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Geochemistry and Petrology of Guguruji Amphibolites from Egbe-Isanlu Schist Belt, Southwestern Nigeria

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Abstract Geochemistry and petrology of Guguruji amphibolites from Egbe-Isanlu Schist belt, Southwestern Nigeria has been carried out to determine its nature and geochemical characteristics. The petrographic study of some of the samples reveals that mineral composition is uniform in some exposures and varied more in others. The thin sections reveal essentially biotite, hornblende, plagioclase, quartz, actinolite, tremolite, and opaque minerals. The minerals have random orientation of long axes of abundant hornblende and subordinate plagioclase crystals. The amphibolites are characterized by average contents of SiO_2 (≤54%), Al_2O_3 (<15%), MgO (<10%), CaO (13.7%) and generally low total alkali (<2%), P_2O_5 (0.3%), MnO (<0.3%) and TiO_2 (<2%) values. Other chemical parameters such as CaO / Al_2O_3 (<0.9) and Rb/Sr (<0.13) confirms its ortho-genetic origin. Binary plot of Na_2O + K_2O versus SiO_2 and ternary diagram of Fe_2O_3– Na_2O –MgO suggests that the amphibolites are of a precursor magma of subalkaline/basaltic and tholeiitic petrogenetic affinity. The trace element characterization of the amphibolites implicates within-plate tectonic setting.

Keywords Guguruji, Amphibolites, Tholeiitic, Petrogenetic affinity

1. Introduction

The Nigerian Basement Complex is dominated by Precambrian gneisses and migmatites with intercalations of quartzites and schists which bears strong imprints of the Pan-African thermotectonic deformations. Nigeria lies in the Pan- African mobile belt of West Africa where rocks are reported to have undergone polycyclic metamorphism and deformation. In Southwestern Nigeria (from where this research emanates), the main lithologies include the migmatite, gneisses, amphibolites, granites and pegmatites. Other important rock units are the schists, made up of biotite schist, quartzite schist, talc-tremolite schist, and the muscovite schist [1]. The crystalline rocks intruded these schistose rocks. The schists as described by [2] has low-medium grade metasedimentary rocks occurring in a nearly North-South trending form and are in-folded into the gneissic-migmatite complex on the western half of Nigeria (Fig.1). The schist belts are dominated by pelitic to semi-pelitic and quartzitic schists interlayered with subordinate mafic-ultramafic rocks, marble and calc-silicate gneissic rocks [3]. The age of these rocks have been reported as Archean to early Proterozoic [3, 4]. Egbe-Isanlu schist belt is one of the schist belts in Southwestern Nigeria and lies northeast of the well-studied Ife-Ilesha and north of Igarra schist belts.

Egbe-Isanlu schist belt is about and has been reported to be dominated by semi-pelitic schists [5] that are interbanded with other lithologies such as quartzites, banded iron-formation, serpentinite, talc schist and amphibolite [6, 7]. Other workers who studied in these areas interest include [3, 8-15]. Each researcher described the environment of interest. Guguruji, the area of study is part of Sheet 226 (Aiyegunle). Guguruji is 70km and 40km west of Egbe and Isanlu respectively, 35km southwest of Okolom. Guguruji and its environ lies in a remote part of the belt and not much research work has been reported in literature. Guguruji is underlain by migmatized biotite gneiss, carbonate rocks, mafic-ultramafic, metavolcanics, the schistose rocks and the plutonic rocks. Amphibolites have been reported from several parts of the Nigeria basement complex namely.

Ilesha and Iseyin areas [16], [17], Sepeteri and Burum [18] Ibadan and Alawa [19], Tegina [20] and Egbe-Isanlu [5], and Zungeru [21]. This paper will consider the nature and geochemical characteristics of Guguruji amphibolites and its implication on their origin.

