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The Petrogenesis and Tectonic Setting of Sara-Fier Younger Granite Complex, Central Nigeria

Aga, T[1*] and Haruna, A. I.[2]

[1]Department of Geology, University of Jos, Jos, Nigeria, mragatersoo@gmail.com.
[2]Department of Applied Geology, Abubakar Tafawa Balewa University, Bauchi, Nigeria.

Abstract: ***The Sara-Fier Younger Granite Complex is one of the several anorogenic granite suite in central Nigeria which intruded the Basement Complex. The complex is found to comprise of felsic rocks like; biotite-granites, biotite micro granites, hornblende biotite granites, syenites, pyroxene-fayalite granite and hornblende-fayalite granite. The complex is also found to be associated with mafic rocks like gabbroic diorites and diorites which, at some portions have formed hybrid rocks. Rebeckite granites is the porphyritic rock that is found in the ring complex which we could not analyze due to alteration. The rock chemistry of thirty six (36) representative samples was carried out on the energy dispersive x-ray fluorescence (EDXRF) for twelve (12) major and thirty seven (37) trace and REE elements. Agpaitic index and alumina saturation index suggest that almost all the samples are peraluminous to metaluminous. The widely used SiO_2vs K_2O classify most of the granite samples as high K rocks while the mafic gabbroic diorites and diorites as calc-alkaline. Use of the popular Pearce et al discrimination diagrams for tectonic interpretation suggest that the rocks are within plate granitoids and A-type granites in the Y vsNb diagram. The enrichment of high field strength (HFS) elements in the investigated granites confirms their A-type identity and exclude them from other granitic types. Spidergraph show negative Sr anomaly suggesting the feldspar fractionated nature of the granitoids where plagioclase played an important role in the evolution of the A-type magmatism. The magma that gave rise to the granitoids most likely came from the lithospheric mantle. The enrichment of Zr and Nb in the rocks indicate Zn-Sn mineralization. The Kwapa valley part of the northern section of the complex contains Pb>15 which confirms that the compex is a tin-bearing granitoid suite.***

Keywords: Petrogenesis, A-type, Granite, Sara-Fier, Mineralization.

I. INTRODUCTION

According toBlack et al., (1985), the Adrar des Iforas of Mali, silica-oversaturated alkaline magmatism began about ten million years (10ma) after the Pan-African Orogeny and lasted for about twenty million years (20Ma). The Niger-Nigerian alkaline ring complexes province were however, emplaced long after the Pan-African Orogeny (Kinnaird and Bowden, 1991). There is an emplacement age decrease from north to south, ranging from Ordovician-Devonian (480–400 Ma) in Aïr (northern Niger) to Carboniferous (330–260 Ma) in Damagaram-Mounio (southern Niger) to Triassic-Early Cretaceous (213–141 Ma) in Nigeria (Fig. 1, Kinnaird and Bowden, 1991). The Cameroon Volcanic Line (CVL) which is Cenozoic (73 Ma to Recent) is situated south east of Nigeria is separated from the Nigerian ring complexes by the Cretaceous Benue Trough (Ngako et al., 2006; Fig. 1).

Sudan, Namibia, Ethiopia, and Egypt are other countries in Africa where A-type granites have been studied. Unlike the ones in Nigeria-Nigeria, anorogenic ring complexes these countries do not show any spatial age progression but, instead, episodically recurrent activity at different times in different places (Trumbull et al., 2004; Martin et al., 2012).

The Younger Granites in Nigeria are comprised of fifty three (53) silica-oversaturated anorogenicsyenite-granite ring complexes. (Fig. 2). These Mesozoic igneous suites cover a total area of 75,000km^2 and occupy a 400-km-long, 160-km-wide, north-trending belt between latitudes 8°N and 12°N and longitudes 8°E and 10°E (Bowden et al., 1987). The distribution of these alkaline ring complexes is controlled mainly by a network of N-S-trending megashear zones and associated deep-seated transcurrent faults created during the waning stages of the Pan-African Orogeny (600 ± 150 Ma), during which Gondwana amalgamated (Black et al., 1985; Black and Liégeois, 1993).

The Nigerian ring complexes range in diameter from 2 to 25 km and crosscut the Precambrian Basement Complex of Nigerian. The Nigerian basement rocks consists mainly of migmatite, gneiss, and metapellite of Paleoproterozoic age with relics of Archean rocks, as well as Pan-African syn-

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collisional to post-collisional granites, monzodiorites, and charnockites of largely crustal origin (Dickin et al., 1991; Dada et al., 1995; Ferré et al., 1998; Ferré and Caby, 2007). According to (Küster, 1990), the post-collisional granites in Nigeria are spatially associatedwith Sn–Nb–Ta mineralized pegmatites that are largely concentratedalong a NE-SW-trending zone known as the older tin belt.

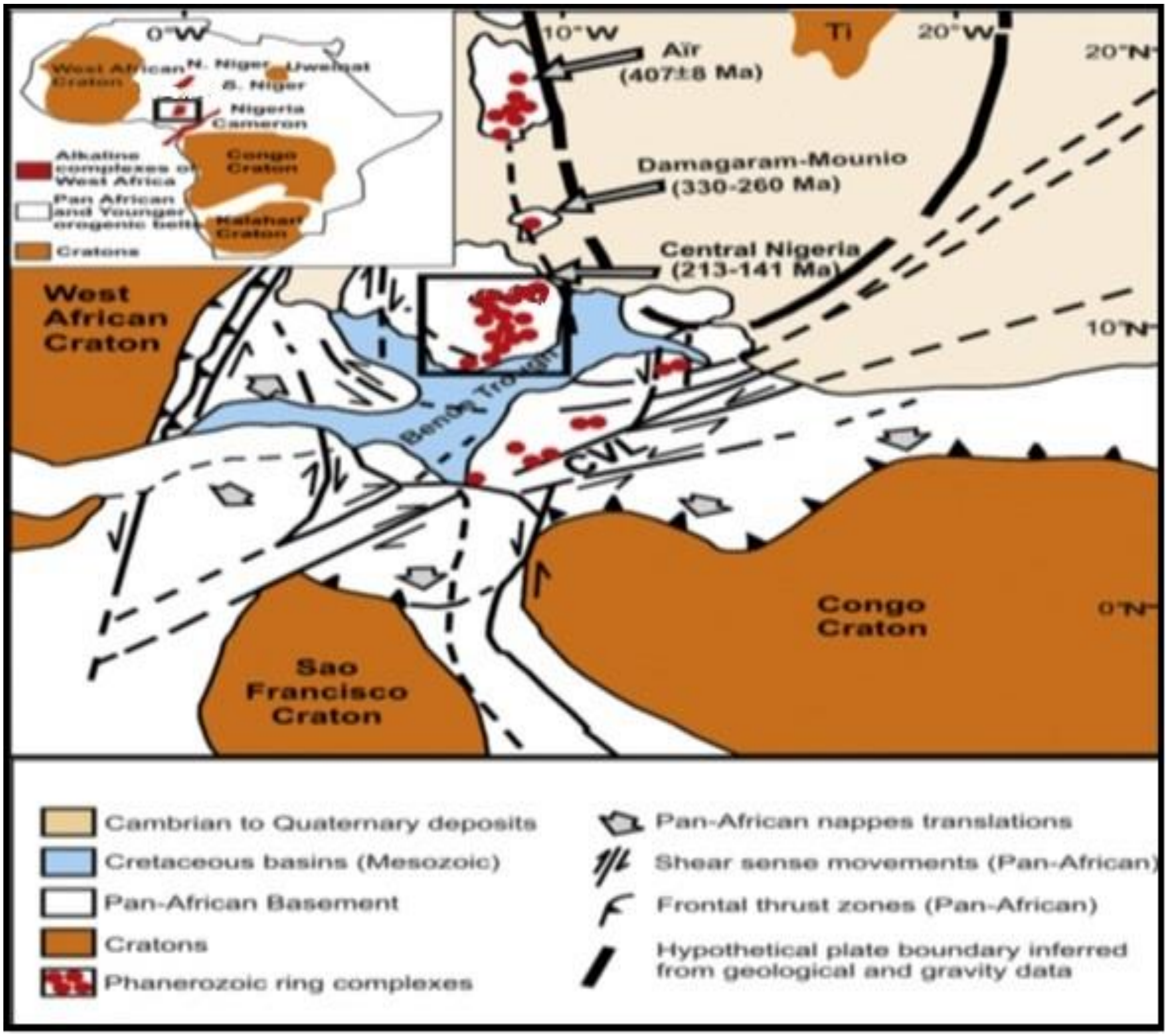


Fig. 1. Map of Anorogenic Ring Complexes in Aïr (northern Niger), Damagaram-Mounio (southern Niger), Central Nigeria, and Cameroon in Relation to Pan-African Continental Structures of Western Gondwana (Modified fromNgako et al., 2006).

