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Geochemical Characteristics and Tectonic Setting of Amphibolites in Ifewara Area, Ife-Ilesha Schist Belt, Southwestern Nigeria

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Abstract

Trace and Rare Earth Elements (REEs) data are used to constrain the geochemical evolution of the amphibolites from Ifewara in the Ife-Ilesha schist belt of southwestern Nigeria. The amphibolites can be grouped into banded and sheared amphibolites. Major element data show SiO_2 (48.34%), Fe_2O_3 (11.03-17.88%), MgO (5.76-9.90%), CaO (7.76-18.6%) and TiO_2 (0.44-1.77%) contents which are similar to amphibolites in other schist belts in Nigeria. The Al_2O_3 (2.85-15.55%) content is varied, with the higher values suggesting alkali basalt protolith. Trace and rare earth elements composition reveal Sr (160-1077ppm), Rb (0.5-22.9ppm), Ni (4.7-10.2ppm), Co (12.2-50.9 ppm) and Cr (2-7ppm). Chondrite-normalized REE patterns show that the banded amphibolites have HREE depletion and both negative and positive Eu anomalies while the sheared variety showed slight LREE enrichment with no apparent Eu anomaly. The study amphibolites plot in the Mid Oceanic Ridge Basalts (MORB) and within plate basalt fields on the Zr/Y vs Zr discriminatory diagrams. They are further classified as volcanic arc basalt and E-type MORB on the Th- Hf/3- Ta and the Zr-Nb-Y diagrams. The amphibolites precursor is considered a tholeiitic suite that suffered crustal contamination, during emplacement in a rifted crust.

Keywords: amphibolite, rare earth elements, tectonic evolution, Ifewara, Ife-Ilesha schist belt

1. Introduction

The amphibolites of Ifewara in the Ife-Ilesha schist belt (Figure 1) in southwestern Nigeria constitute a major rock unit within the amphibolite complex, with which placer gold and disseminated sulphide mineralization have been associated (Elueze, 1981). The study area is located within latitudes 7º30´N to 7º33´N and longitudes 4º35´E to 4º42´E. The major towns in the study area include Ifewara, Oke Owena, Oke Oloyinbo and Itagunmodi (Figure 2). The area is located within the N-S trending schist belt of the Nigerian Basement Complex. The geology of Ife-Ilesa schist belt (Figure 1) has been studied by Hubbard (1975), Ajayi (1980), Elueze (1981) and Rahaman *et al.* (1988). They recognized two contrasting lithologies separated by the NNE trending Ifewara faults. The rocks of the study area may be broadly grouped into gneiss-migmatite complex, mafic-ultramafic suite (or amphibolites complex), meta-sedimentary assemblages and intrusive suite of granitic rocks (Odeyemi, 1981 and Elueze, 1988). The entire area has been affected by polycyclic episodes of deformation and metamorphism (Odeyemi, 1981). The ratio of metasediments to metavolcanics is much higher in the schists belts of Nigeria than in the typical Archaean greenstone belts (Wright & McCurry, 1970). Mineralization is also not strongly developed in the Ife-Ilesa schist belts unlike most well known greenstone belts in the Canadian, Indian, Australian, and South African Precambrian shields.

The objectives of current investigation are to examine the petrography, determine the geochemical composition, appraise the petrogenetic affinity, and highlight the tectonic significance and crustal evolution of the amphibolites.

