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Tectonic Setting of the Syenite Around Igarra, Southwestern Nigeria: Constraints from Geochemistry

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Abstract

Syenites are relatively rare within the Nigerian Basement Complex. As a result of their rarity, these rocks have been given less research attention over time and are consequently poorly understood. The syenitic rocks at Igarra were studied to ascertain their tectonic evolution using geochemistry. Sampling was carried out using the survey-type geological field mapping approach. A total of 10 samples of syenitic rocks were collected for laboratory analyses. Compositionally, the rocks are intermediate with regards to SiO_2 content (58.02% – 60.58%), having Al_2O_3 and alkali ($Na_2O + K_2O$) compositional ranges of 15.34% – 15.52% and 8.99% – 9.7% respectively. The sampled rocks are similar and consistent in their trace and rare earth elements concentrations (the only exception being Zr with values ranging from 4 ppm to 79 ppm). The rocks are relatively enriched in Ba, K, TI, and Sr but depleted in Tc, Nb, U, Hf, Yb, Te and Ta. The syenites also show fairly high ratios of Rb/Nb and Rb/Sr with mean values of 488.627 and 0.171 respectively. As seen from the geochemical analyses, the syenites around Igarra are high-K calcalkaline, alkalic to alkalic-calcic. The rocks are peraluminous in character as shown by the bivariate plot of A/NK vs. A/CNK. Sedimentary protolith with continental crustal parent magma is inferred for these rocks. The similarity and consistency of the trends of major, trace and rare earth elements is indicative of cogenetic origin for the rocks. The geochemistry and discrimination plots for the rocks indicate geodynamic setting ranging from orogenic to post-orogenic. A volcanic arc geotectonic setting is interpreted for the Igarra syenites, with magma emplacement and evolution thought to have been initiated during the late stages of the Pan-African reactivation and continued into post-orogenic times.

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Keywords: Syenite, Tectonic setting, Geodynamic evolution, Pan-African orogeny, Nigerian basement complex

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1. Introduction

Syenites are relatively scarce in Nigeria, making them to attract less research attention. As such, these rocks are often given less research attention and are consequently poorly understood. However, the syenites within the Nigerian Basement Complex are widely distributed amongst the crystalline coun-

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Email address: `ominigboedafe@gmail.com` (O. E. Ominigbo) try rocks – granites, gneisses, and schists [1 – 3]. The rarity of syenites relative to other crystalline rocks is not peculiar to the Nigerian Basement Complex as similar occurrence and distribution pattern has been recognized elsewhere [4]. The occurrence of syenites in Nigeria is restricted to two contrasting petrographic settings with a group associated with the Older Granites whereas the other member restricted to the Younger Granite series. The Older Granites syenites are characterized by significantly high concentrations of CaO, MgO and K_2O, with K_2O typically exceeding Na_2O. On the other hand, the syenitic rocks of the Younger Granites show broader compositional ranges, often with Na_2O/K_2O ratios close to unity [2].

As a result of episodicity and prolonged duration of geological events, different geological settings with diverse geochemical and mineralogical attributes have evolved in the Basement Complex of western Nigeria. To be able to accurately decipher such diverse episodes of geological events and tectonic settings, detailed geological and geochemical studies are required [5]. More so, alkaline rocks typically occur in diverse geodynamic settings – post-orogenic, rift or intraplate tectonic environments. The understanding of these rocks and their tectonic settings provide significant insights into understanding magmatic processes within and around the continental lithosphere [6]. Furthermore, it has been observed that by determining the petrogenesis of a rock suite from a given geological regime, it is possible to infer limits on the geodynamic conditions which were responsible within the mantle for the tectonic or crustal activity during the time of formation of the suite of rocks [7].

Although some appreciable works have been done with regards to geological field mapping and geochemistry of the Nigerian Basement Complex, there remains a glaring need for more studies aimed at enhancing the current understanding of the geodynamic evolution of the crystalline rocks within the region [8]. Notwithstanding the series of researches carried on the Igarra Schist Belt, there is scarcity of detailed studies on tectonic setting of the syenites in the area. It has been argued that such paucity of reliable data or studies has led to “individual prejudices” with regards to the interpretation of the evolution of the Basement Complex in Nigeria [8 – 9]. In view of the apparent knowledge gap regarding the syenitic rocks in Nigeria, the present study seeks to investigate the tectonic evolution of the syenites around Igarra in south western Nigeria using evidences from geochemistry. Geochemical analyses were carried out using data derived from geological field mapping of the area of the study. The use of geochemical data for deciphering and reconstructing the earth’s history, processes and products is a widely acceptable practice in the Earth Sciences research community [5, 10]. This study is expected to give further insights into the geochemistry of the syenites in Nigeria. It is also expected that findings from the present study will contribute towards the overall understanding of the geology and evolution of the Nigerian Basement Complex.

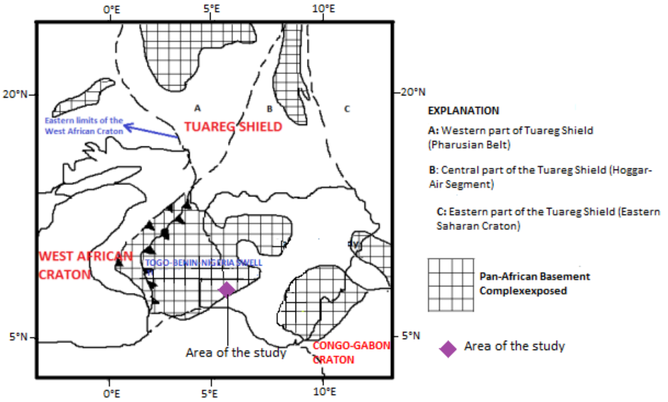

Figure 1: Simplified geological map of West Africa showing the position of Nigeria and its Pan-African Basement Complex, the Congo-Gabon Craton, the West African Craton and the Tuareg Shield [modified after 11 and 14]