The anorogenic activity started to the north in the Dutse complex during the Triassic (213 Ma) and lasted until the Early Cretaceous (141Ma) in the Afu complex near the Benue Trough. The Niger-Nigerian alkaline province has been regarded as an epizonal equivalent of anorthosite-mangerite-charnockite-granite (AMCG) suites (Magaji et al., 2011; Martin et al., 2012), but, unlike in Aïr, Niger, anorthosite occurs only as xenoliths within dolerite dykes near the Jos Plateau, Nigeria (Bowden et al., 1987).

II. GEOLOGY OF THE STUDY AREA

The Sara-Fier Younger Granite Complexes is one of the fifty three anorogenic alkaline Younger Granite Complexes in the Nigerian Pan African Basement Complex (Macleod et al, 1971). The granite suite is located approximately one hundred and twenty (120) kilometres south east of Jos, the Plateau State capital. Sara-Fier Complex constitute a significant window to the detailed understanding of the magmatic evolutionary trends and metallogenic characteristics of the Nigerian Younger Granites as a whole. This is because of the prominent occurrence of mafic rocks which may represent the more primitive magma in the Younger Granite Province. The complex is found to comprise of felsic rocks like; biotite-granites, biotitemicrogranites, hornblende biotite granites, pyroxene fayalite granites and syenite. (Figure 2, Plate II). The sample location and areas covered by the various rock types are are presented in Tables 1 and 2 respectively. They are also found to be associated with mafic rocks like gabbroic diorites and diorites which, at some portions have formed hybrid rocks (Plate I).

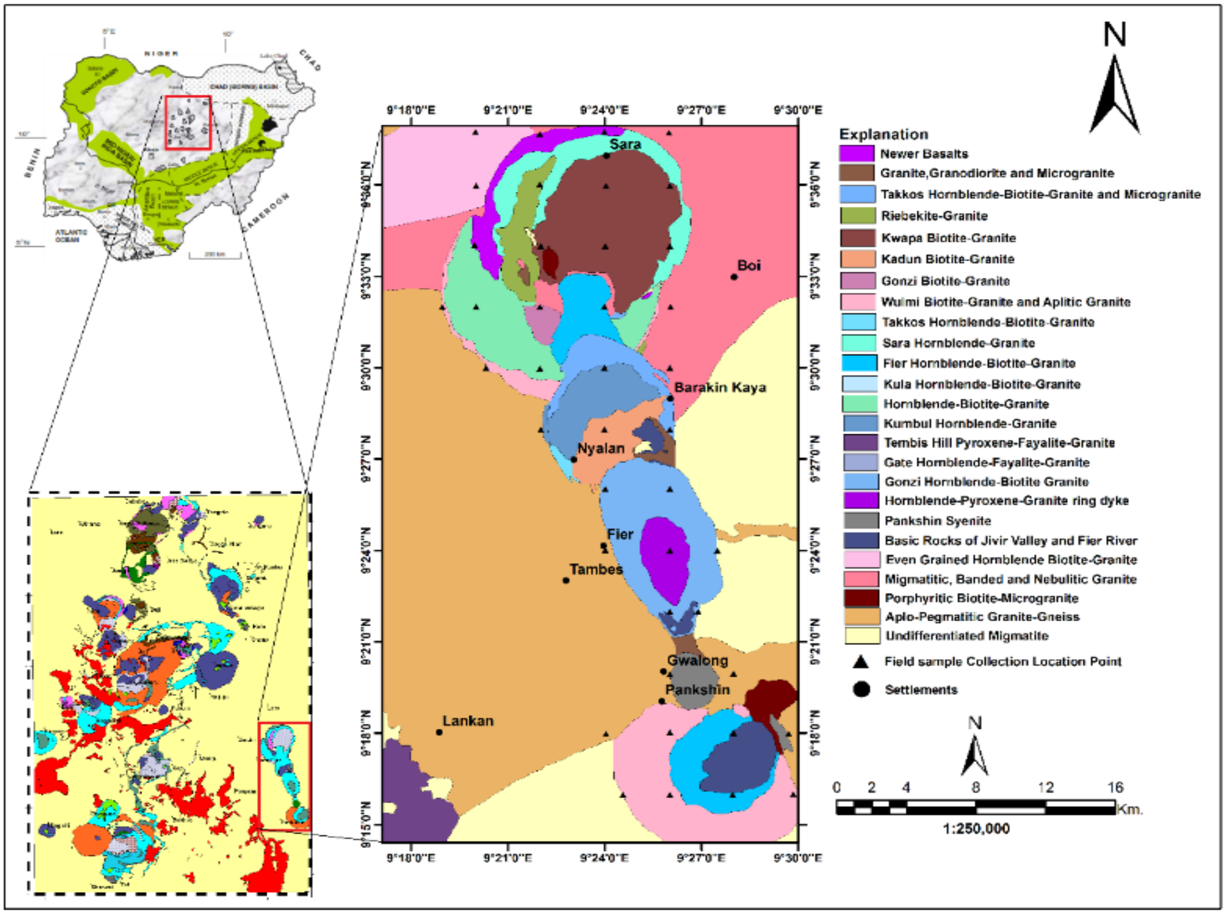


Fig.2: Top = Geological Map of Nigeria Showing the Location of the Younger Granite Ring Complexes (After Obaje, 2009); Left = Map of Younger Granites Ring Complexes of Nigeria (Modified After Kinnard et al, 1985); Centre = Geological Map of Sara-Fier Younger Granite Complex

Table 1: Sample Location for Sara-Fier Complex

S/N	Longitude	Latitude	S/N	Longitude	Latitude
1	09° 35' 52"	09° 20' 39"	34	09° 18' 09"	09° 24' 26"
2	09°35' 48"	09°22' 33"	35	09° 18' 13"	09° 26' 17"
3	09°35'49"	09°24' 23"	36	09° 18' 11"	09° 28' 10"
4	09°35' 47"	09° 26' 17"	37	09° 18' 08"	09° 29' 43"
5	09°34' 14"	09° 20' 41"	38	09° 16' 19"	09° 24' 55"
6	09° 34' 18"	09° 22' 31"	39	09° 16' 19"	09° 26' 19"
7	09° 34' 13"	09° 24' 28"	40	09° 16' 28"	09° 24' 54"
8	09° 34' 14"	09° 24' 19"	41	09° 16'22"	09° 26' 17"
9	09°32' 26"	09° 22' 32"	42	09° 16' 18"	09° 28' 08
10	09° 32'27"	09° 24' 26"	43	09° 16' 21"	09° 28' 09"
11	09° 32' 28"	09° 26' 19"	44	09° 16' 23"	09° 29' 53"
12	09° 30' 40"	09° 19' 41"	45	09° 28' 47"	09° 19' 30"
13	09° 30' 41"	09°20' 42"	46	09° 27' 04"	09° 20' 57"
14	09° 30' 42"	09° 20' 41"	47	09° 27' 05"	09° 19' 34"
15	09° 30' 41"	09° 24' 24"	48	09° 25' 04"	09° 19' 39"
16	09° 30' 39"	09° 26' 20"	49	09° 25' 10"	09° 21' 07"
17	09° 28' 53"	09° 20' 59"	50	09° 25' 16"	09° 22' 33
18	09° 28' 52"	09° 22' 30"	51	09° 23' 32"	09° 23' 32"
19	09° 28' 54"	09° 24' 26"	52	09° 23' 46"	09° 21' 05"
20	09° 28' 52"	09° 24' 24"	53	09° 23' 38"	09° 22' 37"
21	09° 28' 53"	09° 26' 17"	54	09° 29' 52"	09° 21' 39"
22	09° 27' 04"	09° 22' 33"	55	09° 32' 04"	09° 27' 54"
23	09° 27' 06"	09° 24' 23"	56	09° 27' 05"	09° 28' 46"
24	09° 27' 04"	09° 26' 18"	57	09° 19' 40"	09° 26' 57"
25	09°25' 23"	09° 24' 23"	58	09° 16' 19"	09° 22' 42"
26	09° 25' 20"	09° 26'17"	59	09° 16' 09"	09° 18' 55"
27	09° 23' 34"	09° 24' 26"	60	09° 31' 46"	09° 16' 32"
28	09°23' 31"	09° 26' 19"	61	09° 26' 59"	09° 16' 51"
29	09° 23' 29"	09° 27' 40"	62	09° 26'12"	09° 15' 07"
30	09° 21' 44"	09° 26' 17"			
31	09° 21' 41"	09° 27' 09"			
32	09°19' 53"	09° 26'20"			
33	09° 19' 53"	09° 28' 08"			