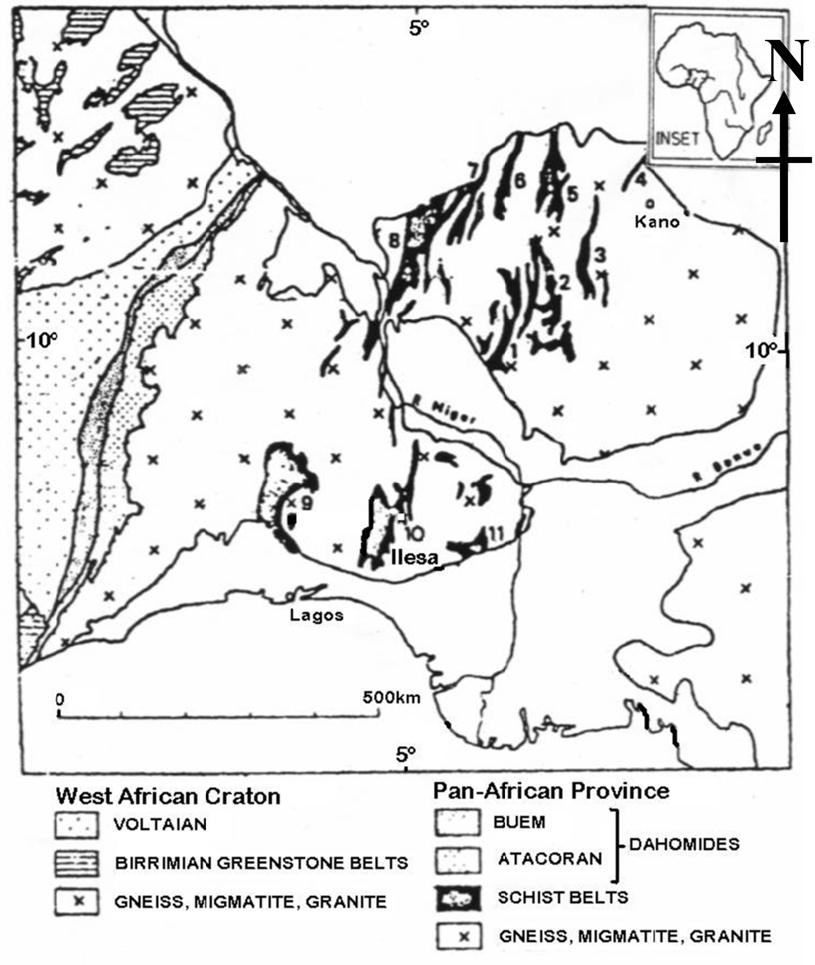

Figure 1. Location map showing the schist belts in the Nigerian sector of the Pan-African Province (after Turner 1983). The location marked 10 is Ilesha schist belt

2. Method

Geological field mapping and collection of amphibolites samples were carried out in Ifewara, Oke-Owena, Oke Oloyinbo, Mokuro and Itagunmodi area of the Ife-Ilesa schist belt. Thin section of the samples was prepared at the laboratory of the Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria. The thin sections were examined using the petrological microscope at the Department of Geology, University of Ibadan, Ibadan, Nigeria. Twenty one samples of the amphibolites were pulverized, packaged and sent to ACME Laboratories, Vancouver, Canada for chemical analysis. Major, trace and rare earth elements compositions of the rocks were determined using a multi-element high resolution Inductively Coupled Plasma-Mass Spectrometer (ICP-MS). The chemical data obtained were group into seven based on their chemical similarities.

3. Results and Discussion

3.1 Petrography

On the basis of the petrographic study, two varieties of amphibolites were identified, they are, the medium to coarse grained, banded amphibolites, consisting of amphibolites from Ifewara, occurring close to the lithological banding with granite gneiss in the southern part of the area (Figure 3a-c) and the fine grained, sheared amphibolites, consisting of samples from Oke Oloyinbo, Mokuro and Itagunmodi in the northern part (Figures 2 and 3 d-f).

The amphibolites from Oke-Owena and Ifewara (1 and 2) (Table 1) are coarse to medium grained, composed of hornblende, plagioclase and quartz. They are banded as shown by the alternation of plagioclase-rich and hornblende-rich layers (Figure 3a-c). The mineralogical banding could be as a result of their occurrence within the transition zones of the amphibolites and the granite gneisses. Olade & Elueze (1979) postulated that banding in such rocks may be attributed to metamorphic differentiation and increased deformation along lithological boundaries. The modal composition of the banded amphibolites is 63% hornblende, 20% plagioclase, 12% quartz and 3% pyroxene while 2% represent other opaque accessory minerals present (Table 1).

The amphibolites from Oke Oloyinbo (3) (Table 1) are medium to fine grained and are mainly composed of hornblende, quartz and plagioclase and a few occurrence of epidote. The amphibolites are weakly foliated and exhibit shearing with replacement of hornblende by epidote (Figure 3d). The modal composition is in the order of 65% hornblende, 18% plagioclase, 12% quartz and 3% epidote while 2% opaque accessory minerals (Table 1, Figure 3d).

Mokuro amphibolites (4, 5 & 6) (Table 1) are dark, fine grained and composed of hornblende plagioclase and quartz (Figure 3e). The sample shows a high degree of shearing; an evidence of strong tectonic activity in the area. The modal composition of the amphibolite is in the order of 68-70% hornblende, 10-12% plagioclase, 12-15% quartz and 3% epidote while 2% opaque accessory minerals present. The Itagunmodi amphibolites are more mafic than the Ifewara and Oke Oloyinbo amphibolite samples. The modal composition is 70% hornblende, 16% plagioclase, 10% quartz, 2% epidote with 2% opaque minerals (Table 1, Figure 3f).