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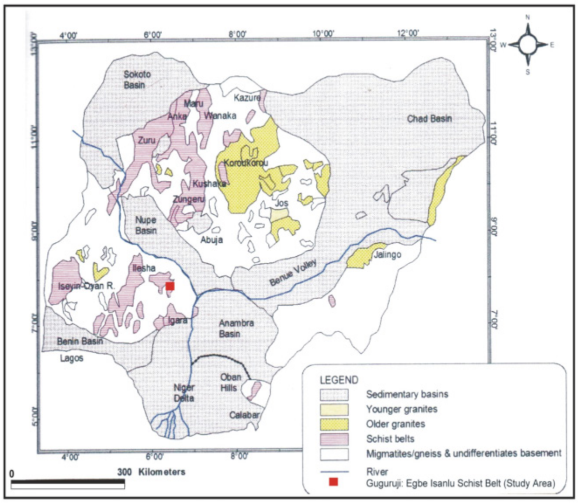


Figure 1. General Geological Map of Nigeria showing the study area

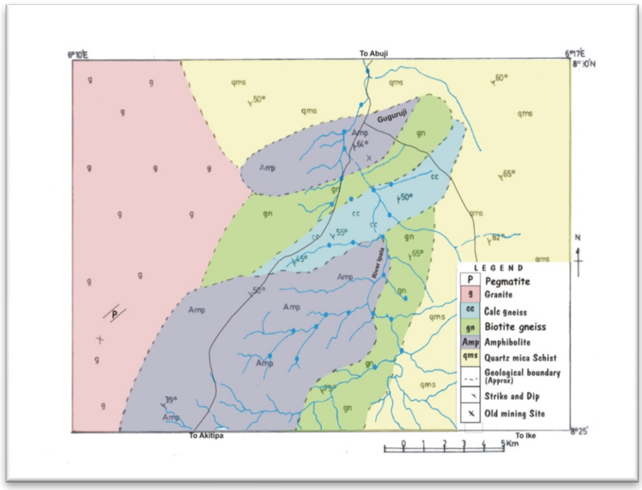
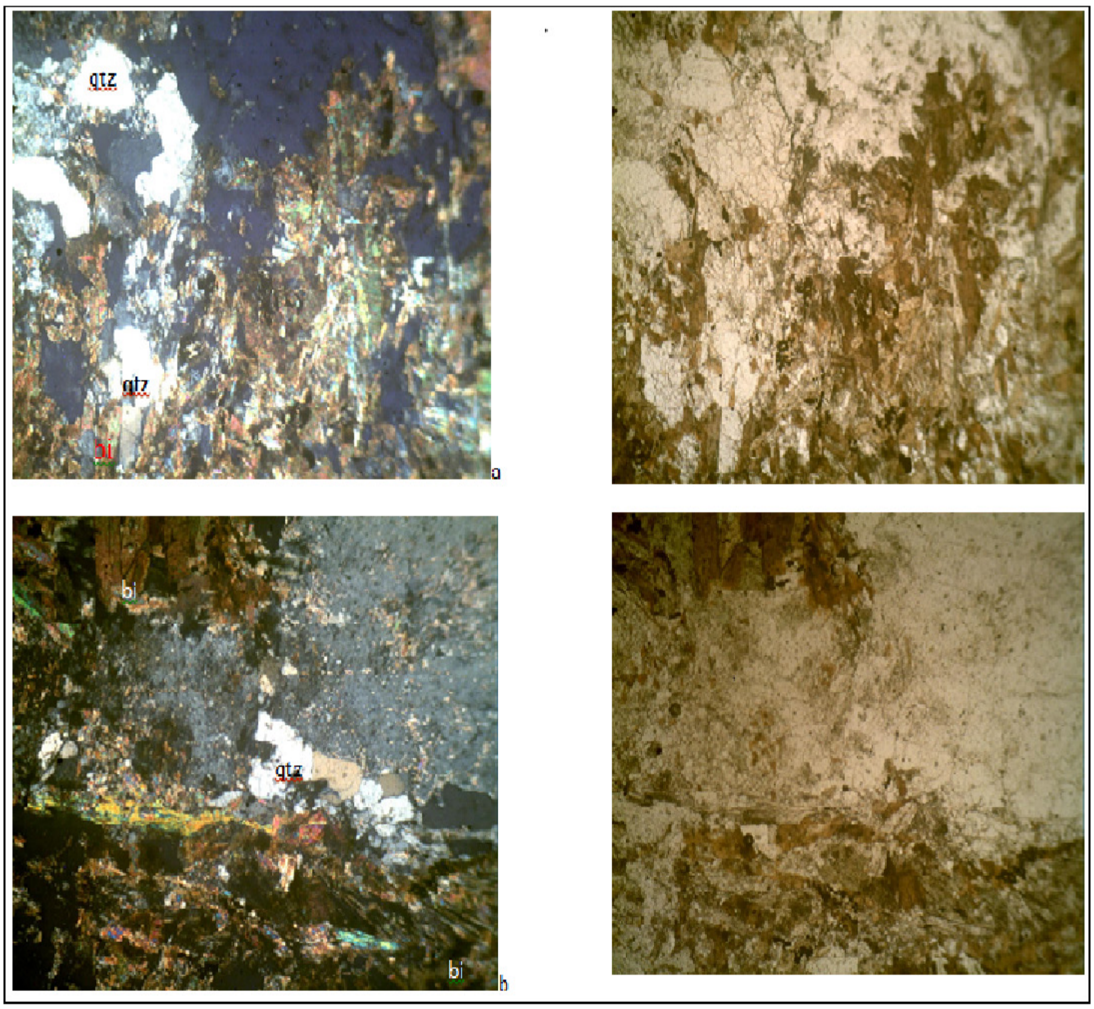