Table 2: Area Covered by Rocks of Sara-Fier Complex

Rock type	Area (sq km)	Percentage
Newer Basalt	78.542	1.270783
Granite,granodiorite and microgranite	313.69	5.075397
Applopegmatitic granite	1988.9	32.17972
Porphyritic biotitemicrogranite	30.005	0.485471
Even grained hornblende biotite granite	253.49	4.101382
Takkoss hornblende biotite granite	95.34	1.542569
Basic rocks of Jivir valley and Fier river	84.019	1.359399
Pankshinsyenite	53.82	0.870789
Fier hornblende biotite granite	324.32	5.247387
Hbld, Porphyritic granite ring dyke	60.837	0.984322
Undifferentiated Migmatite	885.21	14.3224
Tembes Hill	98.105	1.587305
Kadum	73.437	1.188186

The complex intruded the basement rocks of central Nigeria. The major composition of thirty six (36) selected rock samples is given in Table 3. The results were plotted on the petrological classification plot developed after Middlemost, 1985. The felsic granitoids fell in the granite section (Fig. 3) and are quart-rich granitoids (Fig. 4). The mafics which are made up of diorites and gabbroic diorites plotted in their appropriate polygons and the QAPF diagram suggest that the granitoids are rich in alkali feldspars. The rhyolites and basalts have been obliterated due to weathering over a long period of time.

Plate I: Dioritic Enclaves at Duk Area

Plate II. Hornblende Biotite Granite

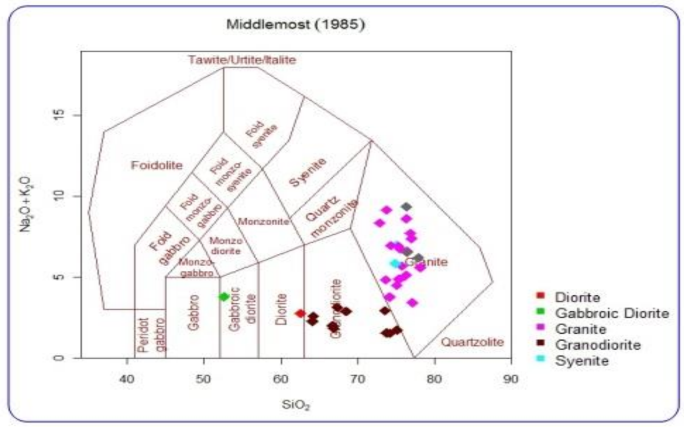


Fig. 3. Rock Classification (After Middlemost, 1985)

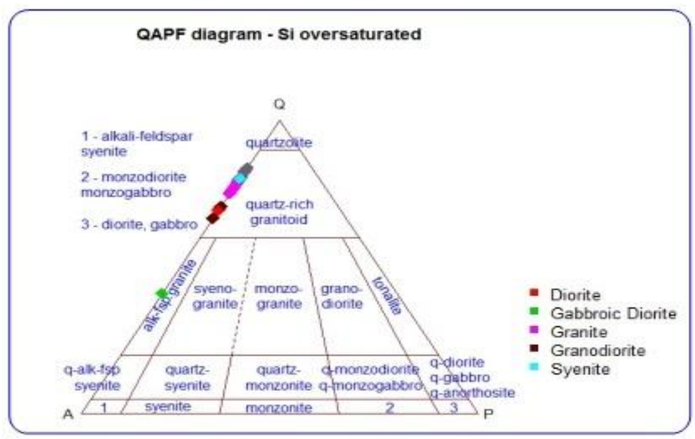


Fig. 4. QAPF – Si Oversaturated Diagram

In Nigeria, the major structural direction is oriented NNE-SSE corresponding to one of the major structural trends in the Basement Complex and direction of alignment of the Younger Granite ring complexes (Rahaman et al, 1988; Turner 1989). The form and general distribution pattern of the ring centres may have been controlled by these pre-existing lines of weakness in the Pan-African Basement into which the Younger Granite Complexes were intruded.

In the study area, the following joint directions were mapped, N-S and NNE-SSW and which correspond with the general structural trend of the underlying basement (Fig. 5). The general structural trend in the study area is shown in Fig. 6. This suggest that these joint direction are outward prolongation of deep seated fracture zones that initiate and guided the location of the Younger Granite eruption centres. They followed these weak zones during eruption in the Jurassic (165 ±25ma).

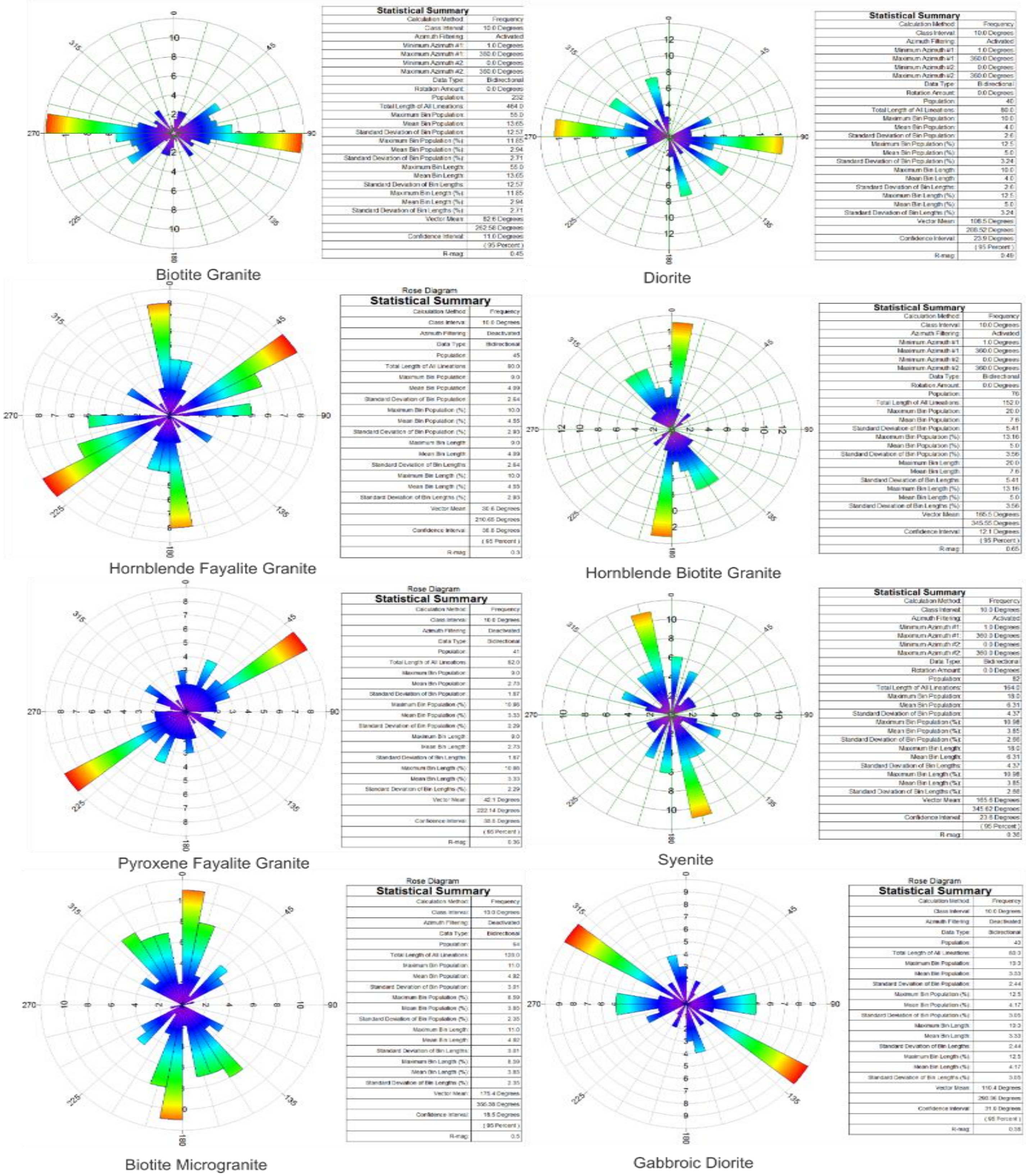
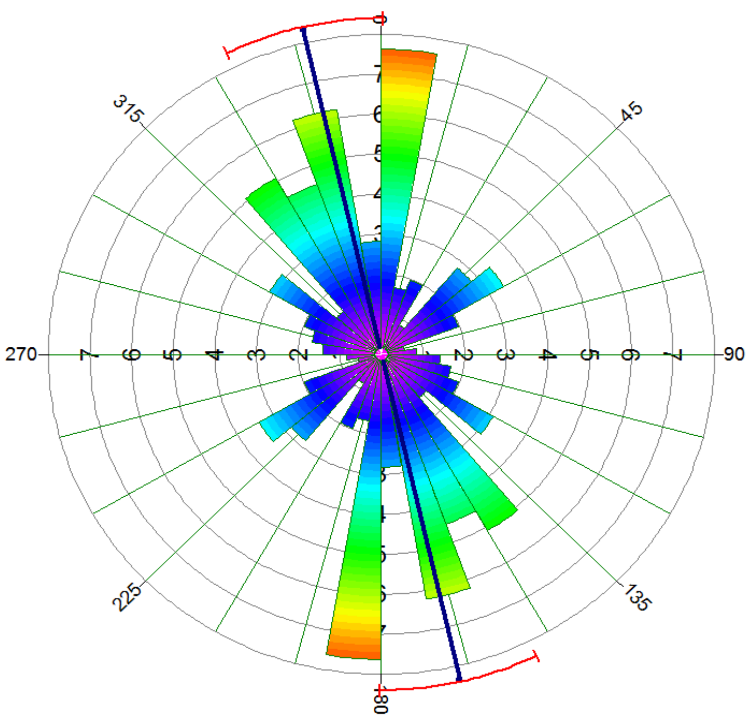