2. Regional Geological Setting and Previous Studies on the Igarra Syenite

The present study was carried out around Igarra in southwestern Nigeria. The Igarra crystalline rocks are part of the Nigerian Basement Complex generally believed to have been impacted by the Pan-African orogenic event (650 Ma ± 150). The Nigerian Basement Complex is an essential component of the Pan-African Mobile Belt occurring east of the West African Craton and south of the Tuareg Shield, northwest of the Congo Craton (Figure 1). The Nigerian Basement Complex is widely thought to have resulted from the collision of the passive continental margin of the West African Craton and the active Tuareg Shield (the Pharusian Belt). This orogenesis often referred to as the Trans-Saharan Pan-African Orogen led to the development of high-grade metamorphism, thrust-nappe, massive granite plutons and late orogen-parallel tectonics [7, 11 – 12].

The Pan-African orogeny was accompanied by the emplacement of syn-tectonic to post-tectonic granites, adamellites, tonalities and granodiorites which are commonly referred to as the Older Granites [13 – 14]. The Older Granites are typically weakly foliated and porphyroblastic in places whilst being nonfoliated and equigranular in others. The Older Granites vary from leucocratic to mesocratic in colour with diverse mineralogical compositions, ranging from biotite granites, hornblende-biotite-granites, hypersthene granites, adamellites, syenites to garnetiferous granites and muscovite-biotite-granites [12]. Although the Older Granites generally have calc-alkaline attributes, the syenites within the Nigerian Basement Complex are typically peralkaline [3]. [15 – 16] have reported on the hydrogeological properties of parts of the southwestern Nigeria.

The Igarra Schist Belt is thought to occur as a broadly N – S trending zone of low – medium grades metasediments and metavolcanics ranging from basic to ultrabasic [17]. As a result of the ubiquity of the Pan-African thermotectonic reactivation, the protolith age of the Basement Complex in Nigeria remains a subject of debate [18]. Although there is a general consensus that the entire Basement Complex in Nigeria was affected by the pervasive Pan African reactivation, there remains a debate on the status of older orogenies within the basement as some authors have opined that traces of all pre-Pan-African events must have been obliterated. The policyclicity of the Nigerian Basement Complex has made the determination of the true age of the rocks rather more difficult [8]. Two distinct compressive stresses (NE – SW and E – W) have been reported to have affected the Igarra Schist Belt during the Pan-African event, with the relatively younger E –W event being more pervasive as structures related to it are more dominant within the basement [19]. According to [19], the syenite and granite in the Igarra area are characterized by E – W structures whereas compared to other rock types within the belt, the NE – SW structure are fairly absent.

The area of the present study is located within the Igarra Schist Belt in southwestern Nigeria. Generally, the Igarra area is made up of several intrusive and metasedimentary rocks. Notable petrological units in the area include schist, marble, granite, calc-gneiss, quartzite and pegmatitic rocks [17, 20]. As reported by [17], the Igarra syenites intrude the marble/calcic gneiss and the quartz-biotite/mica schist, and are considered to be relatively younger than the pegmatites of the Igarra Schist Belt. Greenschist to amphibolite grades of metamorphism have been reported for the Igarra Schist Belt. The greenschist and amphibolite facies are characterized by the presence of chlorite + quartz + epidote ± actinolite and hornblende + biotite + plagioclase ± quartz respectively [17].

The syenites around Igarra and other associated crystalline rocks within the Igarra Schist Belt have been the subjects of some previous studies [e.g.12, 17, 20 – 21]. However, apart from [21], most of the existing works on the area are largely regional in scope without paying close attention to the syenites outcropping around the area. More so, the study by [21] only dwelt on the petrochemical and geotechnical attributes of the syenites. The general petrology and structural characteristics of the granitoids around the Igarra have been reported by [17]. Again, their study was restricted to geological field occurrence and petrographic attributes of the rocks without paying attention to the geochemistry of the rocks. Thus, the present study seeks to use geochemical evidence to ascertain the tectonic setting and evolution of the syenites of the area with a view to situating the rocks within the larger context of the geodynamic evolution of the Nigerian Basement Complex.

3. Research Methods

Geological field mapping was carried out during which ten (10) fresh rock samples were collected for laboratory analysis. Field mapping and sampling were carried out following the survey-type geological field mapping technique described by [22]. Rocks were observed in their in situ conditions, their field relationships and mappable mineralogical attributes noted and then, fresh rock samples were collected from unweathered surfaces for laboratory analyses. Only unaltered rock samples were collected for analyses in order to ensure that such samples give the true geochemical signatures of the rocks. Prior to laboratory analyses, the samples were crushed in hardened steel jaw crusher before being pulverized into fine powder using a disc mill. Sample preparation and analyses were carried out at the Activation Laboratories in Vancouver, Canada. Major elements (Na_2O, MgO, Al_2O_3, K_2O, CaO and FeO) compositions were determined using thermal desorption-mass spectrometry. SiO_2 concentration was analyzed using fusion-inductively coupled plasma; whereas Ti was analyzed using total digestion-inductively coupled plasma (TD-ICP). Loss on ignition (LOI) was determined for each of the samples using the gravimetric method. The trace elements and rare earth elements (REEs) were analyzed using total digestion-inductively coupled plasma. Sc was analyzed using the TD-ICP. For most of the major oxides, detection limit was 0.01% except for TiO_2, and P_2O_5 which had detection limits of 0.0005% and 0.001% respectively. The trace elements and RREs were analyzed using a detection limit of 0.01 ppm. Trace elements and REEs analyzed with different detection limits include: Li, Ni, Pb (0.5ppm), Ba, Zr, V, Sn, Cr, Sc (1 ppm), Ag, Cs, Mo, TI, Eu, Re (0.05 ppm), Bi (0.02 ppm), Zn, Rb, Sr, Cu (0.2 ppm). Although high sensitivity of analytical methods to elemental concentrations in rocks (like the ones adopted for the present study) is highly desirable in geochemical analyses, an excellent detection limit in itself does not necessarily translate into accuracy of analytical outcomes. To check for, and to minimize possible sources of error(s) therefore, internationally certified reference materials were used for instrument calibration, method validation, quality control and comparisons as suggested by [10]. Rare earth element (REE) and trace element normalizations were done using the standard chondrite values and procedures given by [23] and [24] respectively. Those values were then used in plotting discrimination diagrams to ascertain the REE and trace elements patterns of the syenites.

