International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Compositional Characteristics in Relation to the Evolution of Granite Suites in Guguruji Area, Parts of Ayetoro (Sheet 226 NW and NE) and Kagara, Tegina (Sheet 142 SE), North-Central, Nigeria

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Abstract**—***The area of study lies within the Nigerian Basement Complex, largely of sutured low-grade assemblages of Proterozoic rocks. The major rock units in Guguruji area are schists, granites, gneisses and amphibolites, where the granitic intrusives are traversed by pegmatite and quartz veins. The major rock units in Kagara area are migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolite, talcose rock, phyllite, granodiorite, porphyritic granite, fine-medium grained granite, and pegmatite. Geochemically, granites from both locations are characterized by high* SiO_2 *(65.42-72.11 wt. %), high total alkali concentrations displaying the predominance of* K_2O *over* Na_2O*. The negative correlation of* SiO_2 *with* Al_2O_3*,* Fe_2O_3*, CaO,* TiO_2*, and* P_2O_5 *and positive correlation with* K_2O *and* Na_2O *indicate fractionation nature of these granites. The granites are also enriched in Zr, Ba, K, Th and depleted in Nb suggesting the interaction with the crustal materials. The enrichment of large ion lithophile elements, depletion of high field strength elements are pointer to partial melting and crustal contamination of magma above subduction zones or volcanic arc and syn- to post-collisional granitoids. The granites are I-type, enriched in light rare earth elements relative to heavy rare earth elements and may have fractionated rare earth element patterns (La/Yb). The negative anomalies of Dy, Yb and Eu indicate magmatic related origin. However, I-type granitoids may also result from a contaminated mantle - derived magmas by a partial melting of crustal materials.*

Keywords**—** *Partial Melting, Deformation, Fractionation, Mantle–Crust, North-Central.*

I. INTRODUCTION

Guguruji and Kagara areas belong to of the Basement Complex of Nigeria and lies within latitudes $8^0\ 25^1 – 8^0\ 30^1$ N; longitude $6^0\ 10^1 – 6^0\ 17^1$ and latitudes $6^0\ 15^1 – 6^0\ 30^1$ N; longitude $6^0\ 45^1 – 7^0\ 00^1$ E respectively (Figure 1). Several workers have studied the geology, structural elements, geochemistry, petrology and among others on the Nigerian Pan-African Belt. [1] Studied the geology of the crystalline basement complex of Nigeria. He introduced the 'Older Granites' to distinguish the orogenic granites of the basement complex which are mainly Pan-African in age from anorogenic granites of the north central Nigeria which are mostly Mesozoic in age. Details about these granites based the geology of the areas have been reported in literature [2]; [3]. Late tectonic, post-collisional granite suites are a feature of many parts of the Proterozoic to Precambrian West African Orogen (WAO), where they are generally attributed to late extensional collapse of the orogen, accompanied by high heat flow and asthenospheric up rise [4]. These post collisional granitoids intrude both juvenile proterozoic crust (Schist belts) and pre-Neoproterozoic crust (high grade gneissic terrains) and strongly reworked during the Pan-African episode [5]. [6] reported that the last stage of the Pan-African orogeny is represented by conjugate fracture system of strike-slip faults. The areas under review Kagara and Guguruji (Fig. 1) are located in the low-grade, volcanic and metasediments (Schist belts) assemblages of Northern and Southwestern Nigeria Basement Complex. It is intruded by syn-tectonic and post-tectonic granites and unconformably overlain by sedimentary rocks in some parts. Despite the classification based on structural (deformation) and contact relationships with the country rocks to understand the granites, there are limited data constrains on the tectonic setting of granites suites and their geochemistry within the study areas which stern the motivation for this work. The objective of this study is therefore to carry out geological and geochemical (major, trace and rare earth elements) study of the rocks with the purpose of determining geotectonic setting, and the evolution of the granites suites.

II. GEOLOGICAL SETTINGS

The study area form part of the mobile belt [7] of the Precambrian rocks of Nigeria which occur east of the West African- Craton, northwest of the Congo Craton, and south of the Tuareg shield. The region was affected by the Pan African orogeny about 600 Ma. Geochemical evidence indicates that the Nigerian basement is polycylic and includes rocks of Archean (2.0 – 3.0 Ga) Era together with those of Eburnean (2000 ±200 Ma) and Pan - African (750 - 450 Ma) events [8]. Granitoid plutons of the older granites suite are considered as syntectonic to late tectonic granitoids emplaced during the pan Pan - African [9]. The basement complex rocks are subdivided into migmatite-gneiss complexes, the older metasediments, the younger metasediments, the older granites and Younger granite alkaline ring complexes and volcanic [10]. Older granites are widespread throughout the basement complex, the

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granitoids have been emplaced into both the migmatite-gneiss complex and the schist belts and they occur in all parts of Nigeria [10]. Recent works in different parts of the Nigeria Basement Complex have shown that older granites are high level intrusions emplaced by stopping [11]. The dominant N-S trending structures and extensive areas of igneous rejuvenation of this basement are attributed to the Pan-African Orogenic events [12]. The lithological framework, deformation and metamorphism of the study area are established in the work of [13] and [14]). [15] Consider the part of the study area to be fault-controlled rift-like structures. Kagara is located about 15 km northeast of Tegina along Tegina – Pandogari –Birnin Gwari road while Guguruji is in Egbe-Isanlu schist belt and can be accessed through Abuja- Lokoja enroute Kabba Truck A road from the north (Figure 1)