Fig. 5. Structural Trend of Joints in Rocks of the Sara-Fier Complex.



Statistical Summary	
Calculation Method:	Frequency
Class Interval:	10.0 Degrees
Azimuth Filtering:	Activated
Minimum Azimuth #1:	1.0 Degrees
Maximum Azimuth #1:	360.0 Degrees
Minimum Azimuth #2:	0.0 Degrees
Maximum Azimuth #2:	360.0 Degrees
Data Type:	Bidirectional
Rotation Amount:	0.0 Degrees
Population:	354
Total Length of All Lineations:	708.0
Maximum Bin Population:	54.0
Mean Bin Population:	19.67
Standard Deviation of Bin Population:	13.59
Maximum Bin Population (%):	7.63
Mean Bin Population (%):	2.78
Standard Deviation of Bin Population (%):	1.92
Maximum Bin Length:	54.0
Mean Bin Length:	19.67
Standard Deviation of Bin Lengths:	13.59
Maximum Bin Length (%):	7.63
Mean Bin Length (%):	2.78
Standard Deviation of Bin Lengths (%):	1.92
Vector Mean:	167.0 Degrees
	347.01 Degrees
Confidence Interval:	13.3 Degrees
	(95 Percent)
R-mag:	0.31

Fig. 6. General Structural Trend of Joints in the Sara-Fier Complex.

III. GEOCHEMISTRY

The rock chemistry of thirty six (36) representative samples was carried out on the energy dispersive x-ray fluorescence (EDXRF) for twelve (12) major and thirty seven (37) trace and REE elements. The sample preparation and analysis were carried out at the Geochemistry laboratory of the Nigerian Geological Survey Agency in Kaduna. The samples analyzed comprise of one (1) gabbroic diorite, one (1) diorite, nine (9) granodiorites, two (2) syenites and twenty three (23) granites of varying textural and mineralogical compositions. The detailed geology and petrography of the samples is described elsewhere (Aga and Haruna, 2019). The discrimination and correlation diagrams are plotted to characterize each granite type and to discuss the petrogenesis and tectonic setting of the granites from the study area.

Major, Trace and REE Element Classification

The result of the chemical analyses are presented in the tables 3, 4a and 4b below. All the granite samples show only subtle variations in their major element concentrations; a feature typical of the rocks from the Younger Granite Province (MacLeod et al.,1971). The CaO content is consistently low in the granites (0.00 – 2.70), syenite (1.96 -2.04) and the Al_2O_3 content of all the rocks show a wide range between 10.00 and 14.00, which is also generally low. The SiO_2 content in all the granites and syenites are greater than 70 as compared to the gabbroic diorite/diorites (51.06 - 60.10). The inverse relationship exist with respect to the total iron, highest in a gabbroic diorites/diorites (18.41) and lowest in a granite/syenites (0.40). The rocks ranges from peraluminous, to metaluminous; Agpaitic Index (AI= molecular portion of Na_2O+K_2O/Al_2O_3) and alumina saturation index (A/CNK = molecular Al_2O_3/Na_2O + K_2O + CaO) ratio < 1 peraluminous (corundum and anorthite normative; AI >1) (Fig. 7). The Na_2O-Al_2O_3-K_2O triangular diagram plot most of the samples within the metaluminous-peraluminous region (Fig. 8). Further, the widely used SiO_2 vs K_2O diagram classify most of the granites as high-K rocks, with the exception of the granodiorite that belong to the shoshonite series. Meanwhile, the mafic gabbroic diorite and diorite samples belong to the calc-alkaline series (Figs. 9 and 10).

Petrogenesis and Tectonic setting

The geochemical nature of the studied A-type granites are critically tested using the standard common schemes as well as the adopted three-tiered geochemical classification scheme of granites rocks. The extreme Fe*O enrichment relative to MgO (high FeO*/MgO) is a typical signature of A-type granitoids and all the present granite samples are grouped as A-type granite on the $(Na_2O+K_2O)/CaO$vsZr+Nb+Ce+Yvs SiO_2 diagram (Figs. 11).

