area.

2. Location of the study and Regional Geological Setting

Situated at the southern tip of the Obudu Plateau, the area of the study falls within Latitude N06°23′ and N06°30′ and Longitude E008°45′ and E009°2′ (Figure 1). Irruan is an agrarian community in northern Boki in Cross River state, southeastern Nigeria. The area is characterized by an undulating topography, with the highest point being the Ndemenchang Hill which is an extension of the Afi Moutain belt. The Irruan area is generally underlain by a series of basement rocks. These rocks are part of the larger crystalline rocks which make up the Nigerian Basement Complex.

The Nigerian Basement Complex is part of the reactivated Pan-African belt which resulted from the collision of the passive continental margin of the West African craton and the active margin of the Tuareg shield (Pharusian belt, Figure 2). This collision orogenesis otherwise known as the Trans-Saharan Pan-African Orogen is characterized by thrust-nappe development, high grade metamorphism, massive granite plutonism and late orogen-parallel tectonics [1].

Lithologically, the Nigerian Basement Complex consists of four [4] rock units: the Migmatite-gneiss-quartzite complex, the Schist belts, the charnockitic gabbroic and dioritic rocks as well as the Older Granites [14,15,16]. The granites and granitoids generally consist of quartz, biotite, orthoclase and plagioclase feldspars, with the plagioclase being predominantly of oligoclase in composition [1].

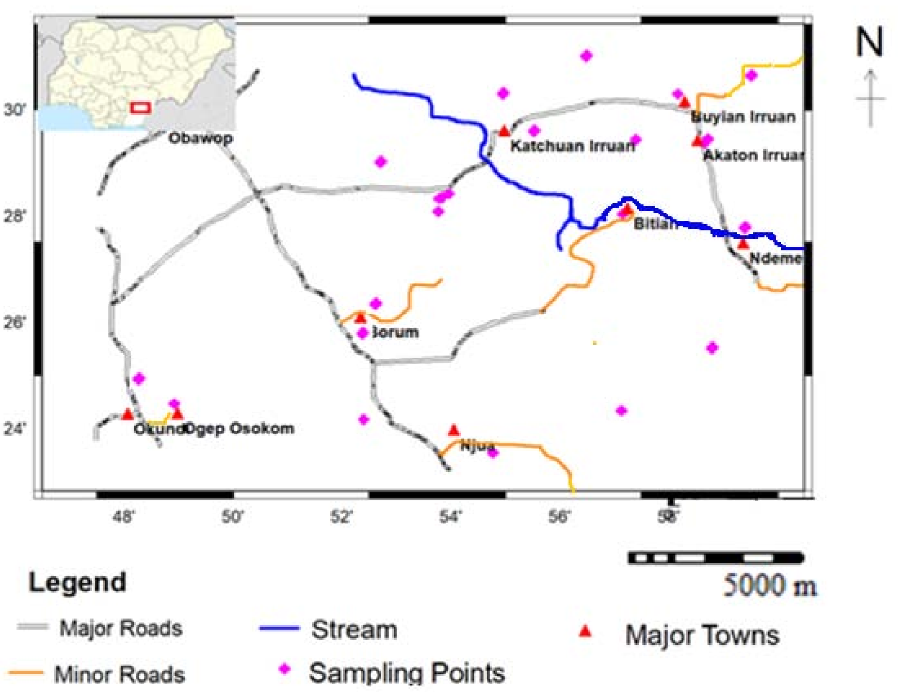


Figure 1. Location map of the area of the study (with insert showing the position of the area of the study on the map of Nigeria)