Figure 2. Geology of Guguruji and environ 2 showing rock types and the drainage system



Plates (a) and (b). Photomicrograph of Guguruji Amphibolites showing crossed and plane polarized formats (bi-Biotite, qtz-Quartz, hb-hornblende)

2. Geological Setting

Guguruji amphibolites outcrop prominently around the central portion of the study area (Fig. 2) as large unmigmatized bodies. The rock is bounded by quartz-mica schist in the north, gneiss in the lower eastern flank and granite to the west. The rocks which occur generally as low-lying are of varying sizes, and are intruded in places by flat lying pegmatites. Many of the pegmatites had been worked for gemstones. The amphibolites are dense, heavy and fine - medium grained in texture with no obvious folds or foliations. The petrographic study of some of the samples reveals that mineral composition is uniform in some exposures and varied more in others. The thin sections reveal essentially biotite, hornblende, plagioclase, quartz, actinolite, tremolite, and opaque minerals. The minerals have random orientation of long axes of abundant hornblende and subordinate plagioclase crystals. The elongated crystals of hornblende in thin sections appear dark brown and greenish in some slides, the plagioclase are also lath like and in chaotic arrangement with the quartz crystals filling the spaces within these minerals. Garnet, biotite, sphene and opaque minerals constitute the accessory minerals.

3. Materials and Methods

Fieldwork for this work was carried out between 2012 and April, 2013; during which several of the rocks were sampled each weighing about 2kg but twelve representative samples were set aside for study in this research. Major and trace element concentrations of the rock samples were determined at the Activation Laboratories in Ontario, Canada using Fusion ICP and ICP/MS analytical methods, the detail of which is available in [22]. This laboratory maintains regular routine exercise to ensure accuracy.

4. Data Presentation and Discussions

4.1. Major Elements

The comprehensive details of the major oxides (%) and trace elements concentrations of the rock samples are presented in Table 1. The petrochemical affinity of the Guguruji amphibolites reflects the followings: the average SiO_2 composition is 51% (48.43-54.04%), and comparable to Ilesha melanocratic amphibolite [17] and Ibadan amphibolite [18], Zungeru [21], and Lema-Ndeji amphibolites [23]. The Al_2O_3 mean value is 14.9% (14 - 17%), this is comparable to Wonu-Apomu [16], Ilesha and Obudu [24] varieties. Total iron (Fe_2O_3) content average is 11% with values ranging from 8 to 13%, this is lower than those of Zungeru, Obudu, and Wonu-Apomu, higher than those of Lema and Sepeteri types, but comparable to Ilesha amphibolites. Calcium oxide has a mean of 11.73% (6.43-13.74%) and it is comparable to those from Isanlu, Ilesha, Lema, Obudu and that of Ibadan but higher than those of Wonu-Apomu, Zungeru and Sepeteri varieties. The high iron content of Guguruji amphibolites is possibly due to possible low abundance of titanomagnetite while the high concentration of CaO indicates the preponderance of Ca – rich pyroxene [1] in the rock. MgO average concentration is 7% (3 – 10%) and compares well with Ibadan schistose variety but lower than those of other referenced. Na_2O values for Guguruji amphibolites (av. 1.6%) and consistently higher than K_2O (av.0.87%) reflect abundance of sodium rich feldspar in the rock. This is consistent with the petrological examination of the rock in which long disoriented large crystals of plagioclase were observed. Total alkali concentration of the rock is 2.2%; this is lower, but relatively comparable to Ibadan amphibolite (3.3%) and almost six-times that of Sepeteri (0.38%) and four-times that of Zungeru (0.51%) (Table 2). The alkali (K_2O / Na_2O) ratio varies from 0.14 - 0.94 with a mean of 0.57 which is greater than twice that of Ibadan (0.23) and about thrice of Ilesha (0.2) amphibolite varieties. These ratios reflect the sub-alkaline nature of the rocks under investigation.