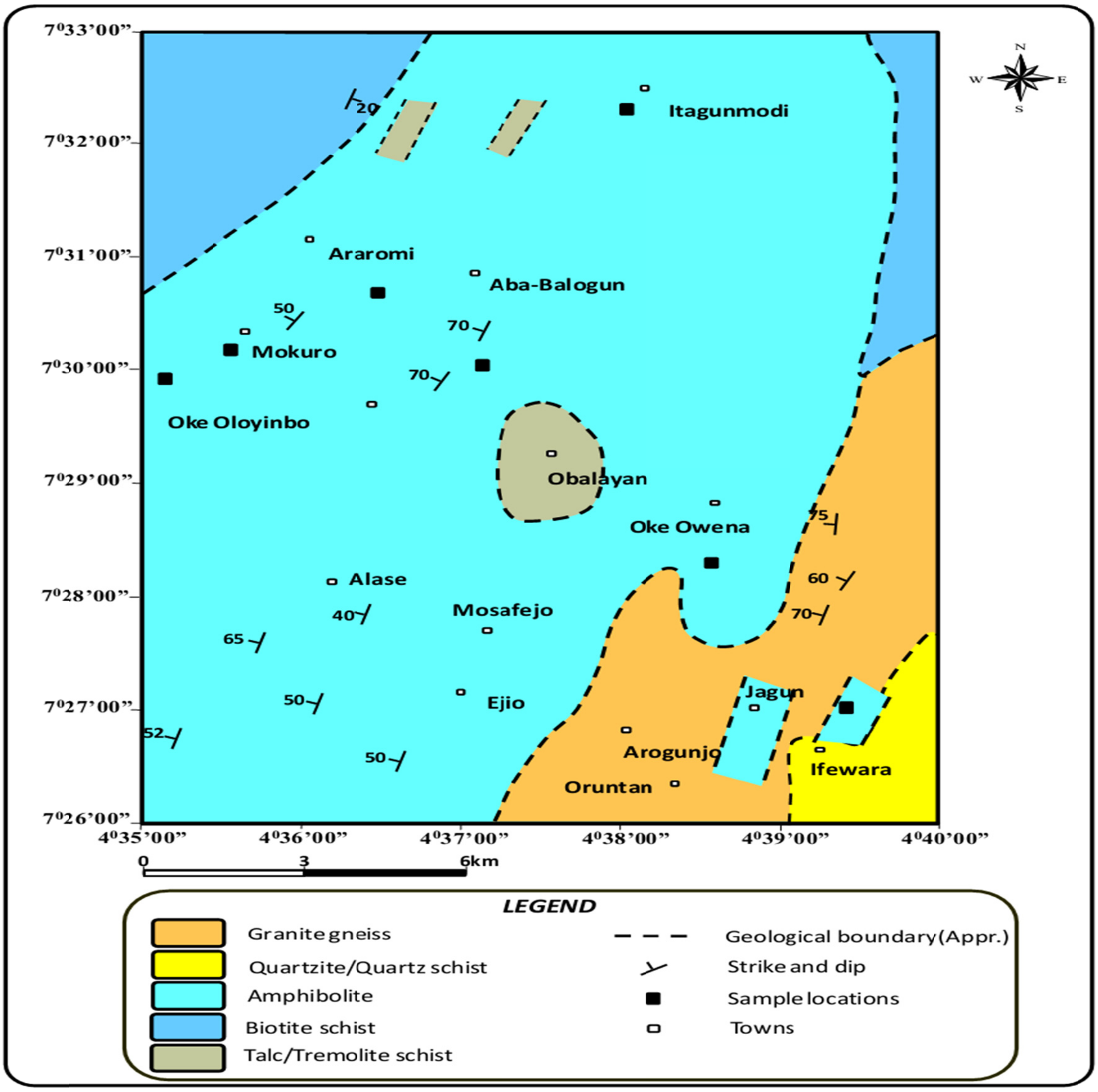

Figure 2. Geological map of Ife - Ilesha area (modified after Kehinde-Phillips, 1991), showing the sample locations of the study sections