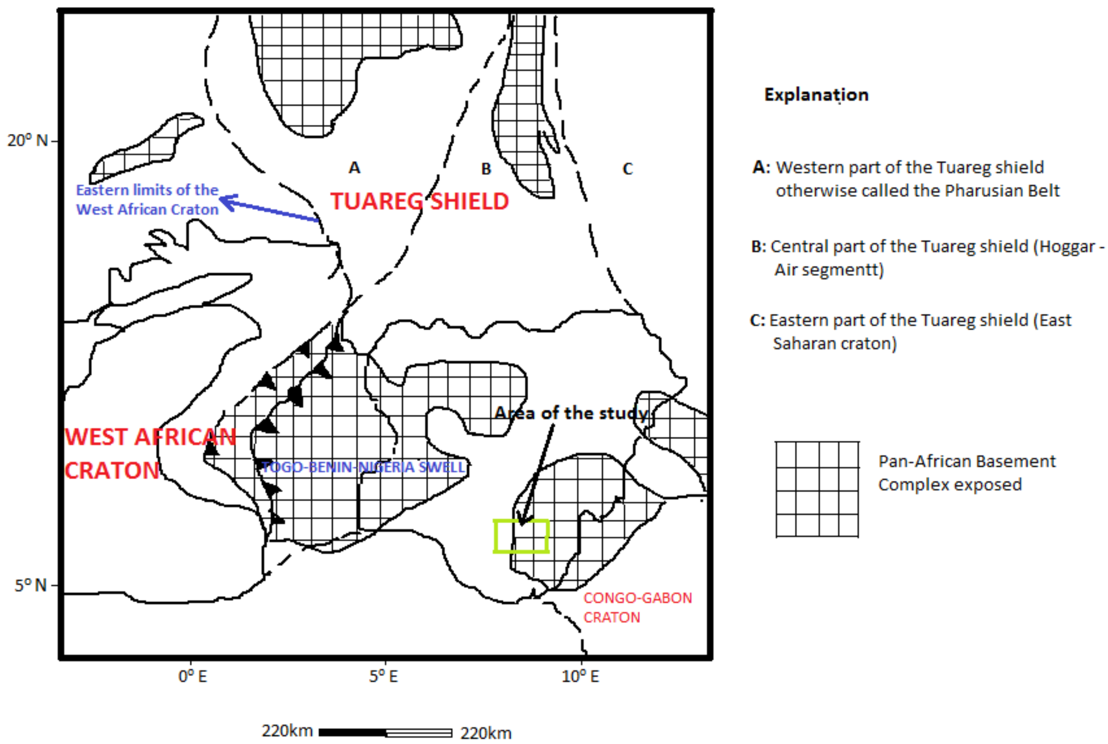


Figure 2. Geological map of parts of West African showing the position of Nigeria and its Pan-African basement, the Congo-Gabon craton, the West Africa craton and the Tuareg shield (modified after 1)

The migmatite gneisses make up about 60% of the Nigerian Basement and consist of a heterogeneous assemblage of dominantly amphibolite-facies, orthogneisses and paragneisses as well as traces of basic to ultrabasic rocks. The petrological units are a grey foliated biotite and/or biotite hornblende quartzo-feldspathic gneiss of tonalitic to granodioritic composition [14,15]. The Schist belt is otherwise regarded as the Younger Pan-African metasedimetary series and occupies north-south synclinoria in the Basement Complex. The Schists Belt overlies the migmatite gnesiss complex and comprises of predominantly metasediments with inter-layered gneisses and in rare cases, amphibolites otherwise interpreted as metavolcanics. These are low grade, metasediment-dominated rocks with lithologic units such as semi-pelites, quartzites, marbles, amphibolites, ultramafic and minor felsic to intermediate metavolcanics and greywackes [15,16].

The Older Granites which are often referred to as the Pan-African granitoids consist of strongly granitic plutons and charnockites. Typically, the Older Granites intrude both the migmatite gneisses and the schists. Important lithologic units in the Pan-African granitoids include biotite- and biotite-muscovite granites, charnockite, diorites, monzonites, serpentinites and anorthosites [14,15,16].

3 Research Methodology

Ground-truthing to ascertain the field occurrence and geological attributes of the rocks was carried out using the standard geological survey-mapping method described by Rahaman [17]. Rocks were observed in their in situ conditions with their field relationships, mineralogical and structural characteristics recorded in a field notebook whilst features of geological importance were plotted on a base map. Thereafter, fresh samples of the studied rocks were collected for laboratory analyses. The determination of the major and trace elements composition of the rocks was done using the X-Ray Fluorescence (XRF) technique. The XRF analyses were carried out using the standard procedures of (18). This was done at the National Geosciences Laboratory of the Nigerian Geological Survey Agency (NGSA), Kaduna, Nigeria.

4. Results and Discussion

4.1. Geochemistry

The Irruan basement rocks are siliceous with SiO_2 weight composition ranging from 61.10% to 83.8% and enriched in Al_2O_3 (Table 1). FeO_3 and Al_2O_3 enrichment are pronounced in biotite granite and granodiorite with both rock types showing average Al_2O_3 wt. % of 12.00 and 12.46 respectively. The granite gneiss, banded gneiss and migmatite gneiss show relatively lower values of 11.87, 7.8 and 8.6 respectively. The rocks are generally depleted in SO_3, MgO and MnO. There is a linear positive correlation between Fe_2O_3 and K_2O in the granodiorite of the area. The (Na_2O + K_2O + CaO/Al_2O_3) ratios range from 0.27 to 0.95 whilst the aluminium saturation index (ASI) for the sampled rocks is greater than one (an average of 2.03 for the gneissic rocks). This is indicative of peraluminous character for these rocks. However, with A/CNK range of 0.74 – 1.46 (average of 1.13), there is clearly the presence of slightly metaluminous rocks in the area, even though the peraluminous rocks predominate.