The MgO / (Fe_2O_3 + MgO) ratios vary between 0.3 and 0.6 with a mean value of 0.37%, it is lower than 0.46% obtained for Ilesha amphibolites [1]. This ratio is also considerably lower than those for rocks of the primitive upper mantle which ranges from 0.68 - 0.75 and a mean of 0.70 [35]. When such a ratio is above 0.70, it is regarded as being indicative of mantle-derived olivine tholeiite which have not been modified by differentiation in the crust; this may then imply that the protolith of the amphibolite may have experienced differentiation. TiO_2 has a mean value of 1.23%, this concentration is rather high compared with those of other amphibolites referenced above. This high TiO_2 content reflects the possible abundance of sphene in addition to titanomagnetite. The mean percentage concentration of P_2O_5 (0.17%) is greater than those of Wonu-Apomu (0.03%), Ibadan schistose type variety (0.12%), but less than that of Sepeteri (0.85%) and Ifewara (1.78%). Guguruji Amphibolites is further compared with Archaean, (0.06%), Zungeru (0.10%), and Ilesha massive Modern Tholeiites, Birrimian Tholeiitic and other published works in Table 2.

4.2. Trace Elements Geochemistry

The trace elements data of the representative samples of the Guguruji Amphibolites is presented along with the major elements in Table 1. The trace elements data reveal that, of the alkali earth elements, only Be, Sr, and Ba were detected while others were either absent or below detection limit. Barium (Ba) and Sr have mean concentrations of 228ppm and 196ppm with wide ranges of 22 - 644pp and 92- 343ppm respectively, while Be has an average value of 1.5ppm. Rubidium (Rb) recorded a low mean value of 26ppm, hence Rb/Sr = 0.13 and is comparable to Ilesha MMA value of 0.11) and Ifewara (0.01) [1]. Of the lanthanides, only the concentrations of Cerium (Ce) with an average of 50ppm and Neodymium (Nd) with a mean value of 20ppm have appreciable concentrations, other elements are generally low.

Cerium, a lanthanide is found in monazite and this implicates sedimentary input into the protolith of the rock [17]. Of the elements of group III family, only Scandium (Sc), Gallium (Ga) and Yitrium (Y) have appreciable average concentrations of 36ppm (11 – 66ppm), 20 ppm (8 – 35ppm) and 21 ppm (7 - 43ppm) respectively. In group IV, Zr, 141 ppm (12 - 430ppm) and Pb, 60ppm (4 – 374ppm) were reported in the analysis. Vanadium, Nb and Ta of group V have concentrations of 229 ppm, 14 ppm and 1.2ppm respectively. In group VI Cr concentration in the samples have an average of 268ppm (90 – 850ppm), Ni with average of 103ppm (40- 170ppm), Zn, 98ppm (70 - 150ppm), and Cu, 86ppm (40 – 150ppm). The compatible element concentrations (Sc, Ni, Cr, Co) of Guguruji amphibolites are comparable with those of Ilesha massive amphibolites (except for higher value of Cr) which [26] considered to have experienced metasomatism from a depleted mantle source. The concentration of Ni (103ppm) in this rock may apparently be due to presence of pentlandite and / high proportion of Fe-Mg silicates (hornblende and biotite) in the rock. Of the incompatible elements (Rb, Sr, Zr, Hf, and Th), only Sr (196ppm) and Zr (141ppm) contents compares fairly with those obtained in Isanlu (214ppm) and Ilesha (192ppm). Rb is slightly enriched in the rock with a content of 26ppm. There are however little variation in the contents of the compatible elements within the samples. In Tables 1 and 2 the Guguruji amphibolites data is compared with those of published works.