Table 3: Major Element Concentration of Sara-Fier Younger Granite Complex

Sample ID	Location	Petrology	SiO_2	CaO	MgO	SO_3	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Fe_2O_3	Al_2O_3	H_2O^+
AT2	Sara-Fier	Granodiorite	63.1	7.05	2.06	0.46	1.03	0.84	2.12	0.26	0	6.04	12.04	3.24
AT5	Sara-Fier	Granite	73.48	2.7	0.06	0.21	4.02	0.71	1.25	0.093	0	2.14	13.03	1.63
AT6	Sara-Fier	Granite	74.08	1.14	0.06	0.048	5.36	1.03	0.84	0.075	0.002	1.18	13.2	2.06
AT9	Sara-Fier	Granodiorite	63.1	2.37	6.34	0	1.46	0.24	3.11	0.3	0	6.25	11.2	3.51
AT14	Sara-Fier	Granite	72.06	0	0	0	7.76	1.2	0.52	0.11	0	3.76	12.32	2.07
AT15	Sara-Fier	Syenite	73	1.96	0.8	0	4.4	2.4	0.23	0.17	0.003	2.25	12.01	1.96
AT19	Sara-Fier	Granite	73.84	1.01	0.03	0.48	0.46	2.8	1.15	0.094	0	3.29	13.06	2.86
AT20	Sara-Fier	Granodiorite	64.48	4.24	3.16	0.57	2.52	0.46	2.06	0.3	0.001	6.67	11.86	3.86
AT24	Sara-Fier	Granite	74.4	0.94	0.03	0.43	6.4	0.74	0.071	0.04	0	0.4	13.62	1.03
AT34	Sara-Fier	Granite	73.7	0.52	0.003	0	7.9	0.42	0.307	0.036	0	1.57	12.06	2.5
AT36	Sara-Fier	Granite	74.06	1.76	0.05	0.26	4.12	0.86	0.65	0.086	0	1.75	13.69	1.96
AT40	Sara-Fier	Granodiorite	72.89	5.37	0.44	0.64	0.64	1.02	1.5	0.08	0.02	3.08	12	1.6
AT41	Sara-Fier	Granite	74.09	0.86	0.41	0.06	4.44	0.48	0.44	0.034	0	3.77	12.84	2
AT43	Sara-Fier	Granodiorite	59.7	4.8	3.92	0.13	2	0.4	2.42	0.24	0	7.08	12.4	6.34
AT46	Sara-Fier	Granite	73.04	2.04	0.43	0.024	1.03	3.32	1.78	0.11	0.001	3.39	12.1	2.46
AT47	Sara-Fier	Granite	73.46	0.6	0.003	0.24	6.63	0.74	0.16	0.033	0	0.37	13.6	2.62
AT48	Sara-Fier	Granite	72.7	1.59	0.08	0.08	3.21	0.46	2.18	0.14	0.02	4.05	13.6	1.4
AT50	Sara-Fier	Granodiorite	65.03	4.54	3.08	0.6	2.3	0.43	1.55	0.25	0.003	6.35	11.4	3.48
AT52	Sara-Fier	Granite	73.07	0.85	0.009	0.24	4.06	1.4	0.46	0.06	0.006	2.52	14	1.48
AT55	Sara-Fier	Granite	72.1	1.49	0.23	0	6.2	2.06	0.57	0.13	0	3.76	12.43	2.08
AT56	Sara-Fier	Granite	73.4	0.57	1	0.21	6.02	0.71	0.52	0.17	0.003	2.8	12.3	2.01
AT57	Sara-Fier	Granodiorite	72	2.03	0.2	0.43	2.8	0.06	3.63	0.2	0	5.07	11.9	1.4
AT58	Sara-Fier	Diorite	60.1	4.3	7.81	0	0.86	1.78	3.66	0.29	0	6.6	10.68	2.56
AT63	Sara-Fier	Granodiorite	72.2	5.5	1.24	0.44	1.4	0.1	2.6	0.24	0.003	2.28	12.33	2.42
AT64	Sara-Fier	Granodiorite	72.06	4.03	3.2	0.24	0.42	1.04	2.03	0.18	0.001	3.1	11.03	1.84
AT65	Sara-Fier	Gabbroic Diorite	51.06	6.29	3.66	0	1.64	2.03	3.29	0.38	0	18.41	10.34	1.89
AT69	Sara-Fier	Granite	75.06	0.89	0.06	0.4	4	1.36	0.57	0.016	0.003	1.24	12.84	2.34
AT73	Sara-Fier	Granite	58	0.28	0.03	0	23.3	1.06	0.62	0.13	0	3.01	10.62	2.48
AT74	Sara-Fier	Granite	72.5	0.46	0.03	0.42	5.7	1.08	0.97	0.1	0.007	3.61	13.04	1.84
AT76	Sara-Fier	Granite	73.62	0.84	0.09	0.63	6	0.56	0.52	0.15	0	2.34	13.3	1.95
AT77	Sara-Fier	Granite	72	2	0.24	0	4	0.71	1.24	0.25	0	5.01	12.24	2.1
AT79	Sara-Fier	Granodiorite	60.08	6.63	4.48	0	0.72	1.4	2.16	0.28	0	8	10	4.36
AT80	Sara-Fier	Granite	74.43	1.13	0.42	0.03	5.63	0.73	0.74	0.14	0	1.02	13.08	1.04
AT82	Sara-Fier	Granite	73.4	0.84	0.26	0.002	4.8	1.04	0.15	0.071	0.024	0.58	13.06	1.01
AT84	Sara-Fier	Granite	74	0.47	0.002	0.4	8.02	1.04	0.1	0.033	0	0.76	12.49	1.24
AT31	Sara-Fier	Syenite	73.48	2.04	0.4	0.44	4.4	1.32	0.9	0.12	0	2.11	13.36	2.12