Table 1. Major oxides composition of the Irruan basement rocks

Oxides (wt%)	AKBG	AKBG2	GGN1	MG	MG1	GGN2	GGN3	GGN4	GGN5	GGN6
SiO_2	79.20	83.90	80.90	82.30	83.80	79.00	72.30	74.50	73.40	72.00
CaO	0.88	2.30	1.07	3.00	0.89	3.00	5.07	2.00	4.32	5.50
MgO	0.06	0.61	0.62	0.50	0.24	0.64	1.00	0.84	1.21	0.87
SO_3	ND	0.06	ND	ND	0.06	0.40	0.21	0.21	0.17	0.07
K_2O	5.71	0.80	3.02	1.60	0.60	2.00	0.70	0.63	0.70	1.00
Na_2O	1.20	1.40	0.84	0.70	1.24	1.01	1.48	1.40	1.04	1.70
TiO_2	0.33	0.40	0.53	1.08	0.84	0.37	0.79	1.38	1.05	1.46
MnO	0.02	0.06	0.10	0.06	0.14	0.07	0.16	0.25	0.16	0.27
P_2O_5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fe_2O_3	0.78	2.10	1.55	1.60	2.10	2.10	2.06	2.40	1.43	1.30
Al_2O_3	8.20	7.40	9.01	7.20	10.00	10.00	14.08	13.06	13.60	14.10
LOI	1.60	0.60	2.01	1.40	0.58	0.72	2.30	1.76	1.06	1.30
TOTAL	97.98	99.63	99.65	99.44	100.49	99.31	100.15	98.43	98.14	99.57
Oxides (wt%)	GGN7	GGN8	GGN9	GGN10	GD	GD1	GD2	GD3	GD4	BG
SiO_2	83.10	70.30	72.60	80.70	73.00	69.30	73.40	75.70	70.11	61.10
CaO	5.01	4.03	3.80	2.21	1.00	1.25	0.68	3.80	1.40	4.58
MgO	0.77	2.11	1.07	1.24	0.76	0.84	0.21	1.42	0.70	0.88
SO_3	ND	0.63	0.64	0.08	0.02	ND	ND	ND	0.21	ND
K_2O	0.43	1.02	1.00	0.94	2.06	4.43	3.00	2.34	4.01	3.07
Na_2O	0.60	1.65	1.04	1.09	1.32	2.00	1.02	1.06	2.00	1.68
TiO_2	0.38	1.03	1.06	1.01	1.03	1.81	1.68	1.37	1.55	1.06
MnO	0.07	0.17	0.15	0.11	0.12	0.45	0.24	0.34	0.43	0.11
P_2O_5	ND	ND	ND	ND	ND	0.02	ND	ND	0.03	0.03
Fe_2O_3	0.86	2.84	3.84	1.08	5.40	6.06	4.70	2.00	4.00	12.46
Al_2O_3	7.81	14.06	13.01	10.00	13.10	12.13	13.02	11.06	13.00	12.00
LOI	0.73	2.14	1.81	1.00	2.10	2.41	1.84	0.98	2.42	3.24
TOTAL	99.76	99.98	100.02	99.46	99.91	100.70	99.79	100.07	99.86	100.21

AKBG = Banded gneiss, GGN = granite gneiss, MG = migmatite gneiss, GD = granodiorite, BG = biotite granite.