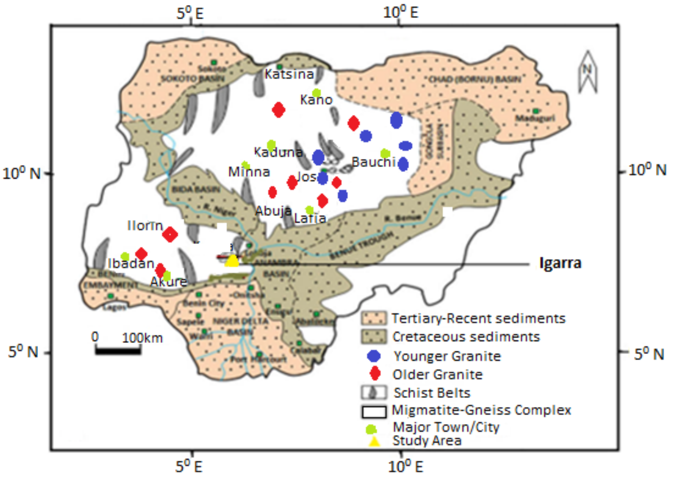

Figure 2: Simplified geological map of Nigeria showing the area of the study [modified after 17]

4. Results

The results of the geochemical analyses (major, trace and REE) are shown in Tables 1, 2 and 3 below. Alongside the major elements composition, some important major oxides' parameters and variables (Na_2O + K_2O, N+K-C, A/NK, CNK, A/CNK, FeO + MgO, FeO/(FeO + MgO) and K_2O/Na_2O) have been included in Table 1. Similarly, some important trace elements ratios and parameters (Rb/Sr, Rb/Nb, Rb/Zr and Y + Nb) have been included in Table 2. These major and trace elements parameters and ratios alongside other elemental compositions were used in plotting discriminant plots for the present study as well as form the basis for many of the inferences made.

The rocks are generally intermediate with SiO_2 ranging from 58.02% - 60.58%. There are significant Al_2O_3 and alkali (Na_2O + K_2O) enrichments with compositional ranges of 15.34% - 15.52% and 8.99% - 9.70% respectively. The trace elements distribution patterns are fairly consistently in all the samples except in Zr (4 ppm – 79 ppm). Generally, there is relative depletion of Tc, Nb, U, Hf, Yb, Te and Ta whereas there is a significant enrichment of Ba, Rb, K, TI and Sr. (Table 2).

5. Discussion

5.1. Classification of the Igarra Syenites

The rocks were classified using different major elements. The application of major elements for the classification and nomenclature of igneous rocks is a widely acceptable practice in geochemistry [10]. As shown in Figure 3, the sampled rocks are syenitic. The total alkali versus silica content (TAS) classification scheme for igneous rocks was adopted for the present study. Recommended by the International Union of Geological Sciences (IUGS), the TAS scheme is suitable for classifying unaltered volcanic rocks, with the total alkalis (Na_2O + K_2O) plotted against the silica contents (Figure 3). This classification is premised on the fact that both alkalis and silica are largely mobile in a variety of deuteric processes which commonly lead to the formation of secondary and post-magmatic feldspar [25].

The Igarra syenites are generally intermediate in chemical composition with regards to silica content (SiO_2 ranging between 58.02% - 60.58%). Similarly, the rocks are fairly enriched in FeO, Al_2O_3 and MgO with values in the ranges of 5.01% - 5.66%; 15.34% - 15.52% and 3.62% - 4.78% respectively, giving the sampled rocks a magnesian characteristic (Figure 4). The compositionally high concentration of Al_2O_3 and the comparatively lower values of K_2O and Na_2O (6.50% - 6.90% and 2.49% - 2.94% respectively) broadly give the syenites overall alkalic to high-K calcalkaline and peraluminous signatures recorded in the bivariate plots (Figure 5a – 5d). Compositionally, the major oxides data obtained from the present study compare closely with earlier ones reported for the Igarra syenites [21]. Meanwhile, compared to the nepheline syenites around the Oyioba-Uganga area in southern Benue Trough as reported by [26], the Igarra syenitic rocks are enriched in CaO and K_2O but depleted in Na_2O and Al_2O_3. However, the syenites in both areas are compositionally comparable in terms of TiO_2, MnO, FeO and P_2O_5.

The high-K calcalkaline characteristics of the Igarra syenites are compositionally different from those of the Kanoma and Sabon Gida plutons in northwestern Nigeria which [3] reported as peralkaline. The high-K calalcaline, relatively high CaO and MgO as well as $K_2O > Na_2O$ shown by the Igarra syenitic rocks however, closely match the geochemical signatures typical of the syenites associated with the Older Granites in Nigeria as earlier reported by [2].