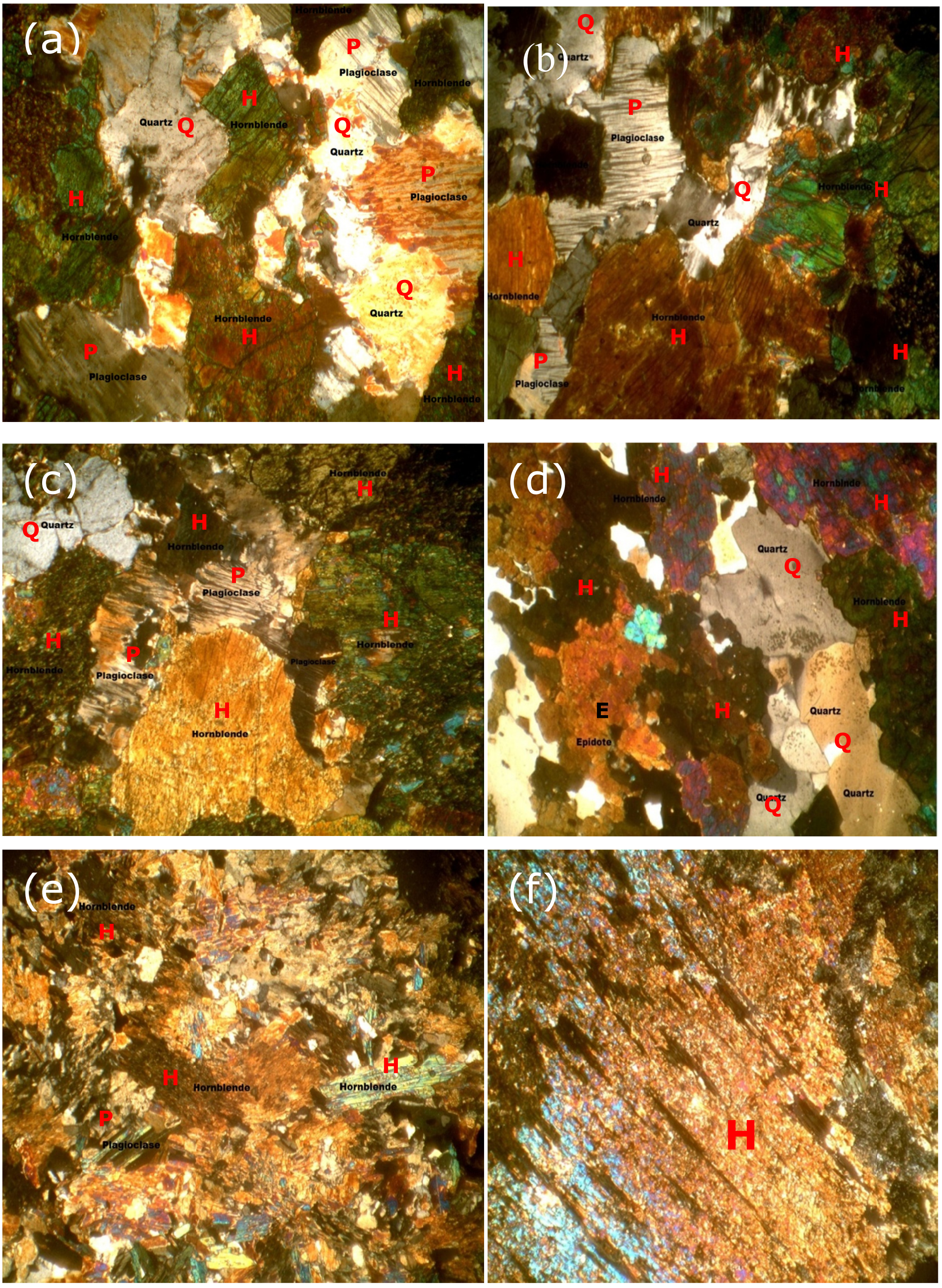

Figure 3. Photomicrograph of the amphibolites showing plagioclase- and hornblende-rich layers (x40, crossed polarized light). (3a-d) – Banded amphibolites; (3e-f) – Sheared amphibolites. H-Hornblende, P-Plagioclase, Q-Quartz, E-Epidote

Table 1. Modal composition (%) of the study amphibolite rocks from Ifewara area

	Banded amphibolites		Sheared amphibolites				
	1	2	3	4	5	6	7
	n = 3	n = 3	n = 3	n = 3	n = 3	n = 3	n = 3
Hornblende	63	63	65	68	70	70	70
Quartz	12	12	12	12	10	11	10
Plagioclase	20	20	18	12	15	14	16
Pyroxene	3	3	-	2	-	-	-
Epidote	-	-	3	3	3	3	2
Opaque	2	2	2	3	2	2	2

1- Oke Owena Ifewara, 2- Ifewara Road, 3- Oke Oloyinbo, 4- Mokuro area,

5- Mokuro River Valley, 6- Mokuro Water Works, 7- Itagunmodi

3.2 Geochemistry

3.2.1 Major Elements

Results of the major oxides of the 21 amphibolite samples are summarized in Table 2. The geochemical data showed that the amphibolites are undersaturated in silica. Major element compositions (Table 2) reveal differences in concentration between the banded and sheared amphibolites. The study banded amphibolite samples (1 & 2) (Table 2) are characterized by higher SiO_2 (51.90 – 52.07%), lower TiO_2 (0.44-0.47%), lower Fe_2O_3 (11.03-11.13%) and higher P_2O_5 (1.78-2.42%) while the sheared amphibolites (3 - 7) have lower values of SiO_2 (45.02-48.22%), higher TiO_2 values (1.12-1.77%), higher Fe_2O_3 (12.97-17.88%) and lower P_2O_5 values (0.04 to 0.3%). The banded amphibolites have higher K_2O (0.60-1.48%) and Na_2O (1.58-2.67%) values as opposed to (0.02 - 0.43%) and (0.09 - 1.12%) for the sheared massive types. K_2O average values lower than 0.5%, which is similar to those of primitive rocks and oceanic theoleiites (Glikson, 1977). The higher Fe_2O_3 values of the massive variety (12.97-17.88%) may be due to presence of high quantity of melanocratic minerals in the amphibolite. Mean TiO_2 value (1.19%) consistent with 1.3% obtained from mafic-ultramafic rocks with theoleiitic character (Floyd & Winchester, 1978).