Table 2. Trace elements composition of the Irruan basement rocks

Elements (ppm)	AKBG	AKBG2	GGN1	MG	MG1	GGN2	GGN3	GGN4	GGN5	GGN6
V	24.00	4.00	20.46	490.00	8.00	0.70	180.00	400.00	290.00	540.00
Cr	36.30	<0.01	31.00	340.00	0.12	<0.01	217.60	430.60	16.00	310.23
Cu	260.00	210.00	200.00	290.00	190.00	280.00	330.00	750.76	360.00	870.00
Sr	1170.00	1800.00	660.30	1050.20	650.00	790.00	2170.33	2001.03	1760.00	5010.00
Zr	290.42	490.00	2250.00	1500.00	2980.00	2100.00	790.40	3400.00	470.00	1400.00
Ba	7100.00	300.00	6400.00	300.00	3300.00	2500.00	<0.01	2000.00	<0.01	1000.00
Zn	2820.00	50.00	250.00	200.00	250.21	430.00	180.70	573.40	290.00	530.30
Pb	70.00	100.00	<0.01	<0.01	<0.01	<0.01	<0.01	860.00	140.00	0.73
Ga	4.24	<0.01	1.40	8.01	0.80	20.00	<0.01	10.23	6.20	26.06
As	21.23	6.80	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Y	3.03	4.00	22.00	<0.01	26.40	53.10	<0.01	4.60	<0.01	<0.01
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	12.03	<0.01	<0.01	<0.01
Rb	37.70	<0.01	200.00	180.00	130.11	100.30	183.00	71.37	250.00	88.81
Nb	<0.01	140.00	<0.01	<0.01	<0.01	16.00	<0.01	<0.01	<0.01	<0.01
Sn	<0.01	180.20	<0.01	<0.01	<0.01	<0.01	0.46	0.76	0.02	0.72
Ta	<0.01	0.24	<0.01	<0.01	<0.01	1.04	<0.01	<0.01	<0.01	<0.01
W	79.36	60.20	<0.01	<0.01	<0.01	54.00	<0.01	<0.01	<0.01	<0.01
Hf	40.30	48.00	51.32	48.10	38.30	40.30	36.00	76.00	36.21	70.33
U	<0.01	21.20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Th	0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sb	<0.01	0.24	<0.01	<0.01	<0.01	<0.01	9.20	2.43	7.01	2.30
Ge	<0.01	<0.01	<0.01	20.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Elements (ppm)	GGN7	GGN8	GGN9	GGN10	GD	GD1	GD2	GD3	GD4	BG
V	100.00	280.40	250.30	190.00	720.20	1000.24	630.00	400.60	400.00	100.50
Cr	55.73	220.00	120.44	12.07	310.00	870.00	500.00	240.00	390.10	40.60
Cu	160.00	360.00	190.00	180.00	460.00	1100.08	730.38	670.00	650.00	500.21
Sr	2310.00	244.00	2430.00	1790.00	1400.00	4700.00	2800.00	2500.00	2800.00	2990.00
Zr	340.11	870.00	800.00	500.20	1500.00	4800.00	2801.38	3600.00	5200.00	5630.00
Ba	<0.01	300.00	<0.01	<0.01	900.00	3000.00	2700.00	<0.01	370.00	6900.00
Zn	20.40	170.76	194.06	140.00	380.00	2300.00	840.00	730.30	990.00	550.00
Pb	230.00	0.47	<0.01	<0.01	1400.00	<0.01	130.00	<0.01	150.00	<0.01
Ga	4.00	<0.01	<0.01	<0.01	<0.01	<0.01	5.48	<0.01	<0.01	<0.01
As	1.06	<0.01	0.01	<0.01	200.00	<0.01	20.00	30.00	26.13	<0.01
Y	<0.01	17.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni	<0.01	12.46	<0.01	<0.01	22.00	70.00	43.30	72.03	74.00	6.60
Rb	120.00	180.00	<0.01	<0.01	<0.01	50.06	0.43	24.42	<0.01	<0.01
Nb	<0.01	<0.01	230.00	190.00	480.30	350.70	110.34	96.81	19.40	480.22
Sn	0.02	0.76	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	75.00
Ta	<0.01	<0.01	0.13	0.12	1.42	15.40	12.68	4.24	30.00	1.07
W	0.45	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	60.33
Hf	43.60	38.12	<0.01	<0.01	<0.01	46.24	<0.01	<0.01	<0.01	24.00
U	<0.01	<0.01	41.30	43.00	49.60	60.20	64.63	70.70	44.14	71.06
Th	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.09
Sb	0.30	1.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03
Ge	<0.01	<0.01	0.95	0.53	8.10	130.00	86.00	11.01	610.20	3.20

AKBG = Banded gneiss, GGN = granite gneiss, MG = migmatite gneiss, GD = granodiorite, BG = biotite granite.

As shown in Table 2, the rocks are highly variable in their trace elements composition. Generally, the concentrations of Sb, U, Th, Tn, and Sn are negligible in most of the sampled rocks. The Ge concentrations are also negligible for the gneissic rocks but fairly enriched in the granodiorite and biotite granite.

4.2. Petrogenesis and Protholiths of the Irruan Basement Rocks

As shown in Figure 3, there is a fairly strong negative correlation of Fe_2O_3, Al_2O_3 and Na_2O with SiO_2 which suggests that fractional crystallization played a role in the evolution of the magmatic suite in the area. [19] opined that a strong negative of SiO_2 with Fe_2O_3 and MgO on the Hacker diagram indicates pyroxene and hornblende fractionation.

Also, the occurrence of gneissose foliation, drag folds and the prevalence of quartzo-feldspathic veins are suggestive of evidence of partial melting (anatectic melt) during metamorphism of the rocks. According to [2], these characteristics are indicative of plastic deformation and mobility typical of the fourth regime of metamorphism. The active contribution of process(es) other than fractional crystallization is further supported by the modified alkali-lime index (MALI) plot (Figure 4). The rocks plot across three (3) different trends of calcic, calc-alkalic and alkali-calcic series. [20] and [21] hold the view that a suite of rocks that cross the trend lines on the MALI is an indicator that the crystallization of the parent magma involved mixing of more than one parent magma. It is therefore suggested that multiple magma crystallization processes accounted for the magamatic evolution of the Irruan granitods, with partial melting and fractional crystallization playing varying roles in the evolution of these rocks.