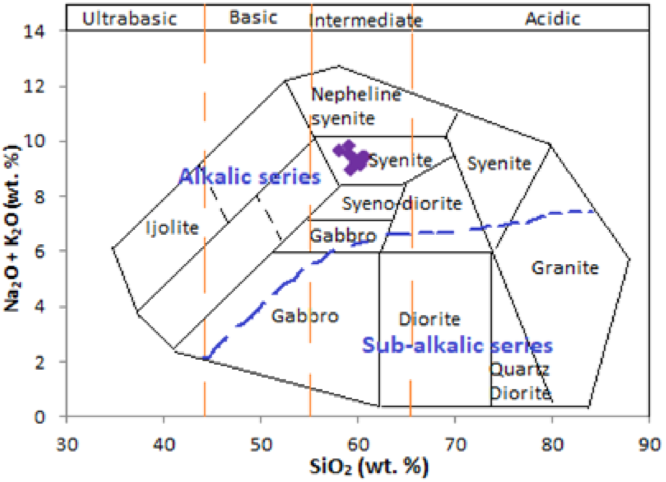

Figure 3: TAS classification of the Igarra syenites [boundaries modified after 11]

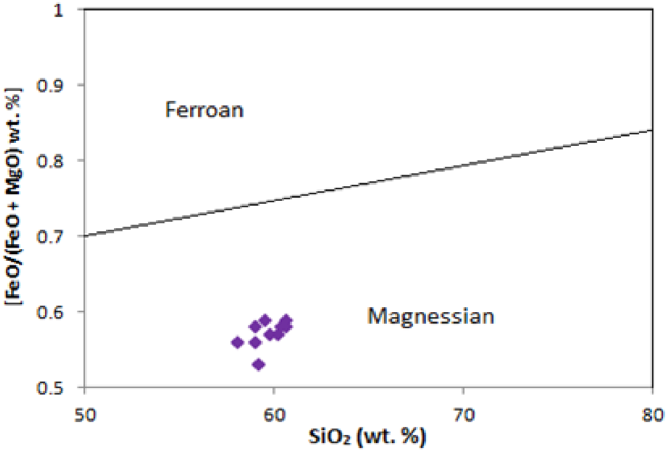

Figure 4: FeO/(FeO + MgO) vs. SiO_2 classification plot for the Igarra syenites [after 11]

5.2. Petrogenesis

The correlation of trends of major oxides against SiO_2 on the Hacker diagram has been used to infer homogeneity or heterogeneity of rock protoliths [14, 27]. As shown in Figure 6, there is a strong negative correlation for all the major oxides plotted. The consistency in trend clearly suggests a common protolith or petrogenetic history for the Igarra syenite. According to [27], a strong negative correlation of FeO_3, Al_2O_3 and Na_2O on the Hacker diagram is indicative of hornblende and pyroxene fractionation. As such, the significantly strong negative correlation of the major oxides against SiO_2 could be inferred to be indicative that fractional crystallization played a vital role in the evolution of the syenite. The peraluminous

Table 1: Major elements compositions of syenites around Igarra

Oxides (wt. %)	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Sample 6**	**Sample 7**	**Sample 8**	**Sample 9**	**Sample 10**
S_1O_2	59.08	60.09	59.68	58.95	58.02	58.90	60.25	59.45	60.58	60.51
T_1O_2	0.82	0.70	0.68	0.76	0.98	0.80	0.76	0.84	0.74	0.88
Al_2O_3	15.42	15.36	15.38	15.50	15.45	15.49	15.40	15.37	15.52	15.34
FeO	5.45	5.27	5.23	5.40	5.66	5.20	5.01	5.31	5.09	5.15
MgO	4.78	4.05	3.98	4.21	4.42	3.70	3.68	3.74	3.62	3.64
Na_2O	2.49	2.65	2.59	2.75	2.90	2.94	2.77	2.67	2.82	2.78
K_2O	6.50	6.54	6.61	6.80	6.80	6.90	6.69	6.72	6.66	6.70
CaO	3.79	4.12	3.96	3.97	3.95	3.80	3.74	3.70	3.69	3.64
P_2O_5	0.30	0.35	0.33	0.34	0.51	0.44	0.36	0.40	0.38	0.42
MnO	0.08	0.06	0.05	0.15	0.28	0.09	0.07	0.12	0.09	0.10
LOI	0.84	1.16	1.01	0.97	0.90	1.18	1.03	0.93	0.98	1.04
Total	**99.55**	**100.35**	**99.45**	**99.80**	**99.87**	**99.44**	**99.76**	**99.25**	**100.17**	**100.20**
Na_2O+ K_2O	8.99	9.19	9.2	9.55	9.70	9.84	9.46	9.39	9.48	9.48
N + K – C	5.20	5.07	5.24	5.58	5.75	6.04	5.72	5.69	5.79	5.84
A/NK	1.72	1.67	1.67	1.62	1.59	1.57	1.63	1.64	1.64	1.62
CNK	12.78	13.31	13.16	13.52	13.65	13.64	13.20	13.09	13.17	13.12
A/CNK	1.21	1.15	1.17	1.15	1.13	1.14	1.17	1.17	1.18	1.17
FeO + MgO	10.23	9.32	9.21	9.61	10.08	8.90	8.69	9.05	8.71	8.79
FeO/(FeO + MgO)	0.53	0.57	0.57	0.56	0.56	0.58	0.58	0.59	0.58	0.59
K_2O/Na_2O	2.61	2.47	2.55	2.47	2.34	2.35	2.42	2.52	2.36	2.41