The SiO_2 content ranges from 45.02 to 52.07%, which is comparable to those of Alawa massive amphibolites (Elueze, 1985), Holleindalen greenstone (Elliot & Cowan, 1966) and the Achaean metabasalt of superior province, Canada (Glikson, 1977). Average Al_2O_3 value of 10.53% is lower than those of Tegina amphibolites (Elueze 1981), Alawa amphibolites and Egbe massive amphibolite (Elueze, 1985), but comparable to that of the Archean metabasalt of Superior province Canada (Glikson, 1977) (Table 3). The mean composition of MgO (8.30%) for the Ifewara amphibolites is comparable to the Tegina Amphibolite, and Egbe and Ilesha massive amphibolites (Elueze, 1981) (Table 3).

3.2.2 Trace and Rare Earth Elements

The trace element concentrations for the study amphibolites are as shown in Table 4. The Sr (960-1077ppm), Rb (9.5-22.9ppm) and Zr (281.1-303.5) concentrations for the banded amphibolites are higher compared to the sheared amphibolites (160 – 720ppm), (0.5-2.8ppm) and (73.4-124.7ppm); correspondingly. Ni is lower in the banded amphibolites (4.7-5.7ppm) compared to those of the massive variety (6.2-10.2ppm). Co in the banded amphibolites samples (12.2-12.7ppm) is lower than those of the sheared massive amphibolites samples (45.4-50.9ppm). Ga concentrations also vary between the banded amphibolites (6.1-9.4ppm) compared to the massive amphibolites (14.8-24.1ppm).

Rare Earth Elements (REEs) are amongst the least soluble trace elements and are relatively immobile during low grade metamorphism, weathering and hydrothermal alteration and can represent the original composition of the unaltered parent (Michard, 1989). Chondrite-normalized REE patterns for the amphibolites are given in Figure 4. The banded amphibolites have higher abundances of the light rare element (LREE), medium rare element (MREE) and heavy rare element (HREE). The banded amphibolites show strong HREE depletion with no apparent Eu anomaly. The massive amphibolites showed REE chondrite-normalized patterns with slight LREE enrichment compared to MREE and HREE. It also shows slight HREE depletion relative to the MREE. This relatively flat pattern is characteristic of tholeiitic basalt as shown by Cox *et al.,* (1979).

A negative Europium (Eu) anomaly is caused by removal of feldspar from a felsic melt while positive Eu anomaly can result from increase in hornblende, titanite and orthopyroxene contents. Most of the study amphibolites show no obvious Eu anomaly except samples 6 and 3 which showed strong positive and weak negative Eu anomalies respectively; (Figure 4). The observed disparity in Eu anomalies could result from the increased mafic mineral composition (Table 1) and removal of feldspar from the felsic melt correspondingly. The pattern of the amphibolites on the MORB-normalized spider diagram (Figure 5) shows significant enrichment in Sr compared to Ce indicating volcanic – arc basalts precursor.

Table 2. Major oxide composition (wt%) of the study amphibolite rocks from Ifewara area

	Banded amphibolite		Sheared amphibolite					
Oxides	1 n = 3	2 n = 3	3 n = 3	4 n = 3	5 n = 3	6 n = 3	7 n = 3	Mean n = 21
SiO_2	51.90	52.07	45.02	47.37	47.38	48.22	46.41	48.34
TiO_2	0.47	0.44	1.52	1.54	1.50	1.77	1.12	1.19
Al_2O_3	2.85	6.31	11.85	14.68	15.55	13.76	8.72	10.53
Fe_2O_3	11.03	11.13	13.53	14.08	13.10	17.88	12.97	13.39
MnO	0.33	0.28	0.58	0.26	0.25	0.30	0.25	0.32
MgO	9.90	7.17	5.76	9.08	8.77	8.65	8.74	8.30
CaO	18.32	13.74	18.12	10.71	11.23	7.76	18.6	14.07
Na_2O	1.58	2.67	0.09	0.89	0.90	0.52	1.12	1.11
K_2O	0.60	1.48	0.02	0.16	0.16	0.11	0.43	0.42
P_2O_5	1.78	2.42	0.30	0.16	0.12	0.04	0.15	0.71
Cr_2O_3	-	-	0.02	0.05	0.05	0.02	0.03	0.03
LOI	0.70	1.70	3.00	0.70	0.70	0.70	1.10	-
Total	99.50	99.40	99.80	99.70	99.70	99.70	99.60	-