Table 1. Major and trace element concentrations of Guguruji Amphibolites

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	Ave
SiO_2	45.64	53.1	48.4	48.53	51.37	53.75	48.84	46.3	49.83	52.87	52.58	54.04	50.43
Al_2O_3	14.68	13.9	15.3	15.2	13.80	13.18	14.46	13.61	16.58	14.96	15.12	16.91	14.8
$Fe_2O_{3(T)}$	12.85	10.55	11.2	10.76	8.32	14.13	12.18	14.03	12.31	11.03	10.96	8.65	11.41
MnO	0.2	0.29	0.19	0.19	0.17	0.23	0.17	0.19	0.16	0.06	0.06	0.12	0.17
MgO	8.94	6.04	9.57	8.54	10.2	5.68	7.82	7.92	6.09	4.1	3.99	7.41	7.19
CaO	12.7	12.21	13.3	13.74	13.3	9.03	12.48	12.85	10.07	12.27	12.4	6.43	11.73
Na_2O	1.45	1.09	1.0	1.19	1.0	0.68	2.05	1.69	2.42	1.21	1.24	2.35	1.45
K_2O	1.37	1.32	0.26	0.17	0.22	0.54	0.55	0.61	1.06	1.1	1.17	1.07	0.79
TiO_2	0.98	0.96	0.18	0.45	0.35	1.97	0.86	1.55	1.47	1.83	1.96	1.81	1.19
P_2O_5	0.07	0.27	0.02	0.06	0.04	0.22	0.06	0.15	0.32	0.26	0.31	0.31	0.17
LOI	0.97	0.6	1.08	0.94	1.55	0.46	0.86	0.99	0.13	0.25	0.26	0.87	0.75
Total	99.9	100.33	100	99.8	100.3	99.9	100.3	99.9	100.4	99.9	100.1	99.97	100.1
M/F+M	0.41	0.36	0.46	0.44	0.55	0.29	0.39	0.36	0.33	0.27	0.26	0.46	0.37
K_2O /Na_2O	0.94	1.1	0.26	0.14	0.22	0.79	0.27	0.36	0.43	0.9	0.94	0.45	0.57
Trace Elements													
Sc	44	11	66	50	49	43	44	43	24	20	19	22	36
Be	0.9	2	0.8	0.7	0.8	2	0.6	0.9	1	3	3	2	1.5
V	295	83	205	236	194	374	284	352	206	163	155	195	229
Ba	42	611	36	22	56	66	182	49	214	506	644	308	228
Sr	122	219	121	105	121	92	135	140	414	262	279	343	196
Y	18	27	15	9	7	28	12	20	19	39	43	29	21
Zr	45	242	12	18	18	143	52	80	130	325	430	200	141
Cr	360	130	850	100	510	90	280	210	200	160	150	180	268
Co	16	16	52	45	41	43	52	58	44	20	18	33	37
Ni	170	40	150	90	150	40	110	110	100	60	60	80	103
Cu	140	50	110	110	40	50	70	150	80	70	80	80	86
Zn	100	80	70	70	70	150	90	120	120	100	100	110	98
Ga	15	19	8	13	10	20	15	18	20	35	34	27	20
Ge	3	3	3	3	3	3	2	2	2	2	2	2	3
Rb	8	116	3	3	5	12	6	6	19	44	43	30	26
Nb	3	20	1	0.9	1	9	3	6	22	35	40	27	14
Mo	2	7	3	3	2	3	3	2	1	1	1.6	1.6	3

Table 2. Major Elements Geochemistry of Guguruji Compared with Other Published Works