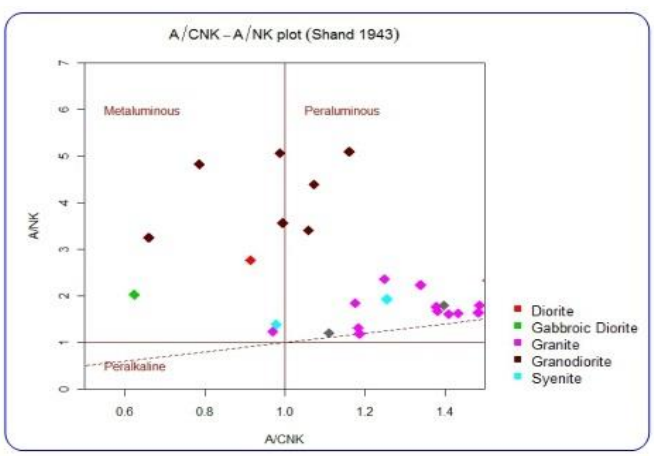


Fig. 7: ANK vs A/CNK diagram for rocks

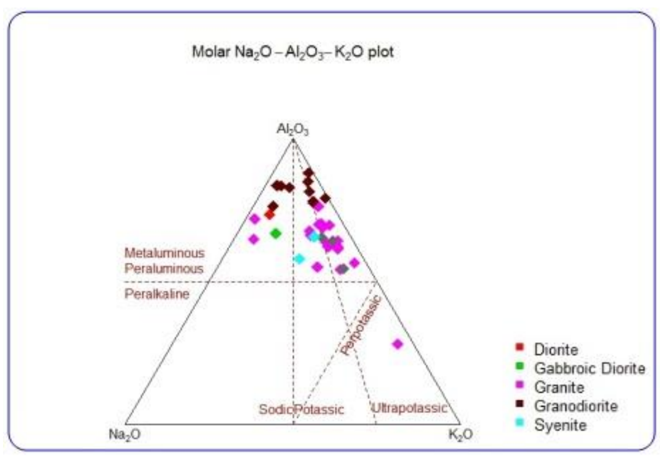


Fig. 8: Molar Na_2O-Al_2O_3-K_2O triangular diagram

Table 4a: Trace and REE Concentration of Sara-Fier Younger Granite Complex

Sample ID	Location	Petrology	V	Cr	Cu	Sr	Zr	Ba	Zn	Ce	Pb	Bi	Ga	As	Y	Ir	Au	Ni	Rb	Nb
AT2	Sara-Fier	Granodiorite	200	8.46	720	1790	2000	3000	480	63	500	12	3.04	4.6	29	<0.001	2	<0.001	22	0.001
AT5	Sara-Fier	Granite	9	0.46	310	470	75	201	120	58	350	<0.001	13	20	3.7	<0.001	1.8	<0.001	9.87	120
AT6	Sara-Fier	Granite	60	58	270	500	1200	400.2	80	55	100	5.74	75	5	19	25	0.14	<0.001	42	0.001
AT9	Sara-Fier	Granodiorite	390	60	340	1400	1600	800	530	5.01	20	2	26	14	2	0.54	0.22	<0.001	28	0.001
AT14	Sara-Fier	Granite	14.01	6.23	520	0.001	5720	<0.001	100	10	50	6	34.02	22	10	5.1	<0.001	<0.001	21.6	150
AT15	Sara-Fier	Syenite	8	3	370	160	940	<0.001	60	64	<0.001	<0.001	9.9	110	28	30	0.021	<0.001	5.5	0.001
AT19	Sara-Fier	Granite	200	80	230	820	1200	300	97	50	260	17.2	91	7.02	15	20	0.22	<0.001	29	0.001
AT20	Sara-Fier	Granodiorite	40	5	370	2030	1500	1800	560	0.001	810	<0.001	22	<0.001	3.9	<0.001	2	<0.001	30	830
AT24	Sara-Fier	Granite	<0.001	<0.001	210	0.001	520	200	20	0.001	0.08	<0.001	14	11	32	2.6	0.001	10	17.3	40
AT34	Sara-Fier	Granite	<0.001	<0.001	190	2.45	1760	300	224	30	160	<0.001	7	24	17	28	<0.001	<0.001	172	400
AT36	Sara-Fier	Granite	40	2.3	200	84.5	1380	900	40	69	90	<0.001	53	370	17	3.2	1.5	<0.001	34	170
AT40	Sara-Fier	Granodiorite	20	8.9	550	1310	200.2	2410	130	40	270	<0.001	9.5	10	15	22	1.8	<0.001	31	1700
AT41	Sara-Fier	Granite	100	21	250	0.001	8260	200	30	11	250	0.041	8	20	63	1.8	0.017	<0.001	61	690
AT43	Sara-Fier	Granodiorite	660	20.43	360	1600	1500	700	450	0.001	0.021	2.02	<0.001	<0.001	62	11	0.054	<0.001	30	0.001
AT46	Sara-Fier	Granite	20	7	360	493	2700	8400	190	0.001	33.65	<0.001	9	6	20	51	0.37	<0.001	86	0.001
AT47	Sara-Fier	Granite	<0.001	<0.001	180	110	730	2	20	54	<0.001	0.22	12	21	24	28	0.8	<0.001	0.001	540
AT48	Sara-Fier	Granite	420	10.4	280	1000	1000	600	160	80	580	<0.001	6	0.46	26	3.8	1.6	<0.001	62	790
AT50	Sara-Fier	Granodiorite	20	2.06	240	1790	2000	1000	460	20	<0.001	10	4	<0.001	19	4.6	1.9	<0.001	47	80
AT52	Sara-Fier	Granite	30	<0.001	580	0.001	2420	400	510	10	740	<0.001	8.7	18	33	30	0.1	<0.001	13.9	480
AT55	Sara-Fier	Granite	8	<0.001	210	380	110	<0.001	15	90	<0.001	<0.001	10	<0.001	28	28	<0.001	<0.001	4.4	0.001
AT56	Sara-Fier	Granite	9	<0.001	580	230	2440	<0.001	180	14	270	<0.001	14	20	28	2	0.021	<0.001	73	0.001
AT57	Sara-Fier	Granodiorite	200	14	430	670	4940	200	370	50	810	<0.001	10	<0.001	58	<0.001	0.18	<0.001	6.2	0.001
AT58	Sara-Fier	Diorite	81	20	510	2430	1600	200	500	0.001	<0.001	33	3	<0.001	36	<0.001	0.26	<0.001	42	0.001
AT63	Sara-Fier	Granodiorite	98	18	450	2520	1100	400	240	0.001	<0.001	0.004	<0.001	<0.001	35	0.76	<0.001	<0.001	24	0.001
AT64	Sara-Fier	Granodiorite	79	7	500	1690	1200	100	360	0.001	720	<0.001	10	<0.001	26	3	<0.001	<0.001	22	0.001
AT65	Sara-Fier	Gabbroic Diorite	30	18.4	2250	316	3500	2900	69	0.001	<0.001	<0.001	18	<0.001	51	<0.001	<0.001	<0.001	40	281
AT69	Sara-Fier	Granite	5	0.203	210	892	820	400	61	130	80	<0.001	7.9	6	2	24	0.13	<0.001	26	0.001
AT73	Sara-Fier	Granite	<0.001	<0.001	49	0.001	1230	<0.001	264	53	20	<0.001	48.96	260	250	7	<0.001	<0.001	36.4	290
AT74	Sara-Fier	Granite	40	5	290	910	1200	100	130	68	600	<0.001	17	9	24	<0.001	1.5	<0.001	83	870
AT76	Sara-Fier	Granite	20	50	230	150	2010	4300	190	91	<0.001	0.004	8.7	7.8	190	2.5	1.5	<0.001	55	320
AT77	Sara-Fier	Granite	30	12.1	300	680	1100	<0.001	370	52	<0.001	<0.001	<0.001	<0.001	50	<0.001	<0.001	<0.001	9.9	140
AT79	Sara-Fier	Granodiorite	64	3.06	340	1600	1780	900	400	0.001	940	300	28	<0.001	27	<0.001	<0.001	<0.001	34	830
AT80	Sara-Fier	Granite	100	18	220	470	1200	300	50	94	200	<0.001	15	4	16	1	0.18	<0.001	54	0.001
AT82	Sara-Fier	Granite	<0.001	<0.001	200	460	1000	<0.001	16	62	100	<0.001	9.8	4	26	21	1	39	81.7	700
AT84	Sara-Fier	Granite	220	61	812	0.001	660	620	92	82	100	<0.001	17	4	54	1.7	1.2	<0.001	119	480
AT31	Sara-Fier	Syenite	100	2.4	300	490	1100	200	83	100	240	22	11	10	19	20	1.7	<0.001	67	720