Table 2: Trace elements concentrations in (ppm) of syenites around Igarra

Element/ Ratio	Sample1 ppm	Sample2 ppm	Sample3 ppm	Sample4 ppm	Sample5 ppm	Sample6 ppm	Sample7 ppm	Sample8 ppm	Sample9 ppm	Sample10 ppm
Sr	1200	904	950	1200	1100	1300	942	1200	1200	935
U	1.4	1.5	1.5	1.6	1.4	1.5	1.7	1.4	1.4	1.3
K	44500	23400	24600	25700	36300	30000	30000	30000	25500	26500
Rb	194	152	162	151	194	182	241	210V	167	185
Cs	5.1	5.26	5.44	5.26	5.31	4.94	6.69	4.88	4.64	4.45
Ba	4130	3250	3460	3360	3900	3420	3440	3530	3990	2990
Th	5.3	6.5	6.7	8.4	6	8.4	8.8	6.8	6.4	6.5
Ce	66.2	64.2	68.8	65.9	67	67.9	65.1	66.9	73.8	66.2
P	3490	2800	2320	2600	4360	4200	4120	4430	3240	3000
Ta	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nb	0.9	0.3	0.1	0.1	1.3	2	1.5	2.9	1.7	0.4
Te	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1
Tc	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1	¡0.1
Zr	43	60	4	6	61	56	58	79	28	10
Hf	0.6	0.8	0.1	0.1	1.1	1.2	1.4	1.8	0.6	0.1
TI	2570	1730	1070	1780	3760	4080	4080	4130	1840	1270
Y	19	18.4	19.2	17.8	19.7	19.8	18.3	19.2	20.7	17.3
Yb	1.8	1.8	1.9	1.8	1.9	1.9	1.9	1.9	2	1.8
Y + Nb	19.9	18.7	19.3	17.9	21	21.8	19.8	22.1	22.4	17.7
Rb/Sr	0.162	0.168	0.171	0.126	0.176	0.14	0.256	0.175	0.139	0.198
Rb/Nb	215.556	506.667	1620	1510	149.231	91	160.667	72.414	98.235	462.5
Rb/Zr	4.512	2.533	40.5	25.167	3.180	3.250	4.155	2.658	5.964	18.5

Table 3: Rare-earth element concentrations in (ppm) of syenites around Igarra

Element	Sample1 ppm	Sample2 ppm	Sample3 ppm	Sample4 ppm	Sample5 ppm	Sample6 ppm	Sample7 ppm	Sample8 Ppm	Sample9 ppm	Sample10 ppm
La	35.4	34.1	36.9	36	36.4	37.7	36.3	36.4	39.8	30
Ce	66.2	64.2	68.8	65.9	67	67.9	65.1	66.9	73.8	66.2
Pr	8.1	7.8	8.3	7.8	8.2	8	8.1	8.1	8.4	8.2
Nd	31.1	30.1	31.3	30.1	31	30.8	29.8	31.9	32.8	31.1
Sm	6.1	5.9	6.1	5.4	6.4	5.7	6	6.5	7	6.4
Eu	1.66	1.53	1.62	1.48	1.62	1.58	1.51	1.6	1.72	1.65
Gd	5.2	5	5.1	4.9	5.5	5.2	5	5.1	5.7	5.3
Tb	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.6
Dy	3.5	3.5	3.6	3.5	3.8	3.6	3.6	3.6	3.6	3.7
Ho	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.8	0.7
Er	1.9	1.8	2	1.9	1.8	1.9	1.8	1.9	1.9	1.9
Tm	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Yb	1.8	1.8	1.9	1.8	1.9	1.9	1.9	1.9	2	1.8
Lu	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3

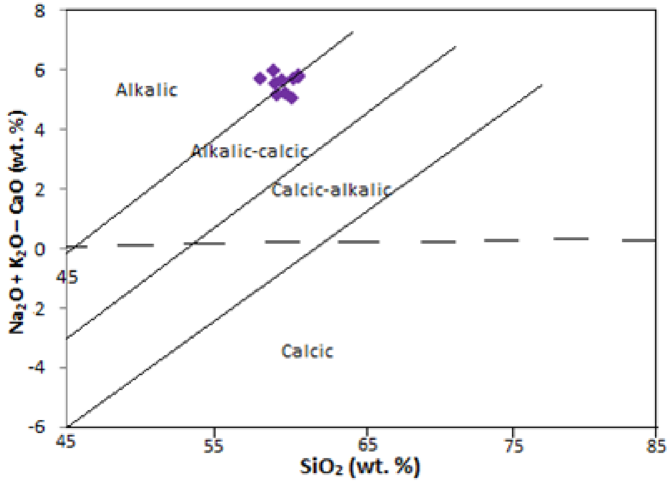

Figure 5a: Modified alkali-lime index, MALI vs. SiO_2 classification of the Igarra syenites [boundaries modified after 11]

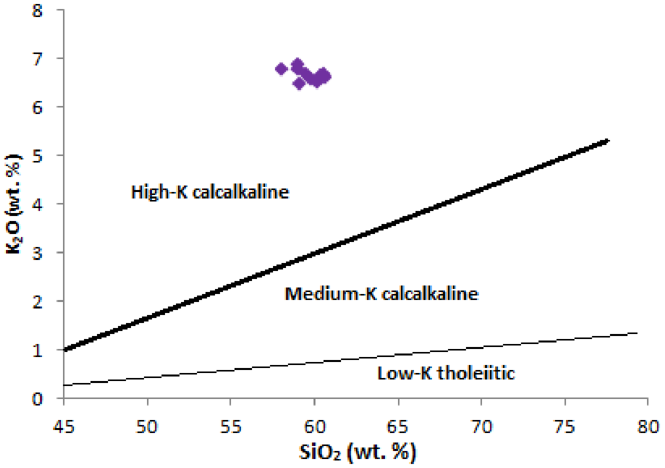

Figure 5b: K_2O vs. SiO_2 classification of the Igarra syenites [boundaries modified after 11]

signature of the rock suggests the melting of sedimentary protoliths for the Igarra syenites. Basement rocks derived from sedimentary sources are characterized by peraluminous chemical attributes [11, 14, 28].