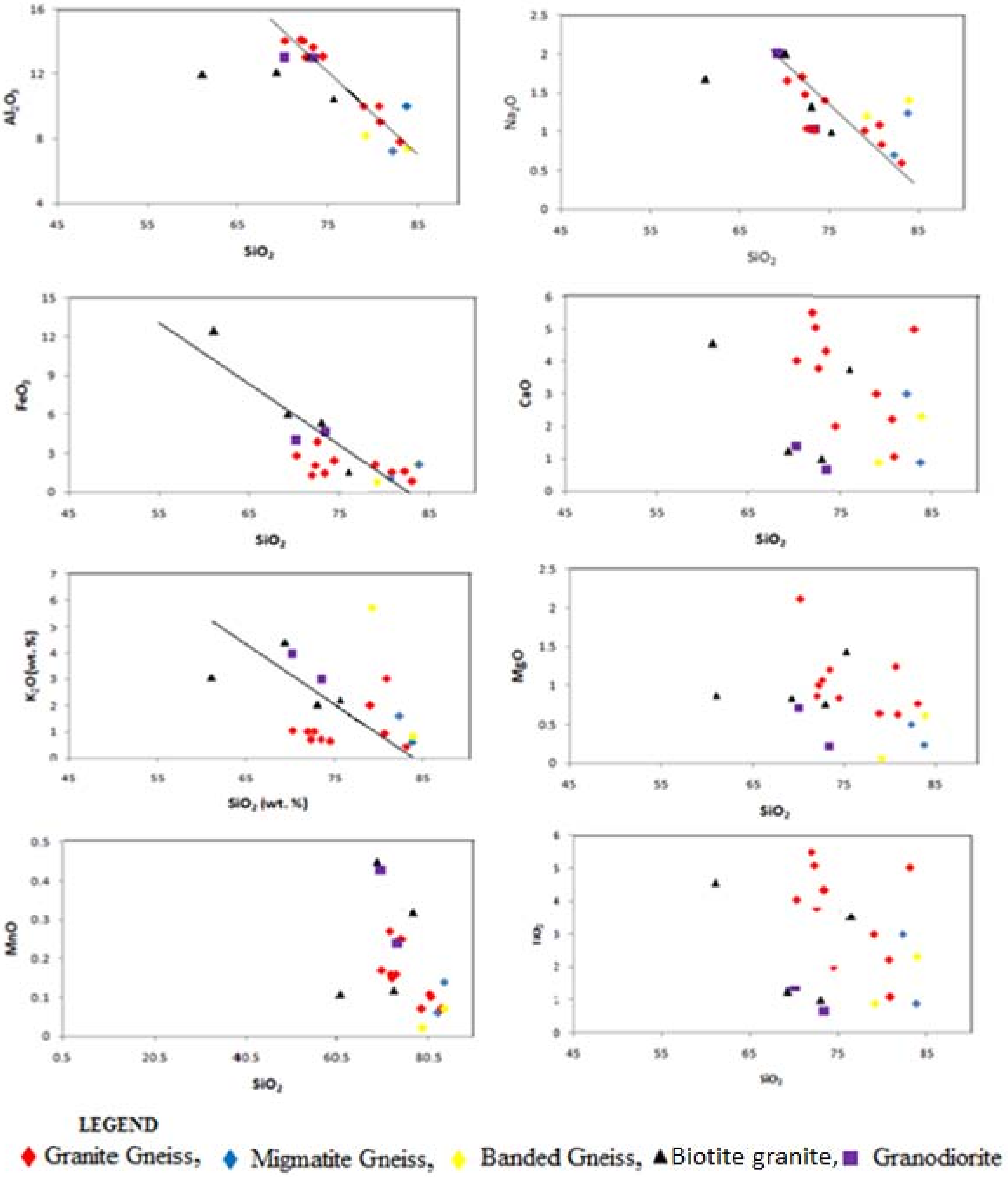


Figure 3. Harker variation diagrams for the Irruan Basement Rocks

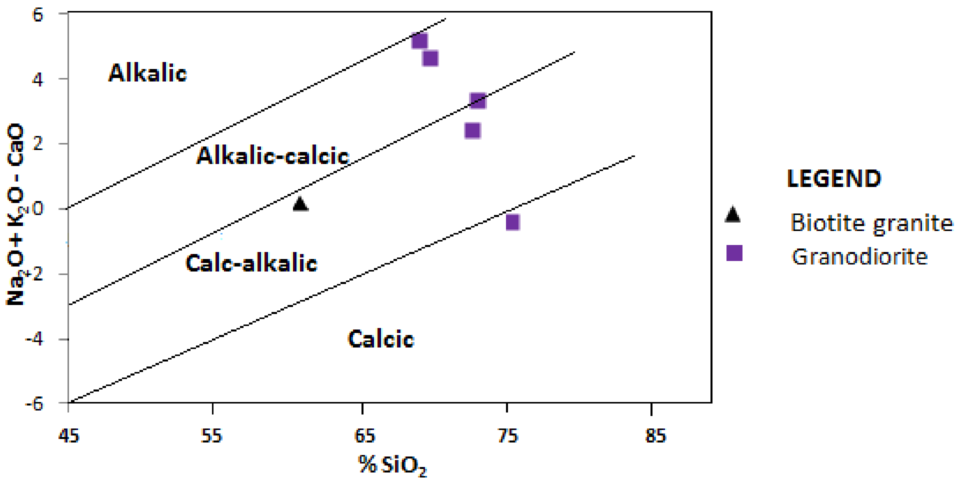


Figure 4. Plot of $Na_2o + K_2O - C_aO$ vs. SiO_2 (modified after 20)