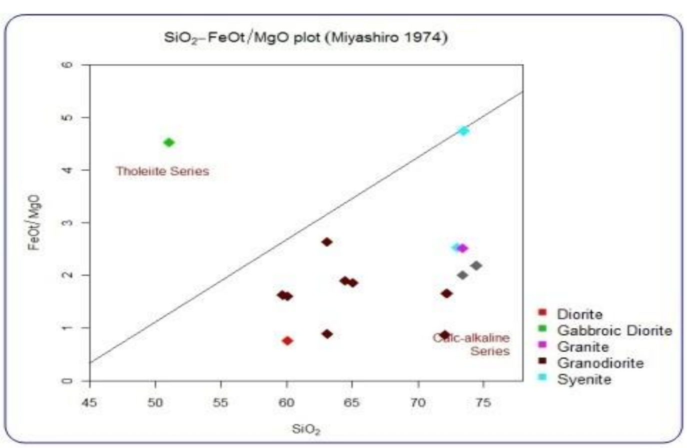


Fig. 9: FeOt/MgOvsSiO$_2$ diagram

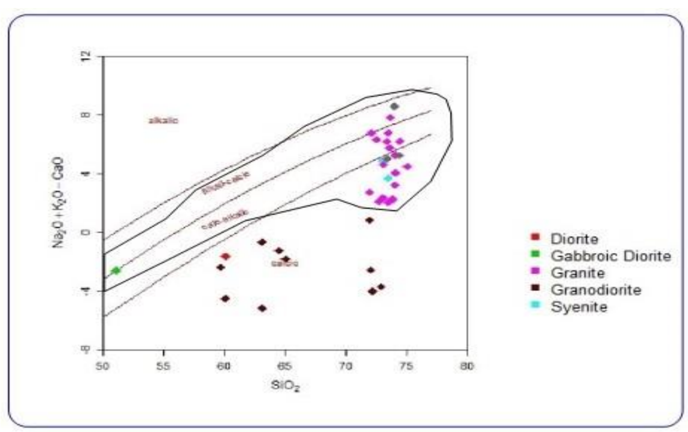


Fig. 10. Na_2O+K_2O-CaO vs SiO_2

Table 4b: Trace and REE Concentration of Sara-Fier Younger Granite Complex

Sample ID	Location	Petrology	Mo	Co	Cd	Ru	Eu	Re	Hg	Ag	Ta	W	Hf	Yb	In	Se	U	Th	Sb	Sn	Ge
AT2	Sara-Fier	Granodiorite	0.004	<0.001	0.001	<0.001	350	4.1	<0.001	0.58	<0.001	<0.001	42	5.1	9.4	0.0003	<0.001	<0.001	9.3	5.172	<0.001
AT5	Sara-Fier	Granite	0.003	0.001	0.001	4.2	160	10	<0.001	<0.001	30	2	3.11	10	2.3	7.3	2.003	6.3	<0.001	<0.001	<0.001
AT6	Sara-Fier	Granite	0.006	0.005	0.0003	3.1	120	20	1	6	<0.001	<0.001	21	20	3.3	<0.001	<0.001	0.74	<0.001	12.501	2
AT9	Sara-Fier	Granodiorite	0.001	<0.001	<0.001	<0.001	32	20	0.74	1.06	<0.001	<0.001	41	20	1.1	22	<0.001	0.001	<0.001	15.32	<0.001
AT14	Sara-Fier	Granite	<0.001	<0.001	<0.001	0.98	160	<0.001	<0.001	2.6	70.2	12	3.78	<0.001	9.72	<0.001	<0.001	<0.001	<0.001	8.821	0.001
AT15	Sara-Fier	Syenite	2.12	<0.001	3.04	<0.001	16	0.57	<0.001	<0.001	<0.001	<0.001	20.4	3.12	2.3	0.022	<0.001	<0.001	<0.001	6.5	<0.001
AT19	Sara-Fier	Granite	<0.001	0.2	<0.001	6.54	180	<0.001	0.051	4	<0.001	<0.001	33	2.78	2.1	<0.001	<0.001	<0.001	2.5	12.323	12
AT20	Sara-Fier	Granodiorite	<0.001	<0.001	0.03	<0.001	36	<0.001	6	<0.001	64	1.46	21	0.88	<0.001	0.031	<0.001	<0.001	2.2	1.245	14
AT24	Sara-Fier	Granite	<0.001	0.0004	<0.001	0.32	54	0.084	0.902	<0.001	83	4.02	14	0.002	2.9	40	0.002	0.001	<0.001	1.8	4
AT34	Sara-Fier	Granite	5	0.001	<0.001	<0.001	81	<0.001	<0.001	<0.001	102	40	62	<0.001	3.1	38	0.01	0.097	<0.001	11.8	<0.001
AT36	Sara-Fier	Granite	<0.001	0.004	0.002	3.1	140	<0.001	<0.001	<0.001	80	6.01	60	<0.001	2.2	<0.001	<0.001	<0.001	1.3	2.52	<0.001
AT40	Sara-Fier	Granodiorite	0.007	0.002	<0.001	<0.001	180	<0.001	<0.001	0.74	110	40	18	2.041	1.6	<0.001	<0.001	0.02	<0.001	3.31	<0.001
AT41	Sara-Fier	Granite	0.001	0.001	0.002	0.12	2.011	16.55	<0.001	0.045	42	12.2	2.14	0.054	3.3	<0.001	0.006	0.001	<0.001	1.11	<0.001
AT43	Sara-Fier	Granodiorite	0.006	0.009	<0.001	<0.001	34	0.541	2	0.541	<0.001	<0.001	34	0.044	0.96	0.006	<0.001	<0.001	3.7	<0.001	<0.001
AT46	Sara-Fier	Granite	0.007	0.004	0.0003	8.7	130	0.045	<0.001	1.3	<0.001	<0.001	14	<0.001	5.2	1.032	<0.001	<0.001	0.3	20.551	<0.001
AT47	Sara-Fier	Granite	0.0042	0.001	<0.001	0.007	57	<0.001	10	<0.001	38	7.84	6.62	<0.001	3.5	<0.001	0.005	0.008	<0.001	7.52	<0.001
AT48	Sara-Fier	Granite	<0.001	0.002	0.001	0.98	23	<0.001	<0.001	<0.001	101	5.62	28	0.045	2.8	50	0.45	2.28	<0.001	<0.001	0.081
AT50	Sara-Fier	Granodiorite	0.0014	0.007	0.002	<0.001	33	<0.001	20	0.48	15	2.45	0.887	<0.001	1.8	0.68	0.025	0.064	<0.001	12.401	0.007
AT52	Sara-Fier	Granite	0.002	0.0004	<0.001	<0.001	150	<0.001	<0.001	6.8	69	4.32	52	0.004	3	0.055	<0.001	<0.001	0.6	4.47	<0.001
AT55	Sara-Fier	Granite	2.001	<0.001	0.002	2.8	17	<0.001	<0.001	<0.001	<0.001	<0.001	7.82	<0.001	2.8	0.001	<0.001	<0.001	<0.001	4.544	5
AT56	Sara-Fier	Granite	<0.001	0.004	0.002	0.37	21	<0.001	<0.001	<0.001	0.544	8.3	18	<0.001	4.5	<0.001	0.207	0.26	<0.001	0.455	<0.001
AT57	Sara-Fier	Granodiorite	<0.001	<0.001	0.0005	<0.001	29	<0.001	0.004	0.006	<0.001	<0.001	30.26	0.02	1.1	2	<0.001	<0.001	<0.001	2.451	<0.001
AT58	Sara-Fier	Diorite	0.022	0.003	0.006	0.042	39	1.881	<0.001	<0.001	<0.001	<0.001	52	<0.001	1.5	<0.001	<0.001	<0.001	2.4	<0.001	0.011
AT63	Sara-Fier	Granodiorite	0.001	<0.001	<0.001	1.08	32	<0.001	2	<0.001	<0.001	<0.001	10.32	0.003	<0.001	8	0.006	0.31	3.6	12.3	0.7
AT64	Sara-Fier	Granodiorite	5	0.001	<0.001	<0.001	270	34	21	<0.001	<0.001	<0.001	16.55	0.001	2	40	0.0002	0.0001	2.4	11.801	<0.001
AT65	Sara-Fier	Gabbroic Diorite	2.001	<0.001	0.002	<0.001	30	20	<0.001	1.7	56	3.21	40	0.016	2	17.3	0.007	0.01	2	0.54	<0.001
AT69	Sara-Fier	Granite	<0.001	<0.001	0.003	0.28	12	24	<0.001	<0.001	<0.001	<0.001	14	0.002	3.2	22	<0.001	<0.001	<0.001	15.32	<0.001
AT73	Sara-Fier	Granite	0.001	<0.001	<0.001	1	22	<0.001	<0.001	0.357	6.06	0.43	14	<0.001	10.1	8	0.006	0.31	<0.001	10.85	0.021
AT74	Sara-Fier	Granite	5	0.001	<0.001	37	190	34	<0.001	<0.001	95	8.42	2.784	2.87	4.3	40	0.0002	0.001	<0.001	<0.001	<0.001
AT76	Sara-Fier	Granite	<0.001	0.004	0.002	<0.001	190	<0.001	1.024	<0.001	76	2.42	36	<0.001	3.4	0.0048	<0.001	<0.001	0.028	11.521	0.064
AT77	Sara-Fier	Granite	<0.001	<0.001	0.005	<0.001	30	10	<0.001	<0.001	27	8.24	40	1.871	1.8	37	0.0002	0.003	<0.001	3.921	0.0013
AT79	Sara-Fier	Granodiorite	0.874	<0.001	0.003	4	39	24	28	<0.001	42	3.03	12	0.548	0.9	22	<0.001	<0.001	4	<0.001	0.988
AT80	Sara-Fier	Granite	<0.001	0.001	0.008	<0.001	160	6	<0.001	<0.001	<0.001	<0.001	18.2	<0.001	3.6	6.4	<0.001	<0.001	0.8	13.51	1.202
AT82	Sara-Fier	Granite	0.0002	0.004	<0.001	35	92	<0.001	2	100	30	24	0.0004	0.0003	0.0003	<0.001	<0.001	0.0004	50.17	0.004	
AT84	Sara-Fier	Granite	5	0.201	<0.001	<0.001	72	<0.001	<0.001	83	2.46	20	0.0002	0.0002	40	0.0002	0.0001	<0.001	11.801	<0.001	
AT31	Sara-Fier	Syenite	<0.001	0.001	0.008	<0.001	170	0.002	0.66	<0.001	16	2.64	6.3	0.12	2.8	<0.001	<0.001	<0.001	0.5	12.04	<0.001

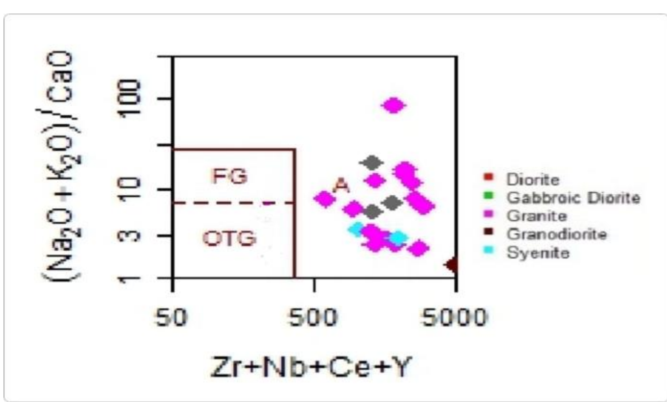


Fig. 11: $(Na_2O+K_2O)/CaO$vsZr+Nb+Ce+Y

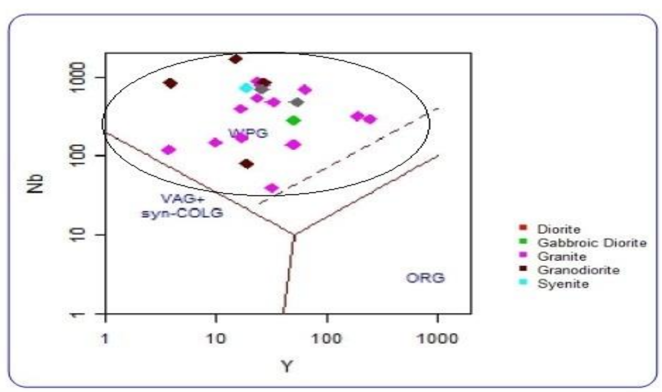


Fig. 12: Tectonic discrimination diagram Nbvs Y

The projection of the field samples on Frost et al modified alkali-lime index vs SiO_2 also plot the rocks within the A-type field (Fig. 10). Use of the popular Pearce et al trace element discrimination diagram for tectonic interpretation plot all the samples as within plate granitoids (WPG) in the Y vsNb diagram, delineated by Stern and Gottfried (Fig. 12). These diorites and gabbroic diorites are high in MgO, FeO*, CaO, Sr while the granitoids are high SiO_2, Na_2O, K_2O, Fe/Mg, Y and show both the LREE and HREE (Eby and Kochhar, 1990). The Ce-Y-Yb triangular plot suggest that the granites in the Sara-Fier Complex are predominantly A_1 type presumably indicating they were derived from plume or hotspot OIB-like source (Fig. 13 after Eby, 1992). Crustal contamination and metasomatic reaction may have been responsible for the modification of the magma during emplacement.