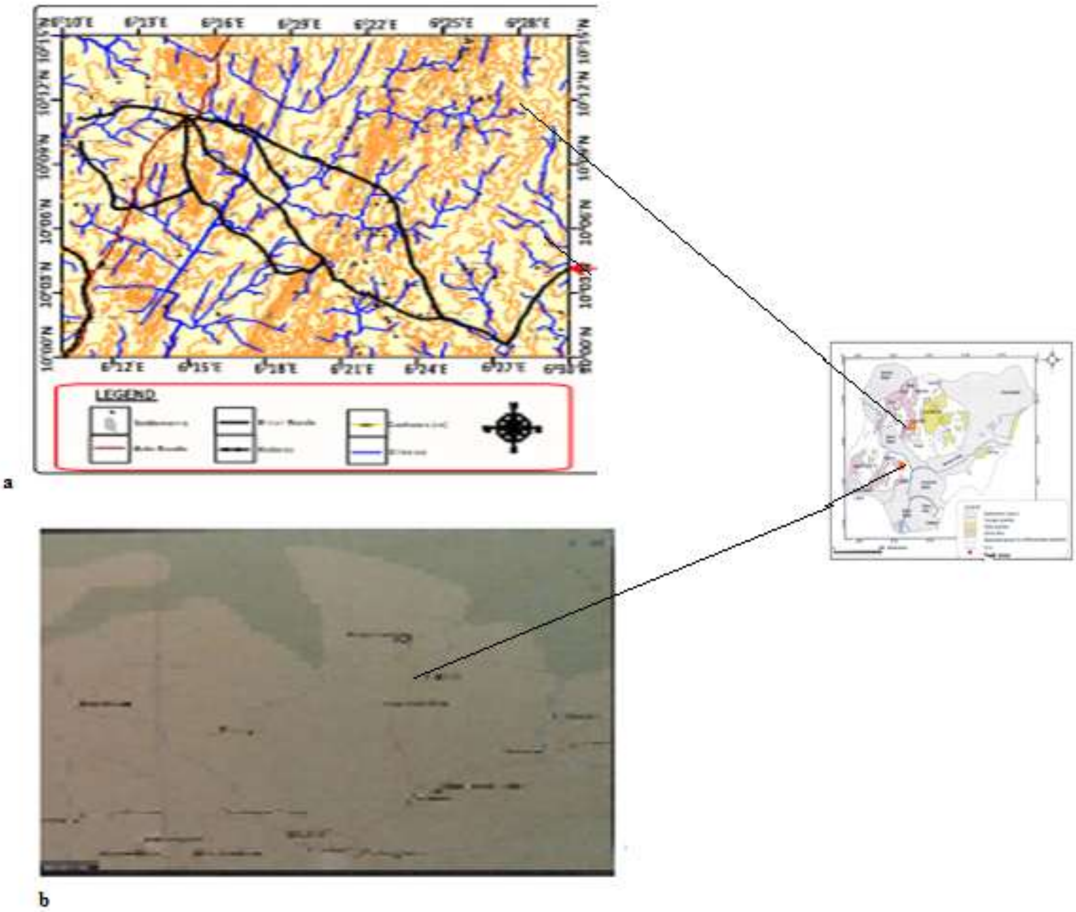
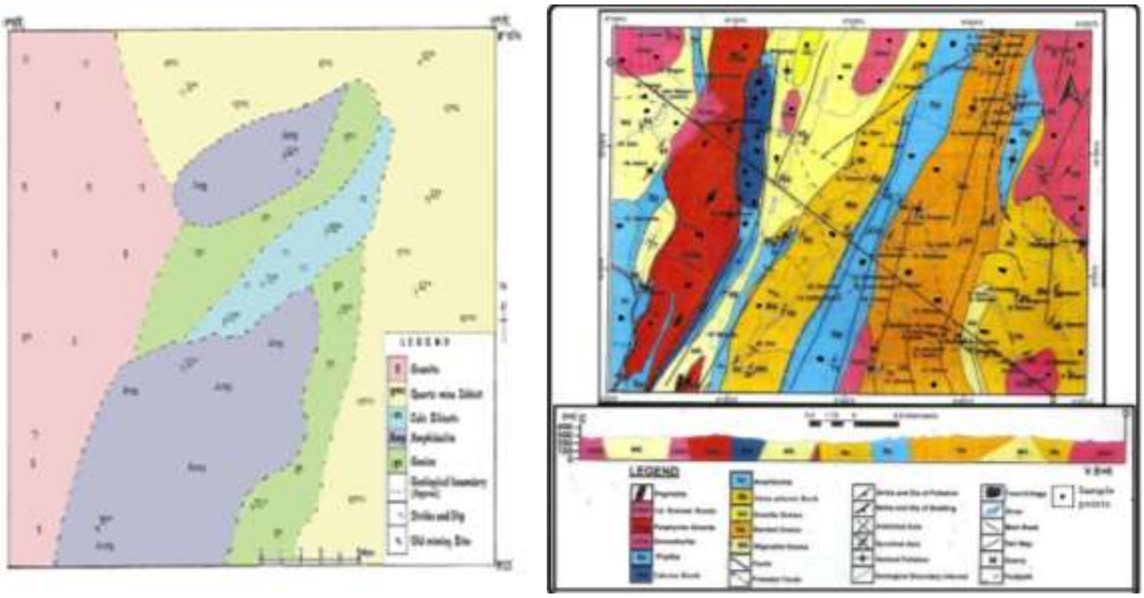


Fig. 1. Location maps of the study areas.

III. Geology of the Study Areas

The lithological units in Guguriji area are granites, schists and amphibolites. The granitic bodies around Guguriji area have pegmatitic facies especially within the amphibolites, where field observations reveal that they are mineralized and had been worked indiscriminately for both metallic and non-metallic minerals such as gold, columbite, tourmaline and beryl by mineral prospectors. There are two granite varieties: pinkish and porphyritic, and medium grained grey types. The pinkish variety is variety is restricted to the south-western portion of the study area where it shares boundary with the amphibolites. The porphyritic type exposes gritty surfaces of preferential weathering of the less resistant minerals thereby exposing markedly quartz, clusters of biotite and other dark coloured minerals(Figure 2a) [16]. In Tegina area, migmatitic gneiss, banded gneiss, granitic gneiss, meta-arkosic rock, amphibolites, talcose rock, phyllite, granodiorite, porphyritic granite, fine-medium grained granite, and pegmatite are major lithological units [17]. Migmatitic–gneisses are extensive in the area, intruded by the Older Granites at the northern part truncating its massive extension from the western part of the area to the eastern. It constitutes well over 52% of the rock types in the study area [18]. The Older Granites in this area are porphyritic and fine-medium grained. The porphyritic granites intruded the other rocks in the area especially in the southwestern axis and central part northwards, covering about 30% of the entire area while fine- medium grained granites covers 4% of the area notably in the northeast and toward the central part of the study area. The amphibolites and phyllites constitute about 8% of the rock types in the area. Outcrops of the amphibolites in are lenticular, texturally distinctive and well oriented sub - parallel to the N-S foliated trend. The talcose rocks constitute about 6% of the rocks in the study area and occur in the northwestern part close to Kagara in Tsaunin Agwaru area in a ridge surrounded by amphibolites and the Older Granites. Outcrop of the talcose rocks occurs as lensoid bodies of moderate size and length. It extends to the southwestern part having contacts with the migmatitic–gneisses and the Older Granites in an oval shaped outcrops of about 15 m above the surrounding ground surface (Figure 2a, b). The NE-SW trending shear – zones with a sinistral – strike slip displacements affect the rocks in both areas [18].



a b

Fig. 2. Geological maps of the study areas modified 'a' after [16], 'b' [18].