Trace elements and REEs have also been widely used as "fingerprints" in understanding the origin and evolution of igneous rocks [e.g. 2, 29 – 31]. Ideally, the compositional depletion of Tc, Nb and Ta alongside enrichment of large-ion lithophiles (Rb, K, Sr and Th) suggests a partial melting of crustal origin for the syenites [32]. Similarly, the moderate to high fractionations and pronounced negative Eu anomalies displayed in the REE patterns are typical of crust-derived granites [28]. The negative Eu anomaly exhibited by the samples is suggestive of either plagioclase fractionation or its retention during the melting of the parent magma. More so, the relatively high values of Rb/Sr and Rb/Nb ratios further support the lithospheric crustal origin for the syenite. Mantle-derived magmas are characterized by low Rb/Sr ratios (usually ≤ 0.023) just as high Rb/Nb ratios are indicative of crustal origin [33]. However, the intermediate compositional concentration of SiO_2 in the rock poses some doubts to the crustal origin assertion as crust-derived magmas typically record silica content in excess of 60% [28] unlike the sampled rock that gave ≤60%. Considering the small sample size used for the present study, it is advisable that the crustal origin suggested for the syenitic rocks at Igarra should be taken with caution, albeit it is safe to conclude that the rocks had common source magma and evolutionary history based on the consistency and similarities in composition and distribution pattern, both for the major and trace elements.

5.3. Tectonic Setting

The syenitic rocks around Igarra are thought to have been emplaced in an arc environment following a major orogenic event based on the discrimination plots for the tectonic setting (Figures 8a – 8c). Whereas Figures 8a – 8c clearly indicate that

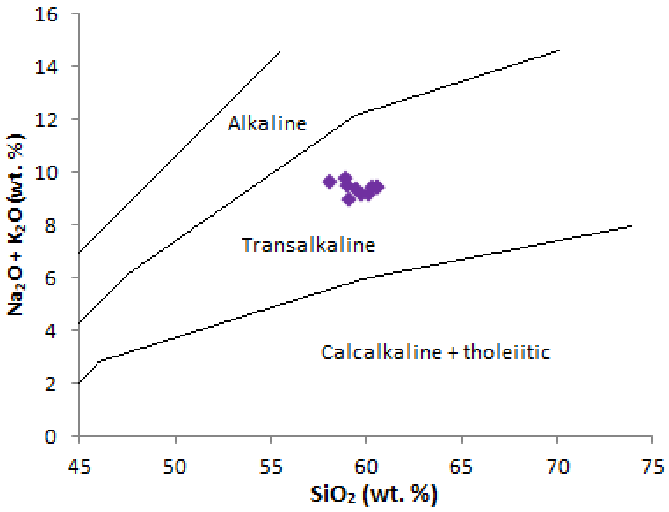

Figure 5c: $Na_2O + K_2O$ classification plot for the Igarra syenites [boundaries modified after 11]

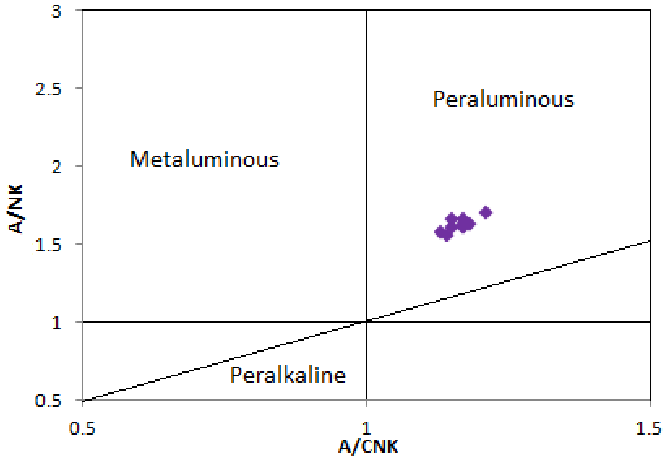

Figure 5d: A/NK vs. A/ACNK plot for the Igarra syenites [boundaries after 11 and 14]

the emplacement and evolution of the syenites occurred in an active orogenic belt, Figures 8d and 8e suggest that the development occurred in more or less transitional setting between orogenic and anorogenic geodynamic settings. Given that the area is part of the Basement Complex in Nigeria generally believed to have been affected by the Pan-African reactivation event, it is our opinion that the emplacement and evolution of the Igarra syenite is related to the Pan-African orogeny which led to the collision of the West African Craton and the Tuareg Shield. [11, 34] opined that the collisional event was preceded by the subduction of the lithosphere beneath an ancient oceanic crust around the eastern flank of the West African Craton underneath the Tuareg Shield. It is believed that it is this ancient oceanic crust that gives rise to the series of basic and ultrabasic rocks of ophilitic complex and high positive gravity anomaly within the Basement Complex of the eastern axis of the West African Craton [11]. Given the orogenic to post-orogenic signatures shown from the discrimination plots for the tectonic setting, we propose that although the emplacement of the Igarra syenite commenced during the active phase of the Pan-African reactivation (probably towards the end of the orogeny), the formation and evolution of the rock continued into the early post-orogenic period.