1- Oke Owena Ifewara, 2- Ifewara Road, 3- Oke Oloyinbo, 4- Mokuro Area,
5- Mokuro River Valley, 6- Mokuro Water Works, 7- Itagunmodi

Table 3. Comparison of the concentrations (wt %) of major element of the study amphibolites rocks with other localities

Oxides	❖	ZA	ALA	AMA	HGN
SiO_2	48.34	50.15	51.4	47.35	47.21
TiO_2	1.19	0.50	0.96	1.24	2.41
Al_2O_3	10.53	12.00	12.51	11.85	11.94
Fe_2O_3	13.39	12.24	8.55	0.43	9.65
MnO	0.32	0.20	0.22	0.23	0.12
MgO	8.30	9.90	6.36	0.99	7.82
CaO	14.07	9.41	12.16	6.35	10.20
Na_2O	1.11	0.39	2.19	0.90	2.77
K_2O	0.42	0.20	0.51	0.04	0.56
P_2O_5	0.71	0.10	0.14	0.33	0.22
Cr_2O_3	0.03	-	-	-	-

❖ Average chemical composition of the study amphibolites rocks
ZA = Zungeru amphibolites (Agbor, 2014)
ALA = Alawa laminated amphibolites (Elueze, 1985)
AMA = Alawa massive amphibolites (Elueze, 1985)
HGA = Holleindalen greenstone amphibolites, Norway (Elliot & Couwan, 1966)

Table 4. Trace and rare elements composition (ppm) of the amphibolites samples

	1 n = 3	2 n = 3	3 n = 3	4 n = 3	5 n = 3	6 n = 3	7 n = 3
Ba	202	510	62	55	43	28	308
Cs	-	0.2	0.2	0.8	0.3	-	0.4
Ga	6.1	9.4	21.5	24.1	22.3	18.2	14.8
Hf	9.9	10.5	2.8	3.0	3.7	2.5	3.5
Nb	5.1	2.9	10.8	11.8	10.0	11.1	13.0
Rb	9.5	22.9	0.5	2.6	2.8	2.0	20.5
Sn	7	8	6	4	4	-	5
Sr	960.0	1077.0	391.0	173.7	203.9	160.1	720.2
Ta	0.4	0.2	0.7	0.7	0.9	0.7	1.2
Th	2.8	5.4	2.0	0.3	-	3.0	-
U	0.4	0.5	0.3	-	-	0.4	-
V	246	232	198	320	310	457	416
W	-	-	3.7	0.6	0.8	-	-
Zr	281.1	303.5	94.9	98.1	122.8	73.4	124.7
Y	34.2	70.1	24.9	27.6	25.8	12.7	25.8
Cu	7.0	7.8	4.9	8.7	5.1	5.8	37.0
Pb	1.2	8.5	1.5	4.8	8.2	3.6	11.5
Zn	18	33	19	8	7	7	36
Ni	4.7	5.7	10.2	8.0	6.2	7.4	40.8
Co	12.2	12.7	45.7	50.5	50.9	50.9	45.4
Sc	160	158	23	44	42	32	59
Mn	367	675	3145	90	66	34	279
As	1.2	1.3	1.0	1.0	1.4	1.6	1.3
Ca	2.41	2.71	0.72	2.13	2.49	3.29	0.55
P	0.79	1.03	0.14	0.06	0.05	0.02	0.05
Cr	2	5	4	17	14	8	27
La	296.1	540.5	22.8	16.2	16.4	13.8	38.0
Ce	442.6	589.6	47.4	36.9	38.8	24.6	87.1
Pr	48.44	105.31	6.72	5.73	5.56	2.82	11.89
Nd	170.6	392.0	25.9	27.5	24.4	10.7	48.3
Sm	22.05	51.74	5.84	6.19	5.96	2.30	9.54
Eu	5.30	11.87	1.47	1.98	1.78	1.39	2.44
Gd	15.18	33.51	5.15	6.12	5.80	2.06	6.91
Tb	1.71	3.69	0.84	0.95	0.87	0.35	1.01
Dy	7.37	16.57	4.91	5.10	4.46	2.08	5.25
Ho	1.26	2.76	0.87	0.96	0.90	0.47	0.91
Er	3.18	6.56	2.58	2.92	2.59	1.40	2.59
Tm	0.45	0.92	0.37	0.37	0.38	0.20	0.33
Yb	3.36	6.03	2.78	2.48	2.24	1.57	2.19
Lu	0.53	0.92	0.36	0.38	0.36	0.22	0.34
Mo	0.6	1.1	-	0.4	0.4	0.3	0.2
CaO/Al_2O_3	6.43	2.18	1.53	0.73	0.72	0.56	2.13