A. Field Occurrence and Petrography of the Granites in the Study Area

Two varieties of the granites exist in Guguriji area: the pinkish and the whitish - greyish granite types. The pinkish variety is less common and ranges from medium to coarse grained and tending being porphyritic in some places. The whitish-grey type covers about seventy percent of the area and is fine to medium grained and even-textured in places. Biotite, hornblende and other ferromagnesian minerals appear as separate flakes or spots rather than clusters.

In Kagara, four varieties of the granites were exposed in the south-western part of the area forming a rugged topography dissected by joints (Fig. 2b).

Fine- Medium grained granite: This granite is well exposed along the River Gora. It is light grey to pink coloured, fine-Medium grained and occurs as large blocks and characterized by narrow contact zone and with fabric development. pegmatitic veins cut the granitic intrusive body. It is composed of plagioclase, K-feldspar, quartz, and biotite.

a) Medium- coarse grained granite: this granite is characterized by a sub-rounded to elongated shape occupying relatively rugged topography, mountains and along both sides of the Kurumi River. Petrography of these rocks reveled that, the granite is constituted by minerals of K-feldspar, plagioclase, quartz, muscovite, and biotite. The granite is massive and undeformed. There are quartz veins cutting the whole granite at the center and shears developed within the metavolcanics and phyllites, trending in a NE-SW orientation which is consistent with the regional structures**.** The quartz veins and pegmatite veins also cut the granite discordantly.

b) Coarse grained granite: This unit is exposed in the northwest part of the study area occupying a flat to rugged topography covering approximately 6km^2. It is light grey to pink coloured, characterized by coarse grained pink and porphyritic to pegmatitic textures. *Porphyritic granite:* The granite occurs as sub circular to elliptical, blocky and it contains porphyritic phenocrysts of K-feldspars. Along the northern margin of the granite adjacent with phyllites, there is a lineament trending NE-SW that might suggests clear impact on the emplacement of Godo granite. This granite has no well exposed contact with the felsic to mafic metavolcanic and phyllite. This granite appears to deflect the syncline in the north of Godo villages as shown in (Fig. 2 b). A compositional variation from south west to north east was noted during the field observation; it represents variation in the abundance of k-feldspar and biotite.

IV. Materials and Methods

A systematic mapping of the area was carried out on the exposed outcrops using the base map extracted from the topographic sheets of Ayetoro (Sheet 226 NW and NE and Tegina 142 SE on a scale of 1:50 000. The methodology adopted in the execution of this research work consists of field study and laboratory analyses. The field study involved systematic geological mapping on topographic map of scale 1:50 000 which was undertaken during the dry seasons. The field exercise also entails sample collection with adequate representation. The laboratory work involved sample preparation and geochemical analysis. The petrographic study for the samples was undertaken at the petrological laboratories of Department of Geology, Ekiti State University, Ado Ekiti and Ahmadu Bello University, Zaria for Guguruji and Kagara samples respectively. Twenty (16) samples of granites rock were prepared for geochemical study. These consist of Sixteen (16) representative's samples of granites, at Activation Laboratories Limited (ACTLAB), Ancaster, Ontario, Canada. The analytical techniques for the whole rock geochemical analysis were performed on the powdered samples. The major elements were analysed using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). As a means of dissolving the mineral constituents, the analytical procedure involved addition of 5 ml each of perchloric acid ($HCIO_4$) and trioxonitrate (V) HNO_3 acid and 15 ml Hydrofluoric acid (HF) to 0.5 g of sample. The solution was stirred and allowed to evaporate to dryness after it was warmed at a low temperature for some hours. Four (4) ml of hydrochloric acid (HCL) was added to the cooled solution and warmed to dissolve the salts. The solution was cooled; then diluted to 50 ml with distilled water. The solution was then introduced into the ICP torch as aqueous – aerosol. The emitted light by the ions in the ICP was converted to an electrical signal by a photo multiplier in the spectrometer. The intensity of the electrical signal produced by emitted light from the ions were compared to a standard (a previously measured intensity of a known concentration of the elements) and the concentration were then computed. Analytical precisions vary from 0.1 % to 0.04 % for the major elements. Trace elements were analyzed by inductively- coupled Plasma Mass Spectrometry (ICP - MS) from pulps after 0.2 g of rock powder was fused with 1.5 g $LiBO_2$ and then dissolved in 0.1 ml of trioxonitrate (V) (HNO_3) acid. Analytical precisions vary from 0.1 to 0.5 ppm for trace elements. The rare–earth elements (REE) contents were determined by Inductively - Coupled Plasma Mass Spectrometry (ICP - MS) from pulps after 0.25 g rock- powder was dissolved with 5 ml of perchloric acid ($HCIO_4$) and trioxonitrate (V) (HNO_3) acid, and 15 ml of hydrofluoric acid (HF). Analytical precisions vary from 0.01 to 0.5 ppm for rare earth elements.

V. GEOCHEMISTRY

Major Elements Composition

Major elements composition provides information on the elemental concentration for use in establishing the geological, geochemical and the geotectonic processes that have taken place in the study area. Oxide of the major elements concentration provides the basis for a comprehensive rocks classification. Major elements compositions of the samples of granites from the study area are presented in Table (1).

TABLE 1. Major elements composition of major rock types in the study area (wt %).