Oxides (%)	GAMP (n=12)	WAP n=5	ZAMP (n=6)	IAMP (n=11)	LEMA	SAMP (n=10)	LAMP (n=18)	OAMP (n=2)	BAMP (n=7)	Archaean (#)		Preterozoic (€)	Phanerozoic		
										Depleted Tholeiitic	Enhanced Tholeiitic	Birrimian Tholeiitic	MORB	Arc	Continental Rift
SiO_2	51.27	48.49	50.15	49.02	53.92	59.27	49.11	46.21	53.51	50.2	49.5	48.7	49.8	51.1	50.3
Al_2O_3	14.89	15.48	12.00	13.49	13.21	7.95	14.69	14.72	12.02	15.5	15.2	13.7	16.0	16.1	14.3
Fe_2O_3	11.16	13.20	17.13	11.79	9.06	9.35	11.22	15.33	9.7	10.9	12.0	13.8	9.5	10.3	12.8
MnO	0.17	0.13	0.20	0.20	0.01	0.19	0.17	0.28	0.17	0.22	0.18	0.21	0.17	0.17	0.2
MgO	7.02	9.89	9.90	8.99	9.14	11.87	9.65	5.39	7.2	7.53	6.82	6.53	7.5	5.1	5.9
CaO	11.09	9.31	9.41	11.79	10.78	9.05	12.15	11.71	13.02	11.6	8.8	9.4	11.2	10.8	9.7
Na_2O	1.61	1.61	0.39	1.38	2.0	0.12	0.82	1.48	2.68	2.15	2.70	2.45	2.8	2.0	2.5
K_2O	0.87	0.72	0.20	0.50	0.26	0.26	0.16	0.87	0.62	0.22	0.69	0.34	0.14	0.30	0.8
TiO_2	1.23	0.53	0.50	0.81	0.09	0.82	0.81	2.65	0.28	0.94	1.49	1.2	1.5	0.83	2.2
P_2O_5	0.17	0.03	0.10	0.47	1.6	0.85	0.12	0.39	0.06	0.10	0.17	0.15	0.20	0.15	0.16
M+F+M	0.39	0.41	0.37	0.43		0.56	0.46	0.26	0.43	0.41	0.36	0.32	0.44	0.33	0.32

GAMP=Guguruji Amphibolite; WAP=Wonu-Apomu (Bolarinwa & Adeleye, 2015); ZAMP=Zungaru Amphibolites (Agbor, 2014); IAMP=Isanlu Amphibolite (Olobaniyi, 2008); LEMA=Lema-Ndeji(Okunlola et al.,2007); SAMP=Sepeteri Amphibolite (Okunlola et al., 2005); LAMP=Ilesha Melanocratic Amphibolite (Oyinloye and Odeyemi, 2001); OAMP=Obudu Amphibolite (Ekwueme, 2003), BAMP= Ibadan Amphibolite (Okunlola et al., 2009), (# - Chondrite ,1976, 1981); (€- Leube et al.,1990). M/F+M= MgO/ Fe_2O_3+MgO

5. Petrogenetic Affinity

Several authors (e.g. [21], [26], [27] and [28] from different regions of Nigeria and geological settings have presented varied opinions concerning the origin of amphibolites that can be grouped into three. One, metamorphism of basic igneous rocks, two, metamorphism of sedimentary rocks and three, metasomatism of pre-existing rocks. Despite these varied views petrologists believe that amphibolite can either be para-genetic (altered sediments) or ortho-genetic (modified igneous rocks), however the latter is believed to be more common [21]. [29] applied the ratio CaO: Al_2O_3 to determine rock protolith. According to this author, when this ratio is less than 0.9, it implies that the rock is of igneous parentage i.e. (ortho-genetic), if otherwise it is para-genetic. In this study, CaO / Al_2O_3 is 0.74 implying that it is of igneous parentage. To confirm this, $Na_2O + K_2O$ versus 10^2 x K_2O/ $Na_2O + K_2O$ of Guguruji.

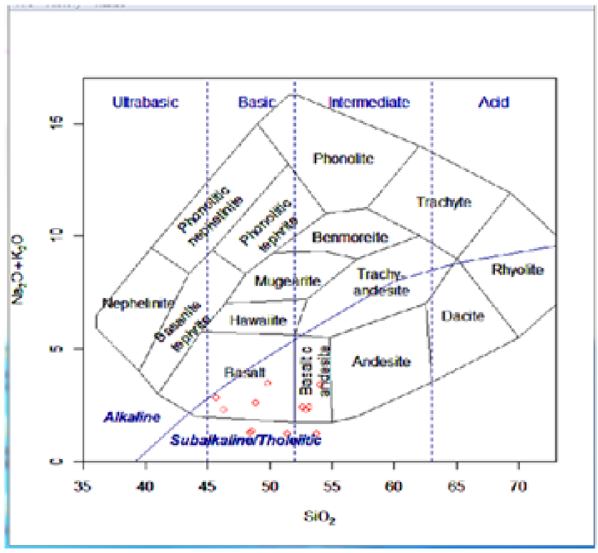


Figure 4. Plot of Na_2O+K_2O vs SiO_2 discrimination diagram reveals the subalkaline, basaltic nature of the amphibolites, After Cox *et al* (1979)