1- Oke Owena Ifewara, 2- Ifewara Road, 3- Oke Oloyinbo, 4- Mokuro Area,
5- Mokuro River Valley, 6- Mokuro Water Works, 7- Itagunmodi

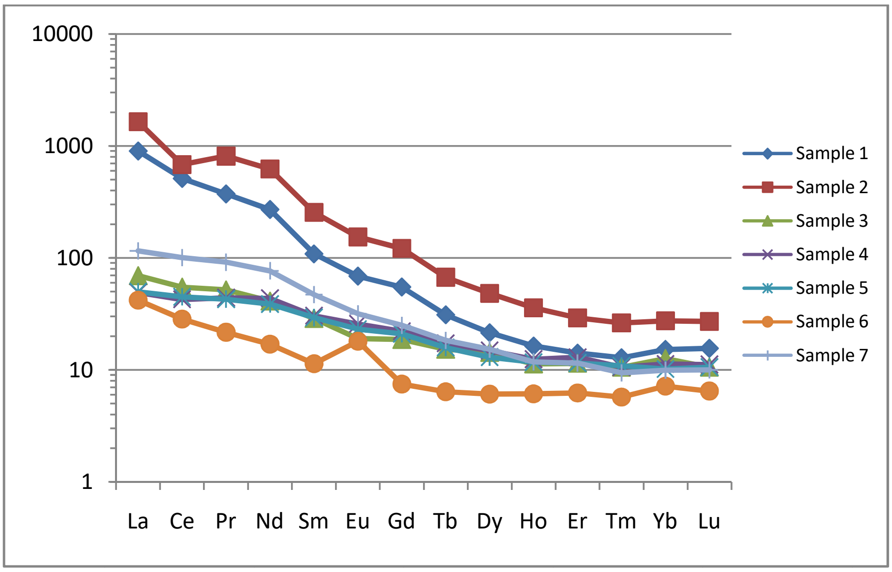

Figure 4. Chondrite-normalized rare-earth element (REE) patterns for the study amphibolites rocks (after Nakamura, 1974)

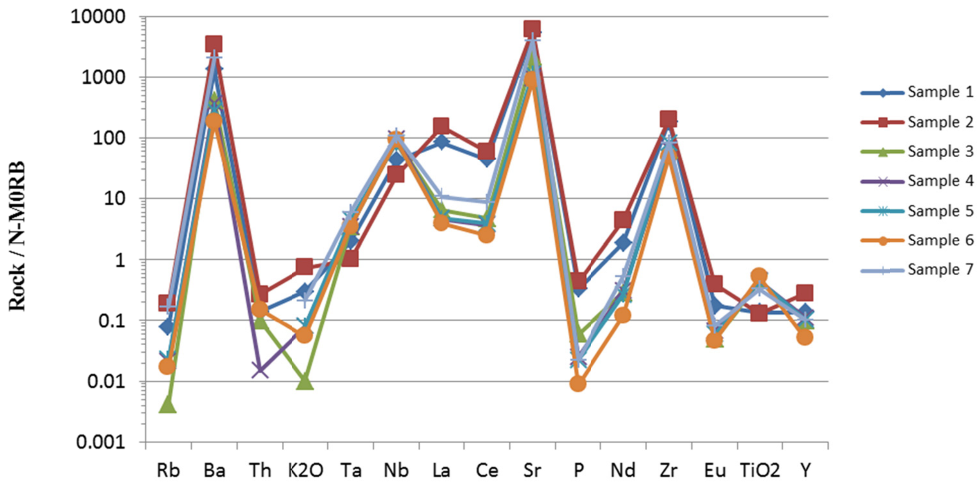

Figure 5. MORB normalized incompatible element patterns (spidergrams) for the study amphibolites rocks. Normalizing values are from Pearce & Cann (1973)

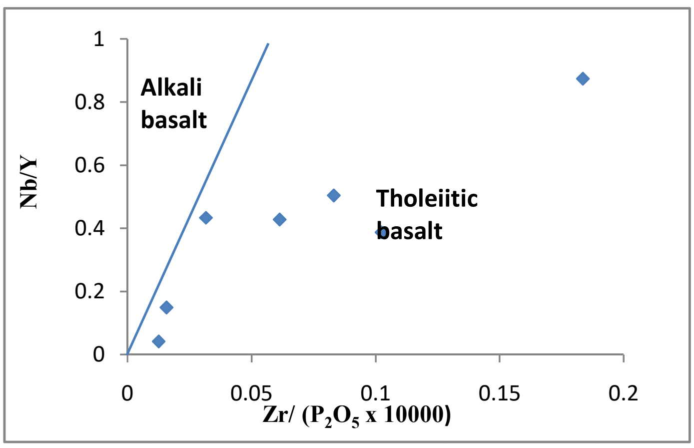

Figure 6. Plot of Zr/ (P_2O_5 x 10000) against Nb/Y for the amphibolites (Floyd & Winchester, 1975)