Oxides	**G1**	**G2**	**G 3**	**G 4**	**G 5**	**G6**	**G 7**	**G 8**	**G 9**	**G 10**	**G 11**	**G 12**	**T1**	**T2**	**T3**	**T4**
SiO_2	69.89	68.27	69.02	68.92	69.23	68.46	69.23	70.19	67.03	69.01	69.19	68.58	69.2	72.11	66.39	65.42
Al_2O_3	14.7	15.91	15.29	14.78	14.89	14.5	14.82	14.1	15.21	14.38	15.25	14.44	11.13	14.82	15.62	15.9
$Fe_2O_{3(T)}$	3.54	3.28	3.57	3.6	3.4	3.9	3.27	3.58	3.66	3.87	3.88	3.43	0.98	2.38	6.84	7.24
MnO	0.075	0.074	0.072	0.064	0.068	0.071	0.141	0.065	0.069	0.074	0.049	0.058	0.04	0.148	0.09	0.136
MgO	0.9	0.84	0.85	0.89	0.99	1.03	0.98	0.63	1.02	0.92	0.76	1.06	0.8	0.78	2.03	2.05
CaO	1.75	1.96	1.97	2.05	1.86	1.93	1.54	1.75	2.85	2.2	1.48	2.51	1.72	2.01	0.53	1.69
Na_2O	3.99	4.18	4.17	4.14	3.86	3.85	4	3.77	4.25	3.88	3.62	3.92	7.02	4.26	2.65	2.69
K_2O	4.58	4.26	4.42	4.35	4.43	4.71	4.32	4.47	3.52	4.57	4.48	4.5	0.02	3.46	3.45	3.43
TiO_2	0.367	0.425	0.415	0.391	0.332	0.377	0.391	0.364	0.546	0.342	0.33	0.574	0.039	0.313	0.791	0.84
P_2O5	0.19	0.27	0.26	0.22	0.15	0.28	0.15	0.19	0.32	0.18	0.24	0.22	0.13	0.08	0.21	0.21
LOI	0.35	0.47	0.33	0.43	0.63	0.63	0.83	0.56	0.43	0.84	0.89	0.92	3.57	0.4	1.46	1.38
Total	**100.3**	**99.94**	**100.3**	**99.83**	**99.80**	**99.7**	**99.70**	**99.7**	**99.90**	**100.30**	**100.2**	**100.2**	**99.60**	**100.9**	**101**	**101**
CaO/Na_2O	0.439	0.469	0.472	0.495	0.482	0.51	0.385	0.464	0.671	0.567	0.48	0.64	0.245	0.472	0.577	0.63
Na_2O/K_2O	0.871	0.981	0.943	0.952	0.871	0.82	0.926	0.843	1.207	0.849	0.808	0.871	351	1.231	0.768	0.784
$K_2O/$ Na_2O	1.148	1.019	1.06	1.05	1.148	1.22	1.08	1.186	0.828	1.178	1.238	1.148	0.003	0.812	1.302	1.275
Fe_2O_3/MgO	3.933	3.905	4.2	4.045	3.434	3.79	3.337	5.683	3.588	4.206	5.105	3.235	1.225	3.051	3.369	3.532
A/NK	1.715	1.767	1.78	1.741	1.825	1.69	1.781	1.711	1.958	1.702	1.883	1.715	1.581	1.92	2.561	2.598
A/CNK	1.424	1.53	1.448	1.402	1.467	1.38	1.503	1.411	1.432	1.35	1.592	1.321	1.271	1.523	2.356	2.036

The major elements Geochemistry.

Silica (SiO_2) concentration ranges from 65.42 - 72.11 wt %, Al_2O_3 ranges from 11.13 - 15.62 wt %, Fe_2O_3T ranges from 0.98 – 7.24 wt %, MgO ranges from 0.63 – 2.05 wt%, L.O.I ranges from 0.40 – 3.56 wt %, from the rocks noteworthy is that the concentration of CaO, Na_2O, K_2O, MnO, TiO and P_2O_5 from the study area also varies from 1.53-2.85 wt %, 0.65 – 7.02 wt %, 0.04 – 1.48 wt %, 0.033 - 0.155 wt %,0.039 – 0.84 wt %, 0.08 – 0.21 wt % respectively. Silica (SiO_2) content is slightly higher in sample from Kagara area as against those from Guguruji area. Alumina (Al_2O_3) concentration in the granites from Guguruji does not show a strong variation as they are relatively close in Wt % indicating a close relationship between the rocks whereas Kagara show a strong variation of Al_2O_3 that range from 11.13 - 15.62 wt %. The chemical composition of granites from Kagara area shows that MgO concentration and L.O.I are rich but poor in granites of Guguruji area (Table 1). The stability of iron – bearing minerals is dependent on the oxygen fugacity $f(O_2)$ in a system. Total iron increase with decrease in silica, reflects the late crystallization of iron oxides in the study area. The compositions of the granites are similar but they show also significant contracts as indicated by the variation of silica of the major oxides. In the Harker diagrams there is a negative correlation between the silica and

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Al_2O_3, MgO and CaO and positive correlation between silica and K_2O. The FeOt, contents do not vary significantly and are lower in the oxidixed ferran granites (Figure 3).

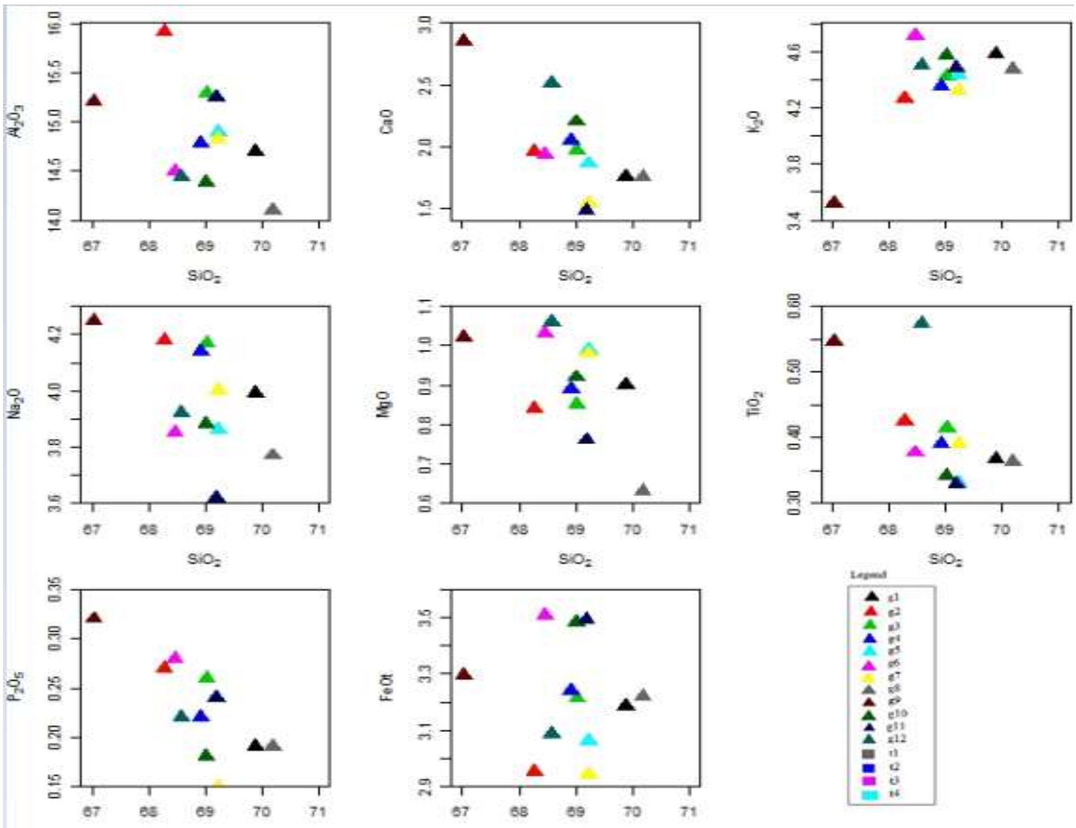

Fig. 3. Harkers varaition diagrams (SiO_2 versus Al_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, FeOt) granites within the study area.