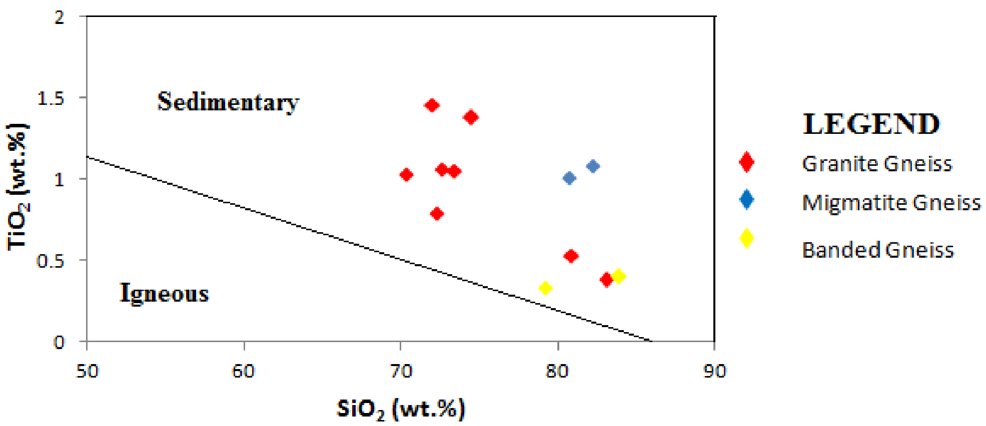


Figure 5. TiO_2 vs. SiO_2 Discriminant Plot (modified after 28).

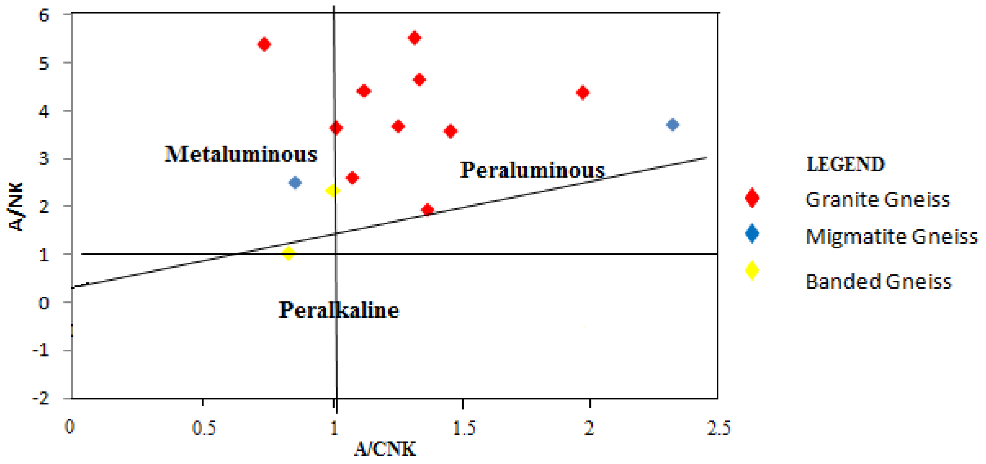


Figure 6. A/NK vs. A/CNK classification diagram (boundaries modified after 11, 29)

As shown in Figure 5, the gneissic rocks of the area metamorphosed from sedimentary and/or metasedimentary protoliths. The strongly peraluminous (Figure 6), fairly potassic and high silica content of the rocks clearly further supports the inference that the metamorphic rocks of the Irruan area metamorphosed from sedimentary and/or metasedimentary protoliths [20]. The peraluminous character and sedimentary protoliths interpreted for the metamorphosed rocks of the area are consistent with recent findings by [31] on the source of the granitoids around the Irruan area.

4.3. Tectonic Setting

The Irruan granitoids are thought to have originated from the continental crust. This inference is strongly supported by discriminant plots of the tectonic environment (Figure 7 and Figure 8) which clearly show active continental tectonic setting for the rocks. The continental origin of the rocks is further supported by the felsic (SiO_2 ≥61.10 wt.%) composition of the rocks. These rocks are considered to have evolved within continental crustal environment (within plate granites) without significant contributions from oceanic ridge and/or arc-related events (Figure 12). Similarly, the Irruan granitoids, as shown from the discriminant plots (Figure 10 and Figure 11) are predominantly syn-collisional with traces of volcanic arc granite present.

Magmatic evolution of the granitic rocks of the area are clearly polygenic, with imprints of both orogenic and anorogenic origin. Figure 7, Figure 8 and Figure 9 suggest a significant contribution of active orogeny to the evolution of these rocks. However, as shown in Figure 13, there is also a noticeable post-orogenic signatures in these rocks. Magmatism of the Irruan granitoids may have occurred during the later stages of the Pan-African orogenic event and continued till the collisional events of the post-orogenic period in the area. Thus, we propose that it is the continued magmatic events (peri- and post-orogenic) in the area that gives some of the sampled rocks their syn-collisional and post-collisional signatures as seen in the discriminant plots for the tectonic setting of the rocks.