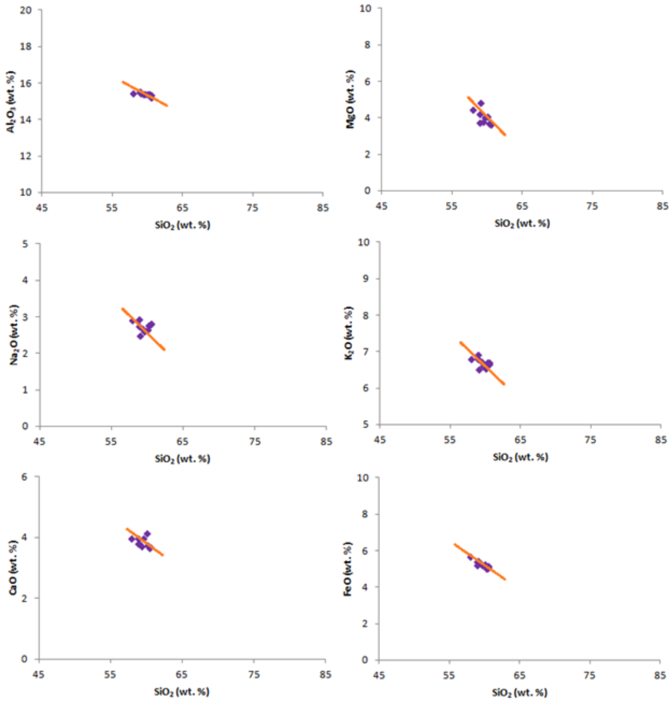

Figure 6: Hacker diagram (major oxides vs. SiO_2) the Igarra syenites

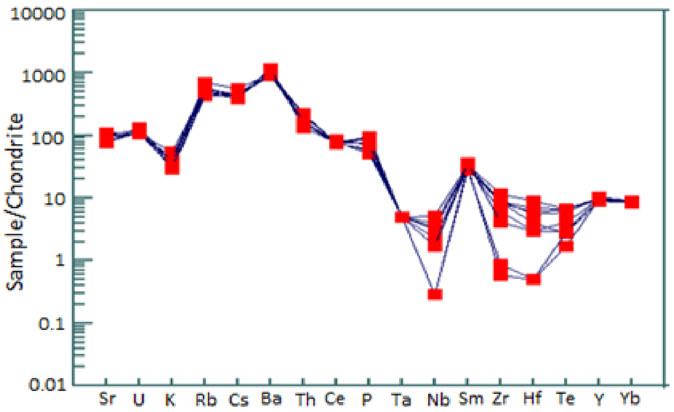

Figure 7a: Primitive-mantle normalized trace elements pattern for Igarra syenites [chondrite normalization values after 24]

Similarly, the emplacement and formation of the syenites in the area of the study have also been interpreted to have occurred in a tectonic arc as clearly revealed in Figures 8c – 8f. Given the significant negative Eu anomalies displayed by the REEs and the relatively high ratios of Rb/Nb, Rb/Sr and Rb/Zr, an active continental arc tectonic setting is inferred for the Igarra syenite. The active continental tectonic setting is further supported by the plot of K_2O/NaO vs. SiO_2 (Figure 8b). Generally, 3

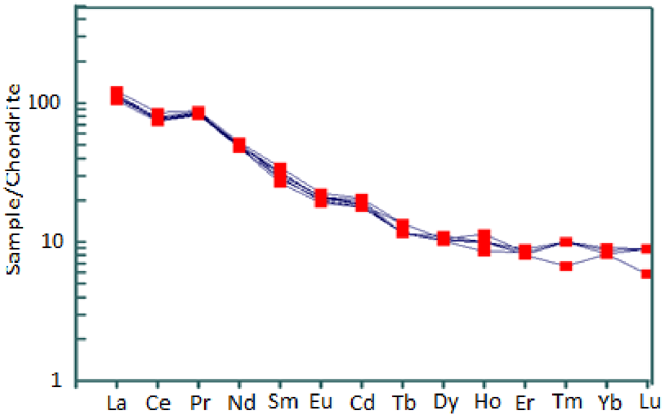

Figure 7b: Chondrite-normalized REE diagram for the Igarra syenites [normalization values after 23]

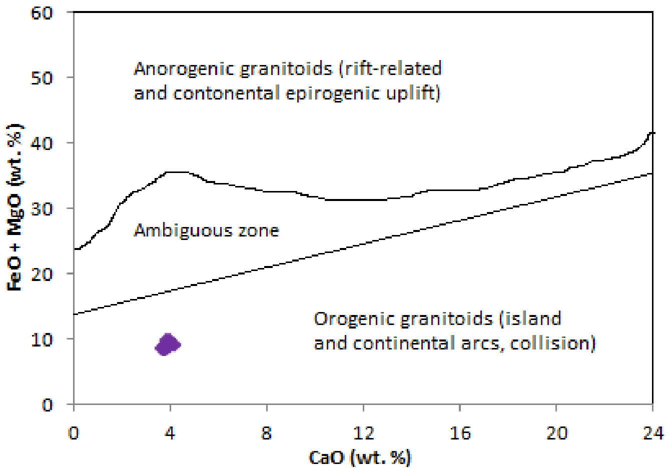

Figure 8a: FeO + MgO vs. SiO_2 plot for the Igarra syenites [boundaries after 14 and 35]

geotectonic models have been proposed for the formation and evolution of syenites gobally: those associated with attributes of mantle evolution; those linked to crustal origin; and those associated with mantle-crustal origins for parent magmas [4]. The crust-derived syenites model proposes melting of crustal substrates with the rocks showing geochemical imprints similar to those recorded in the present study [4].

The arc geodynamic setting inferred for the Igarra syenite is in agreement with existing knowledge on the Basement Complex rocks of south western Nigeria which are thought to have developed in a back-arc basin [37 – 39]. The initiation of magmatism during active orogeny and its continuation well into post-orogenic periods have also been reported for basement rocks elsewhere within Nigeria [e.g. 11, 14, 40]. It is hoped that findings from the present study will spur further research interests in the syenites in Nigeria just as integrated approach of combining geological and mechanical attributes is recommended for such studies.