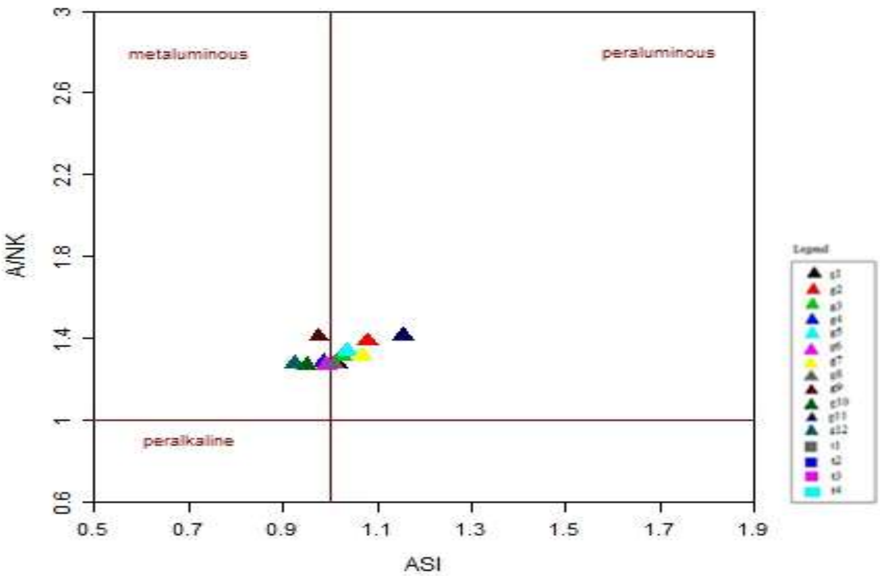

Fig. 4. Chemical classification of the granitic rocks using the Molecular ration of alumina to alkalis after [19]. Al_2O_3/ (Na_2O + K_2O) A/NK versus alumina to lime and alkalis (Al_2O_3 / (CaO + Na_2O + K_2O) A/C/NK plot.

The Alumina saturation in the granites is based on comparing the mole proportion (mole proportion = weight percentage of oxide / molecular weight of the oxide) of the alkalis to alumina in the rock. In order to determine the petrogenetic trait, the samples were plotted on classification diagram of A/CNK versus A/NK (where A/CNK = molar Al_2O_3 / (CaO + Na_2O + K2O) and A/NK= molar Al_2O_3 / (Na_2O + K_2O) (after Shand 1943). The rocks plot mostly within the peraluminous field (Figure 4). An overall peraluminous character is inferred from A/NK and A/CNK.

K_2O versus SiO_2 Plot

K_2O versus SiO_2 plot after [20] was used to determine the calc-alkaine and tholetiitic charateristics of the granitic rocks. The potassic composition of the granites decreases with increasing in SiO_2 contents and reveal that the granites are of medium to high – K affinity. Specifically, the granites belong to high – K calc – alkaline series with exception of sample G1 that fall along the margin (Figure 5).

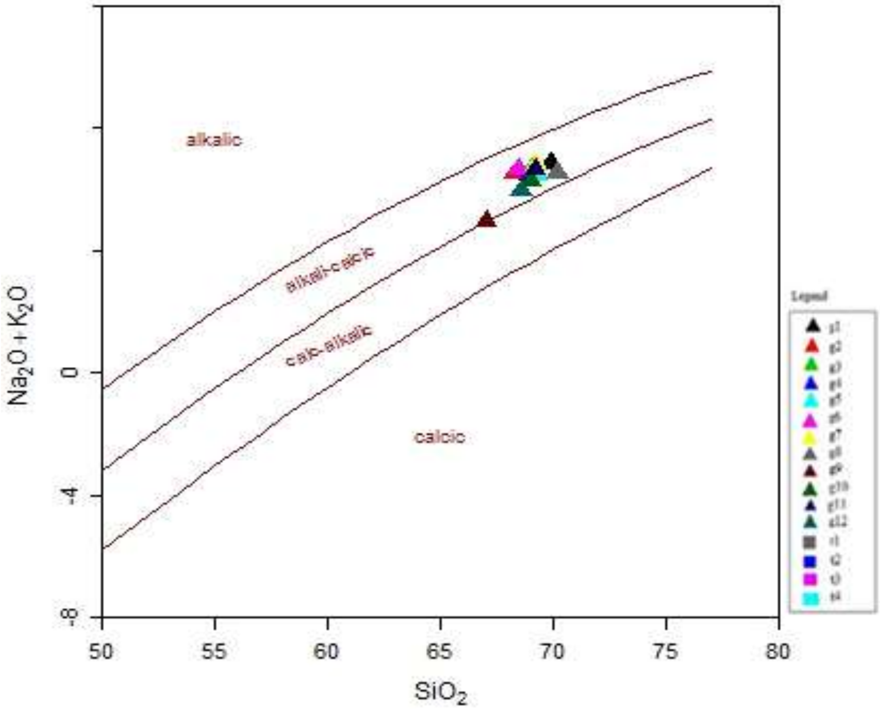

Fig. 5. The SiO_2 versus K_2O diagram (after [20]) showing the Sub-alkaline nature of the rocks on the basis of potassium enrichment.

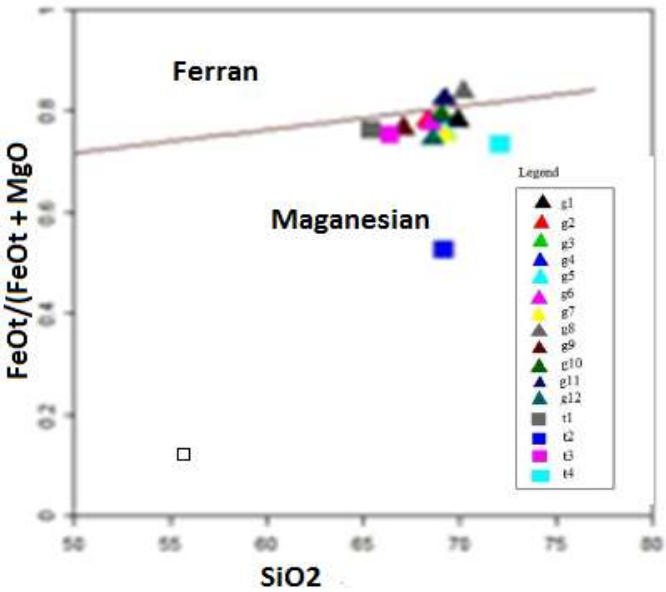

Fig. 6. FeO_{tot} / FeO_{tot} + MgO versus SiO_2 discrimination diagram (after [21]), for the granitic rocks .