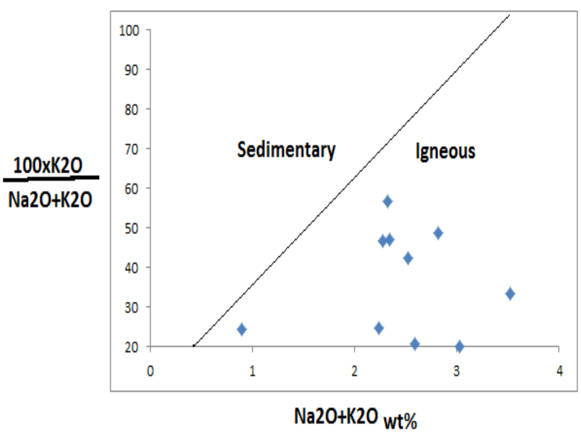


Figure 3. Plot of $Na_2O + K_2O$ vs 10^2 xK_2O/ $Na_2O + K_2O$ of Guguruji Amphibolites, After [30]

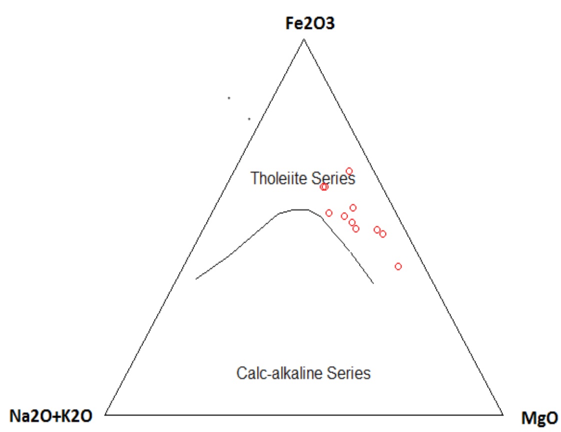


Figure 5. Ternary plot: $Fe_2O_3 – Na_2O + K_2O$ – MgO of the amphibolites showing tholeiitic affinity, After [32]

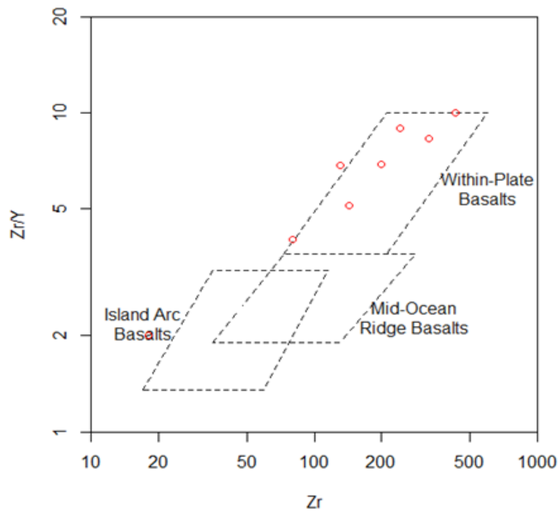


Figure 6. Plot of Zr/Y vs Zr assigns Guguruji Amphibolites to Within-Plate basalts

Amphibolites data was plotted (Fig.3, after [30]. This reveals that all the samples plotted in the igneous field. The chaotic arrangement of the minerals, having no preferred orientation as observed in the slides also confirms this assertion. These undoubtedly implicates that the largely massive amphibolite is of igneous parentage. The Na_2O+K_2O versus SiO_2 discrimination diagram of [31], reveals the subalkaline /basaltic nature of the Guguruji amphibolites (Fig.4). When the data were projected on $Fe_2O_3 - Na_2O + K_2O - MgO$ ternary plot of [32] showed a tholeiitic affinity (Fig.5) for the magmatic precursor of the amphibolites. The use of immobile trace and minor elements to determine the petrogenetic and tectonic settings of volcanic rocks is well reported in literature [33], [34] and, [35]. There is a generally low TiO_2 contents (<2%) in all the Guguruji amphibolites, similar to some of the published works and this is believed to be typical of basalts. The plot of Zr/Y versus Zr (after [35], Fig.6.), assigns the amphibolites to Within-Plate basalts tectonic setting.

6. Conclusions

This study reflects that Guguruji amphibolites compares favourably well with other amphibolites referenced in this work in terms of Geochemistry and petrogenesis. Plots of discriminating elements: $100XNa_2O/Na_2O+K_2O$ versus Na_2O+K_2O wt %, The Ternary plots and the Zr/Y versus Zr implicate an orthogenetic source for the Guguruji amphibolites.

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