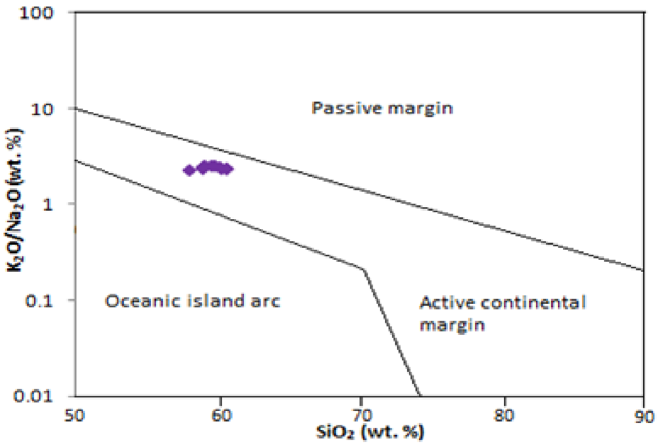

Figure 8b: K_2O/Na_2O vs. SiO_2 plot for the Igarra syenites [after 14 and 35]

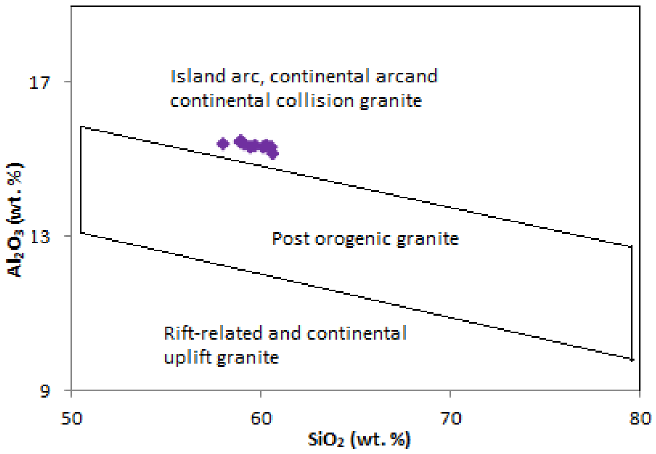

Figure 8c: Al_2O_3 vs. SiO_2 tectonic setting bivariate plot for the Igarra syenites [after 14 1nd 35]

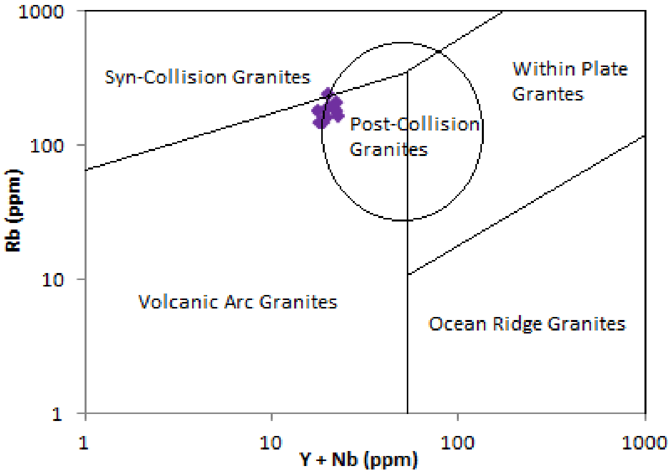

Figure 8d: Rb vs. Y + Nb bivariate for the Igarra syenites [after 11 and 14]

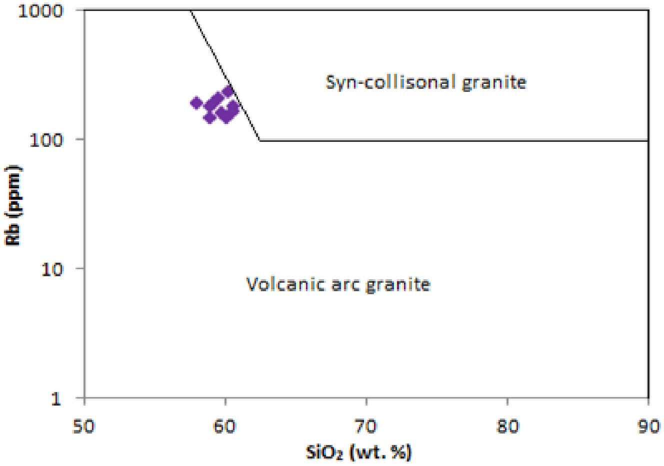

Figure 8e: Rb vs. SiO_2 discriminant plot for the tectonic setting of the Igarra syenites [boundaries modified after 14]

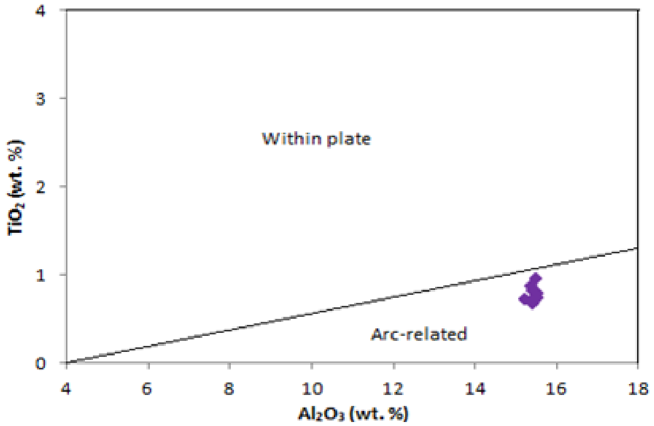

Figure 8f: TiO_2 vs. Al_2O_3 bivariate plot for the Igarra syenites [after 14 and 36]

6. Conclusions

The syenites around Igarra in southwestern Nigeria were examined to ascertain their tectonic setting and petrogenetic history using evidences from geochemistry. The data and resultant bivariate plots for the Igarra syenites show that the rocks are high-K calcalkaline, alkali to alkali-calcic and peraluminous. Based on the peraluminous character of the rocks, the melting of sedimentary protolith is inferred, with primary magma probably derived from the lithospheric crust. The syenites were emplaced and formed in an arc tectonic environment during the Pan-African reactivation event and continued into the early post-orogenic periods. The findings from the study compare closely with those of earlier studies on syenites within the Nigerian Basement Complex. The present study contributes to the existing literature on the syenites in Nigeria by giving further insights into the geochemical attributes of the Igarra syenites. This is important considering that the syenites in Nigeria have over the years been poorly understood relative to the other crystalline rocks within the basement complex. Findings from the study are also expected to enhance the overall understanding of the Nigerian Basement Complex with regards to its geodynamic evolution and tectonic setting.

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