Iron Index Discrimination

The Fe- number (FeO_{tot} / FeO_{tot} + MgO = Fe*) called iron index discrimination diagram after [21] was used to classify the granitic rocks based on their ferroan and magnesian content. Bivariate plot for this diagram is shown on Figure (6).

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International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

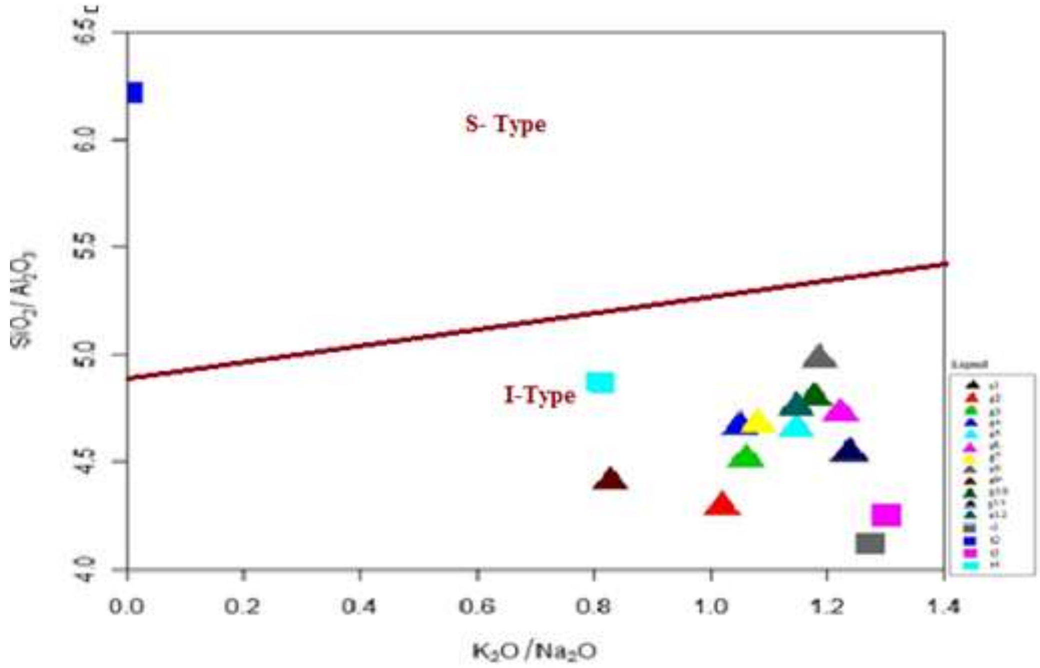

Fig. 7. SiO_2/Al_2O_3 versus K_2O/ Na_2O discrination diagram (after [22].

TABLE 2. Trace elements composition of the granites (ppm).

	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	T1	T2	T3	T4
Sc	4	5	5	4	4	5	4	4	7	5	12	6	1	4	18	13
Be	3	3	3	3	2	2	5	2	3	3	3	3	<1	3	2	3
V	31	32	33	30	27	34	20	27	40	29	91	46	<5	26	82	97
Ba	965	1024	1047	1012	906	974	722	907	1098	961	1162	1108	7494	1172	577	837
Sr	296	391	402	384	296	292	217	288	472	308	256	457	383	461	671	196
Y	15	17	15	16	14	12	17	15	18	12	36	16	9	8	17	24
Zr	222	268	219	266	171	162	142	276	324	161	496	327	7	133	623	219
Cr	110	90	110	100	110	120	110	100	110	130	110	60	30	180	140	9
Co	7	7	7	6	6	8	6	6	8	8	8	9	32	56	46	31
Ni	30	30	30	30	30	40	30	30	30	30	30	30	30	<20	20	40
Cu	50	50	50	50	70	50	40	60	50	50	30	40	130	10	40	40
Zn	40	50	50	50	40	50	120	40	50	50	130	70	200	60	130	80
Ga	20	21	22	21	19	21	24	19	22	21	28	21	45	31	29	24
Ge	2	2	2	2	2	2	2	2	2	2	1	2	2	1	2	2
Rb	133	134	135	129	123	139	224	109	103	144	79	116	355	<5	<5	<5
Nb	14	16	15	15	12	11	21	14	16	11	33	15	<2	107	69	120
Mo	8	7	7	7	8	9	24	7	6	10	0	0	1	6	22	14
Sn	5	6	5	5	7	5	16	5	6	5	8	3	7	<2	4	<2
Cs	2.8	3.3	3	2.8	2.5	2.7	5.5	2.1	4.2	3.5	3.8	4.1	<0.5	<0.5	1.6	0.5

Trace Elements Composition

Trace elements composition is useful in finger printing of the origin of igneous rocks and igneous processes because they exhibit a range in concentration far greater than major elements [23]. The trace elements composition of the rock samples obtained from the study area is presented in Table (2). The distribution of the elements in the rock shows enrichment in Barium having concentrations ranges from 722 to 7494 ppm. Ba values are anomalous and perhaps may be due to plagioclase and hornblende presence in the mineralogy of the rock. Ba is capable of replacing potassium in early formed K-feldspar. According to [24], the high Ba value may either reflect plagioclase fractionation, crustal contamination or related to metasomatised source [25]. Strontium values ranges from 217 to 457ppm, may have substituted for Ca in plagioclase feldspar and such high concentrations is typical of intermediate magma or melts derived from a crust rich in the element. Rubidium concentration ranges from <5 to 224ppm this is considered low, 112ppm being normal for granites. Barium and Sr are lithophile elements and alkaline earth metals of end members. Y and Nb contents do not show significant difference.

Tectonic Affinity

The chemical composition of granitoids, their source rocks and tectonic setting can be obtained using their compositions [26]. However, [27], reported that granitic magmatism is believed to associate with several tectonic settings and various evolutionary stages while [28] introduced a geochemical method to characterize the tectonic environment of granitoids. The bivariate plots of Rb versus Y+Nb, and Rb versus Ta+Yb of (after [28]) were used to distinguish the granites based on their intrusive setting into four groups namely: Oceanic Ridge Granite (ORG), Volcanic Arc Granite (VAG), Within Plate Granite (WPG) and Collision Granite (COLG) Figure (8). The granitic rocks plotted within Volcanic Arc Granite domain

There is a significant variation in trace elements concentration among the rock units. The variation in Ba, Sr, and Rb content is very useful in determining whether magmatic evolution was controlled dominantly by fractional crystallization, partial melting or more complex processes [29]. The Ba (577 - 7972ppm), Co (6-56), Nb (11-120), Zr (7- 623ppm), Zn (40-200), Sr (196-671 ppm) and Rb (5-224ppm) concentrations are generally high in granites from Kagara when compared with Guguriji granites.