Spidergraphs show negative Sr, Th, Nb and Yb anomalies, indicating either the retention of plagioclase and accessory minerals in the source during partial melting or their separation during fractionation (Figs. 14). It also supported by their high Zr, Y and low Ti contents, characteristic of acid magmas generated within-plate tectonic environment. Enrichment in the high field strength (HFS) elements is a characteristic feature of alkaline A-type granites in general. The high enrichment of these elements in the investigated granites confirm their A-type identity and exclude them from other granite type on the Y vsNb diagram. All of the REE patterns have strong negative Eu anomalies and exhibit concave downward shapes of obvious positive slopes due to heavy REE enrichment relative to middle and light REE. The heavy REE are more greatly depleted suggesting absence of garnet in the source, since heavy REE are highly compatible in garnet (Wilson, 1989). This further indicate that, if mantle participation is assumed in the source material, a shallow mantle is preferred rather than deep one where spinal stability is favored rather than garnet (Ragland, 1989). The enrichment of Zr and Nb in the rocks indicate Nb-Sn-W mineralization. The northern parts of the Complex especially the Kwapa valley contains Pb>15 which confirms that the Sara-Fier Younger Granite Complex is a tin-bearing granitoid suite.

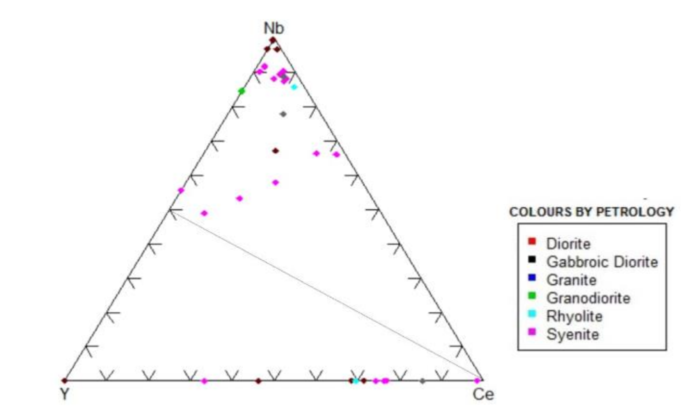


Fig. 13. Nb-Y-Ce Triangular diagram.

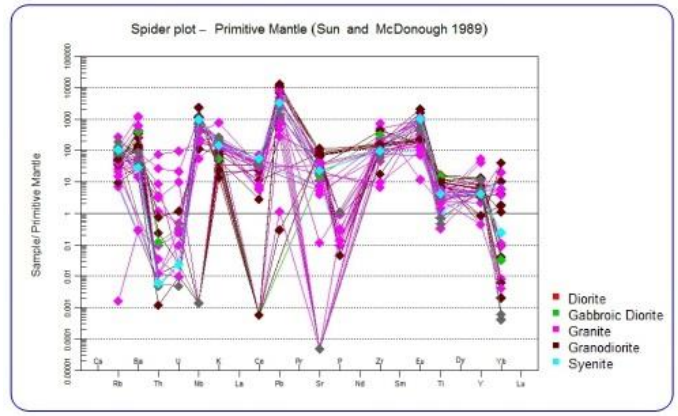


Fig.14. Spidergraph - Primitive Mantle

CONCLUSION

Following the conclusion of field and laboratory studies, the authors would like to suggest the following petrogenetic model for the Nigerian Younger Granites (Fig. 15). The model which looks more like a fussion of the White Mountain Province in East North America and that of the Chilawa Alkaline Province (CAP) in Malawi (Eby, 1992). The inward-dipping near the surface, steepening at depth is similar to that postulated for the Yega and Toon calderas in Tibesti (Vincent,1970). The gabbroic diorites and diorites are a unique feature of this model for the Nigerian Younger Granites. The unique net-veining within the suites are comparable to the mixed system of the Mount Waldo Granite in Coastal Maine (Gibson et al, 2004).

1. Peralkaline, aluminous to peraluminousgranitoids Sara-Fier Younger Granite Complexes were emplaced are A-type granitoids and are formed in within plate setting.

2. The Sara-Fier Younger Granite Complexes A-type granitoids were likely emplaced during the Jurassic. This is inferred from previous Rb/Sr and Zr/Pbistopic studies which reveal that the Nigerian anorogenic ring complexes exhibit a North-South decreasing age trend that is Jurassic (Van Breemen et al., 1975; Bowden et al., 1976; Rahaman et al., 1984).

2. The mafic rocks in the Sara-Fier Younger Granite Complexes which have been widely reported by previous scholars as gabbros are actually gabbroic diorites and in some cases diorites. These rocks may likely have resulted from the lithospheric mantle as suggested by their A1 signatures. Field and petrographic studies suggest magma mingling with felsic magma.

3. Whole-rock, trace element and rare earth elements data analysed in this work indicate that the peralkaline, aluminous and peralumious granites formed from extensively differentiated magmas derived from enriched OIB-like mantle sources that were modified through assimilation of the Pan-African upper crust into which the granites were emplaced. The scattering in some of the plots suggest contamination and metasomatism.

4. The granites from Sara-Fier Younger Granite Complexes and their parental melt were generated within a transtensional

regime prior to the Late Jurassic breakup of Gondwana, leading to reactivation of major lithospheric shear zones and opening of associated transcurrent faults. This, in turn, triggered pressure release, partial melting, and melt generation at the base of the lithosphere. Lithospheric fracturing can release pressure and channel hot metasomatic fluids upward, resulting in partial melting and magma generation at the base of the lithosphere (Black et al., 1985).

5. Periodic opening and closure of lithospheric faults can account for apparent age migration in the Nigerian anorogenic complexes (Lameyre, 1988). The Sara-Fier with distinct overlapping intrusions may have began at the north around Sara-Boi axis and ending at southern Pankshin.

6. The tin, zinc and gemstone mineralization in the Sara-Fier Younger Granite Complex resulted from complex magmatic evolutionary processes involving extensive fractional crystallization coupled with crustal assimilation and late stage hydrothermal alteration.

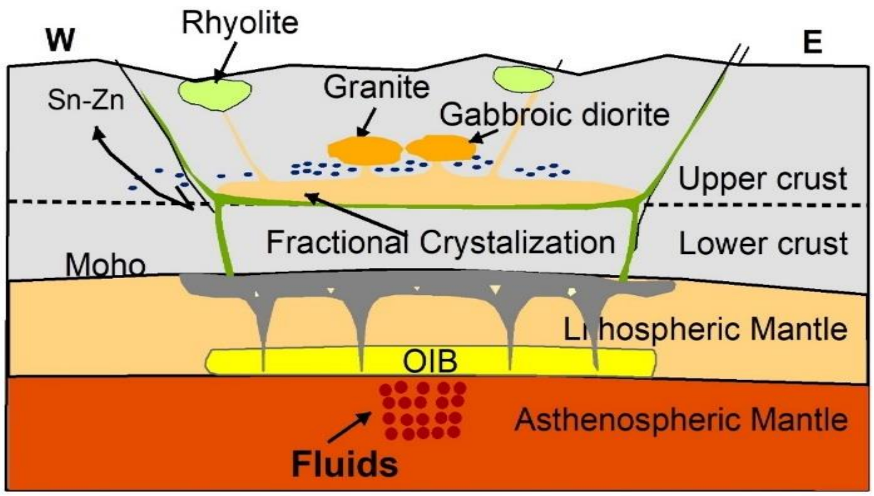


Fig. 15. Petrogenetic Model

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