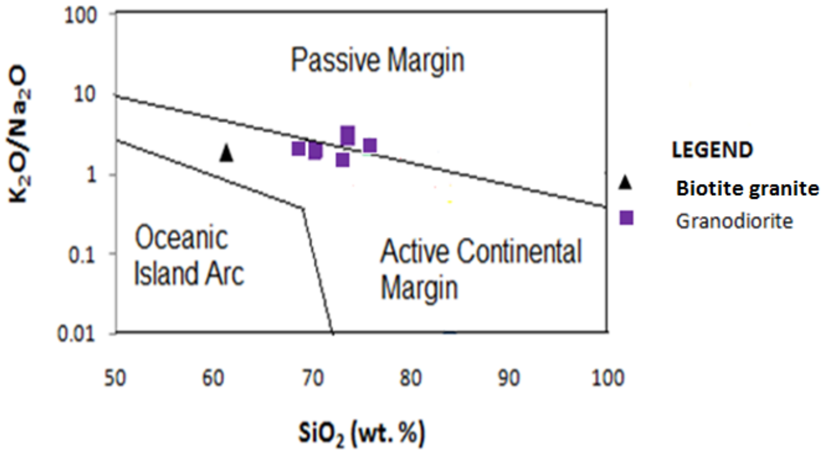


Figure 7. Plot of K_2O/Na_2O vs. SiO_2 (boundaries modified after 22)

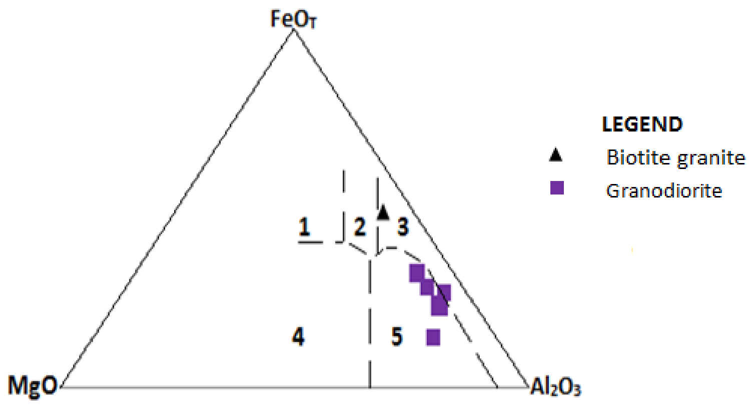


Figure 8. Ternary Plot of Tectonic Setting of the Irruan Basement Rocks (boundaries modified after 23, 24). 1 = Ocean Island, 2 = Continental, 3 = Spreading Centre Island, 4 = Mid Oceanic Ridge, 5 = Island and Active Continental Margin

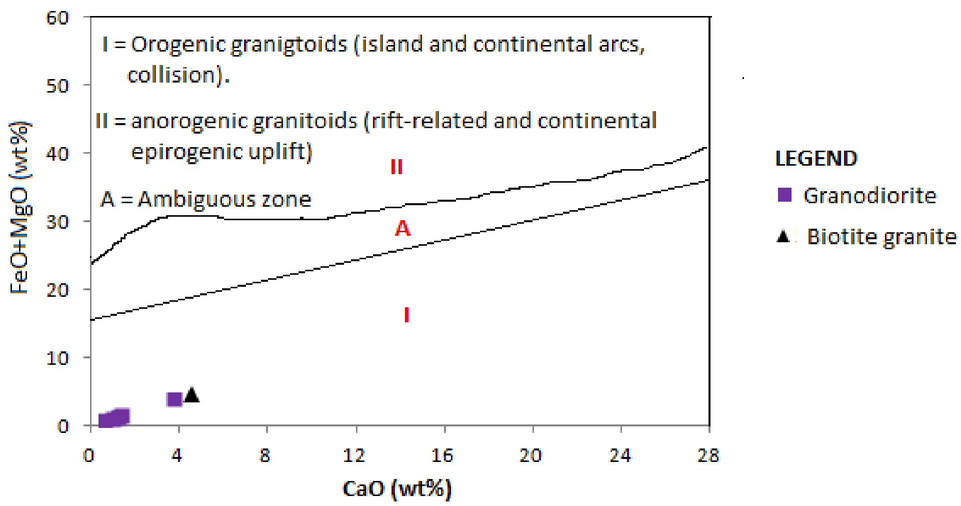


Figure 9. Discriminant plot of FeO+MgO (wt%) vs CaO for the Irruan granitoids (modified after 25)

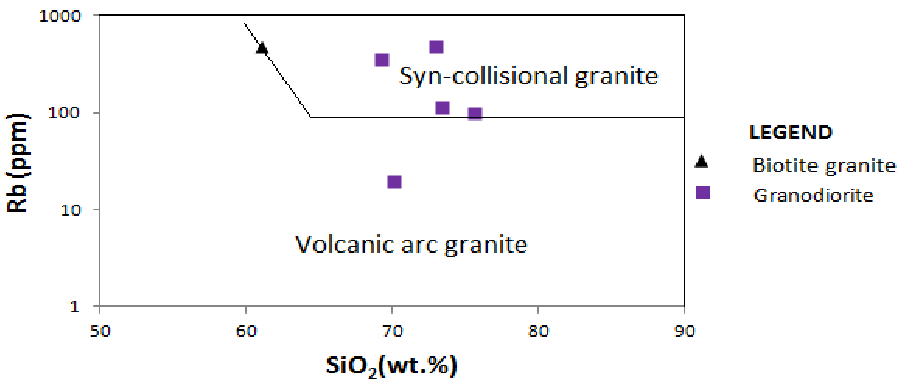


Figure 10. Rb vs. SiO_2 Discriminant plot (boundaries modified after 26)