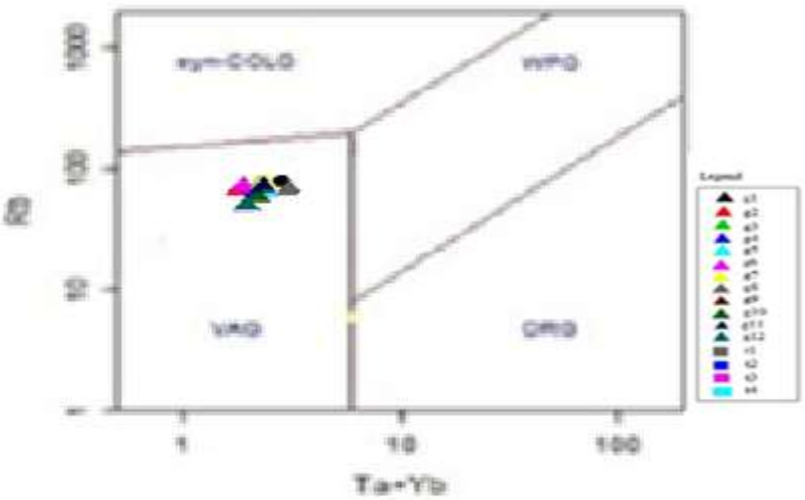

Fig. 8. Rb versus Y+Nb and Rb versus Ta+Yb discrimination diagrams for granites (after [28]).

TABLE 3. Rare earth elements concentration of granites (ppm).

Elements	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	T1	T2	T3	T4
La	69.1	110	83.3	79.5	56.2	51.7	35.1	91.3	91.4	52.7	72.1	42.5	7.1	34.4	22.7	35.2
Ce	124	181	166	145	105	96.3	71.1	160	167	96.6	156	83.2	44.3	57.5	47.6	73
Pr	12.7	19.4	15.2	14.7	10.6	9.75	7.65	16.2	16.6	9.95	16.6	8.77	1.42	6.4	5.91	8.32
Nd	40.2	60.5	47.1	45.7	33.7	31.5	26.3	51	52	31.6	57.6	30.2	6.2	21.7	25.2	31.8
Sm	5.8	7.9	6.4	6.3	5	4.7	4.9	6.9	7.5	4.5	10.4	5.1	1.6	3.1	6.2	6.5
Eu	1.07	1.38	1.21	1.19	0.93	0.92	0.18	1.28	1.52	0.89	2.02	1.15	0.42	0.88	3.17	1.51
Gd	3.8	4.8	4.1	4	3.3	3.1	3.7	4.2	4.7	2.9	8	3.8	1.7	2	5.9	5.4
Tb	0.5	0.6	0.5	0.6	0.5	0.4	0.6	0.5	0.7	0.4	1.2	0.6	0.3	0.3	0.9	0.8
Dy	2.6	3.1	2.8	2.9	2.6	2.3	3	2.7	3.3	1.3	6.8	3.1	2.1	1.2	4	4.6
Tm	0.22	0.28	0.24	0.31	0.27	0.24	0.25	0.22	0.28	0.25	0.56	0.25	0.4	0.2	0.9	0.9
Yb	1.07	2	1.7	1.7	1.5	1.4	1.7	1.7	2	4.6	3.8	1.7	1.3	0.8	1.5	2.5
Lu	0.29	0.33	0.31	0.31	0.27	0.24	0.28	0.32	0.33	1	0.64	0.3	0.18	0.11	0.21	0.38
Hf	6.2	7.3	5.9	7.3	4.6	4.6	4.4	7.9	8.5	0	12.7	8.4	1.1	0.7	1.2	2.2
Ta	1.2	1.3	1.3	1.3	1.1	1	1.7	1.2	1.3	1	2.9	1.2	0.15	0.1	0.18	0.36
Tl	0.8	0.9	0.9	0.8	0.8	0.9	1.4	0.7	0.7	0.8	0.5	0.7	0.3	3.2	14.1	5.3
Pb	36	39	42	36	38	40	59	37	34	37	151	37	0.5	1.2	1.7	1.4
Th	27.4	30.3	29.3	24.8	24.2	21.9	25.2	33.3	28	21	24.7	16.6	5	361	223	96
U	7.3	6.2	4.8	5.9	4.4	4.1	6.6	7	6.1	3.7	10	4.3	<0.2	0.5	0.3	0.5

Rare Earth Elements Composition.

The rare earth elements (REE) data from the Guguruji and Kagara is presented in Table 3.

When the rare earth elements data of the granites were normalized to chondrite values of [30] , the pattern of the granites display a steep slope from LREE to the HREE and a negative Eu anomaly (Figure 9). Fifteen out of the samples of the granites do not show remakeable differences. All of them show negative anomalies in Dy and Yb,except in Ce for sample T1. Py and Sm show either positive or negatives anomalies. Specifically, the Negative europium anomaly (Eu/Eu)* relative to chondrite in granites.

Amos Olusola Olaolorun and Ojo Adeoye Akintola, "Compositional Characteristics in Relation to the Evolution of Granite Suites in Guguruji Area, Parts of Ayetoro (Sheet 226 NW and NE) and Kagara, Tegina (Sheet 142 SE), North-Central, Nigeria," *International Research Journal of Advanced Engineering and Science*, Volume 3, Issue 3, pp. 80-90, 2018.