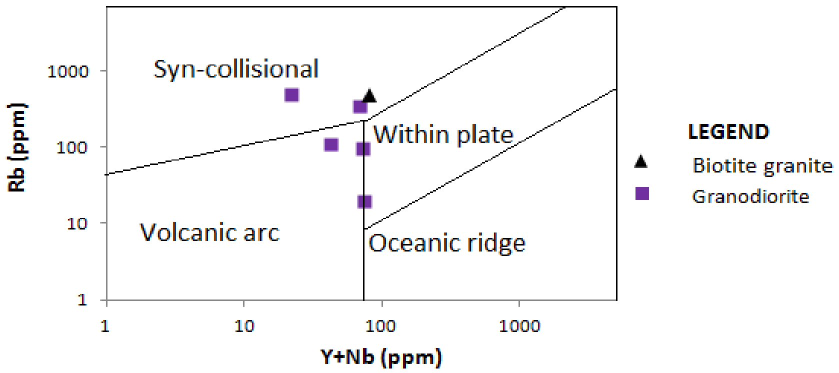


Figure 11. Rb vs. Y+Nb Discriminant plot (boundaries modified after 23)

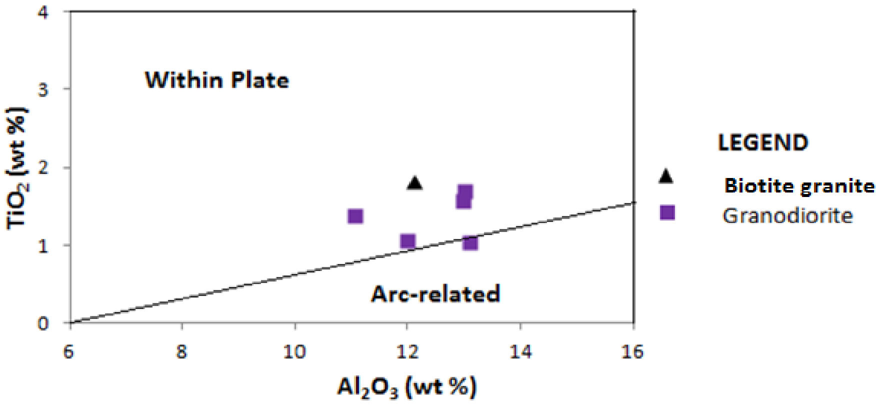
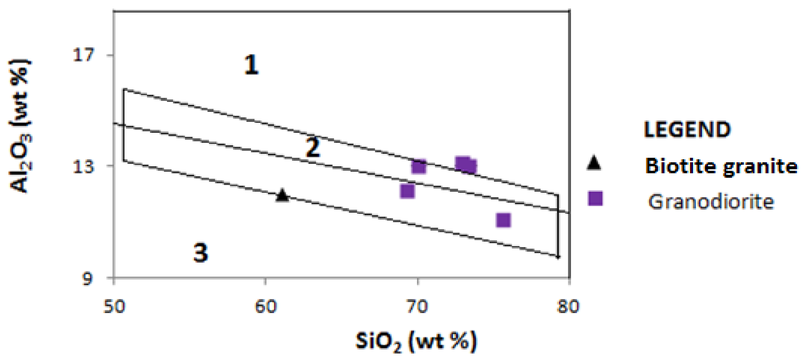


Figure 12. TiO_2 vs Al_2O_3 Discriminant Plot for the Irruan Basement Rocks (modified after 27).



1 = Island arc, continental arc and continental collision granite;
2 = Post-orogenic granite; 3 = Rift-related and continental uplift granite

Figure 13. Al_2O_3 vs. SiO_2 discriminant plot for the tectonic setting of the Irruan Basement Rocks (boundaries modified after 25)

The inference that the Irruan basement rocks were emplaced during the collision of the passive continental margin of the West African craton and the active margin of the Pharusian belt (the Tuareg shield) during the Pan-African orogeny and continued into the post-orogenic period is in agreement with some earlier studies on the tectonic evolution of the southeastern Nigeria [1,30].

5. Conclusion

The Irruan area is underlain by quartzo-feldspathic igneous and metamorphic rocks. The granitic rocks are thought to have evolved from both partial melting and fractional crystallization. A sedimentary and/or metasedimentary protolith has been interpreted for the metamorphosed rocks in the area which are largely peraluminous. The variations in the lithologic units within the area may have been due to differences in the compositions of the sedimentary progenitors. Orogenic to post-orogenic tectonic settings in a largely continental environment have been inferred for these rocks. The findings from this study are comparable to some of the earlier studies on the crystalline rocks of southeastern Nigeria.

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