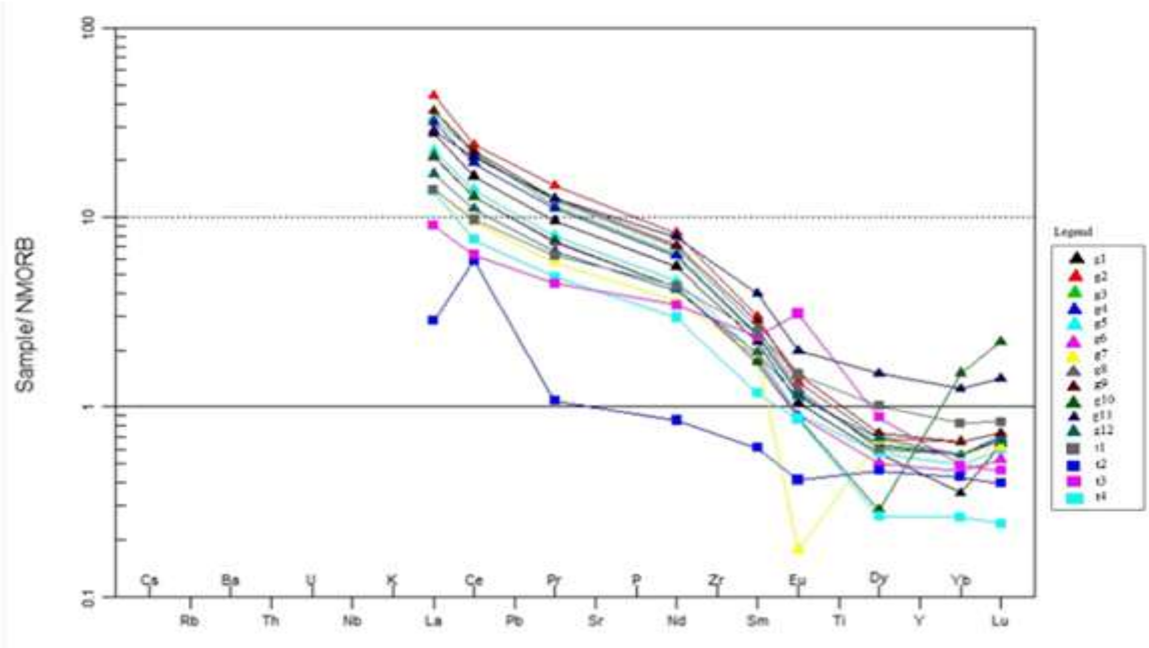

Fig. 9. Rare earth elements distribution pattern of the rock from the study area normalized to the average crust. Normalizing value are those of [30].

VI. Discussion: Possible Source Rock

Field relationships show that gneiss and schist in kagara study area have been deformed due to the presence of antiformal and synformal folds and shear fractures. [9], reported that most of the granites and gneisses in the Nigeria Basement Complex are intrusive while [31], [32] used partial melting of crustal rocks to evoke the genesis of the granite-gneiss of North-Central Nigeria. Pegmatite and quartz veins also intruded the granites. Granites species that dominated the study area include alkali-feldspar granite and granite. The granite varies between medium to coarse grained while the gneisses are fine grained and exhibit lineation and foliations structures suggesting polyphase deformational history. The folds in the study area occurs as minor structures on the gneiss and may have been formed in response to lateral compression of the rocks possibly due to heat accompanied by magmatic activities which emplaced the granitic pluton [33], attributed differentiation of the magma at higher structural levels in addition to partial melting of crustal rocks to generate the magma. The extent of deformation of host rocks to granites from Guguriji and Kagara were expressed on occurrence and the magnitude of metamorphism and metamorphic structures of the area like foliations, joints and minor faults. The faults and other structures are believed to be due to Late Pan–Africa brittle deformation that occurred on a continental scale [34].

Mineralogical comparisons of Guguruji granite with Kagara granite show similarity in mineralogical composition (Tables 1, 2 and 3). This indicates similarity in their mode of formation. The possible source rocks of igneous rocks can be interpreted using trace and rare earth elements patterns in conjunctions with some major elements discrimination [35]. The high- K Calc-alkaline affinity and negative distribution trends of Eu, Dy, Yb and Sr as well as the enrichment of Nd and Sm in the granites suites suggests crustal source [36]. In addition, high Th/ U (greater than 2.5), in the granites suites suggests continental crust [37]. However, the metaluminous nature of the granites suites, particularly the less evolved members precludes an origin from melting of a strong peraluminous sedimentary protolith. This character requires a metaluminous protolith such as the mantle or other igneous sources [38]. Nonetheless, the slightly peraluminous nature of the granites suites particularly the more fractionated members cannot be explained by an evolution via fractional crystallization dominated by fractionation of plagioclase. This is because fractionation of plagioclase is expected to decrease the concentration of Al_2O_3 in the melt which will in turn decrease the aluminum saturation index. According to [36] the peraluminious chemistry of I-Type granite can either suggest fractionation of hornblendes, or that the source material for the granites is probably peraluminious .The negative Dy and Yb anomaly observed in the trace element spider diagram suggest the presence of hornblende in the soures material [39]. Zn is the most abundant among the chalcophile elements in the granites from the study areas with concentration ranging from 40 to 200ppm. Cu and Ga follows, ranges from 30 to 130ppm and 19 to 45ppm respectively. The concentration of Y ranges from 12 to 36ppm lower than the quoted average value of 40ppm for normal granites [40], [41]. Nb ranges from < 2 to 120ppm is also considered low. The granites contain appreciable concentrations of large ion lithophile elements (LILE) such as Ba, Sr, Rb and low high field strength elements (HFSE) except Zr (39.4ppm) as an average. The close associations of ultramafic and related rocks with the fault structures suggest that they are crustal sutures of Pan-African collision as earlier proposed by [42], and [43]. The granites from Guguruji and Kagara areas were enriched in zirconium with values ranging from 142 to 496 ppm. In line with [44] have shown that Zr concentration increases with fractionation, and its content in a rock is a function of alkalinity of the rock and that the element tends to dissolve more in alkaline magma. The I-type granitic magma will inherit stable and radiogenic isotopes signatures that could be misinterpreted to reflect mixing with mantle-derived magmas, especially if the evidences based on isotope compositions were considered in isolation. An isotopic study carried out on most of the Nigerian Older Granites suggests mixing of mantles and crustal components in their magmatic sources [45].

However, unless further work proves otherwise, partial melting of the crustal rocks is hereby proposed for the origin of the granite suites in the study areas. Such melting is envisaged to have taken places after the metamorphic episode associated with orogenic activity which linked to closure of the West African sea located within an ancient convergent plate boundary [46].

VII. CONCLUSION

Petrogenetic indices reveal that the evolution of the granites from Guguruji and Kagara (though from different areas) were cogenetic. They exhibit similarity in geochemical behaviors as both samples plots within calc-alkaline field in SiO_2 versus K_2O diagram. Similarly in iron index discriminant FeO_{tot} / FeO_{tot} + MgO versus SiO_2, they fall within the magnesian field. They both plot in the I-Type field in SiO_2/Al_2O_3 versus K_2O/Na_2O (after [22]) while the granites tectonically fall within the volcanic arc granites (VAG) domain in Rb versus Y+Nb and Rb versus Ta+Yb. Trace elements concentrations of the granite rocks indicated enrichments in Ba, Sr, Rb and Zn.

Therefore, field relationship and geochemical evidences between granites from Guguruji and Kagara show that, the granites from Guguriji and Kagara areas are magmatic in origin as evidence from petrochemical trends of the major and trace element data of the granite rocks.

ACKNOWLEDGEMENTS

The authors express their appreciation to co-operation of many people involved in making available the specimens used in this investigation. Authors are also appreciative of the support of the members of the communities around the study areas.

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