3.3 Origin and Tectonic Setting

Discriminatory diagrams were used to ascertain the chemical affinity and tectonic setting of the amphibolites. A plot of Zr/ (P_2O_5 x 10000) against Nb/Y (Floyd & Winchester, 1975) (Figure 6), which provides a more accurate discrimination between alkali and tholeiitic basalts (Rollinson, 1993) is used to confirm the tholeiitic basalt nature of the amphibolites. A ternary discrimination diagram of FeO – MgO – Al_2O_3 after Pearce *et al.,* (1977) (Figure 7) indicates that most of the samples fall within the Oceanic Island field.

The high field strength elements (HFSE) such as Zr, Nb, Ta, Y, Hf and Ti are generally considered immobile during metamorphism and secondary alteration compared with alkaline elements such as K, Na, Ba and Rb (Pearce & Cann, 1973; Pearce, Gorman & Birkett, 1977; Pearce & Norry, 1979) and so can be used to identify the tectonic setting and the protoliths of the amphibolites. Ti, Zr, Y and Co concentrations have been used by Pearce and Cann (1973), Floyd and Winchester (1978), and Pearce & Norry (1979) to show petrogenetic character and tectonic setting of mafic rocks. The Zr/Y vs Zr plot for the study amphibolites (Pearce and Norry, 1979) indicate Mid-oceanic ridge basalt (MORB) and Within plate basalt (WPG) as the tectonic regime of the amphibolites (Figure 8).

The Th- Hf/3- Ta diagram (Wood, 1980) (Figure 9) is used to distinguish basalts formed in different oceanic tectonic settings. The amphibolites fall mostly within and around the volcanic arc basalt which are commonly enriched in incompatible trace elements (Meschede, 1986). The Zr-Nb-Y discrimination diagram for the amphibolites (Meschede, 1986) gives a comprehensive view of the tectonic environments of the amphibolites as E-type MORB, within-plate tholeiites and volcanic-arc basalts (Figure 10).

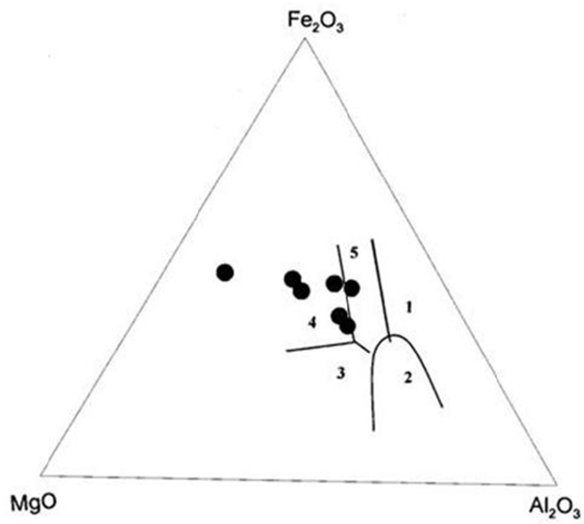

Figure 7. A ternary discrimination diagram of FeO – MgO – Al_2O_3 (Pearce *et al.,* 1977) of the sample amphibolites. 1. Cont-continental basalts; 2. IAT-Island arc tholeiitic; 3. MORB-Mid-oceanic ridge basalts; 4. OIB-Ocean Island basalt; 5. WPB-Within plate basalts.

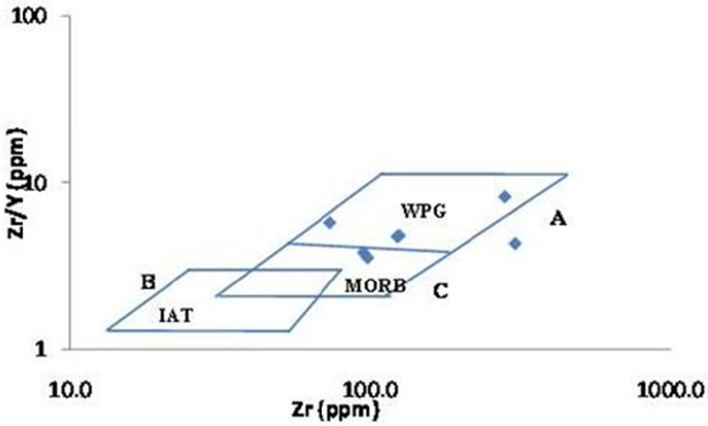

Figure 8. Zr/Y vs Zr diagram for the amphibolites (after Pearce & Norry, 1979)

IAT - Island arc tholeiitic, MORB - Mid- oceanic ridge basalt, WPG - Within plate basalt.

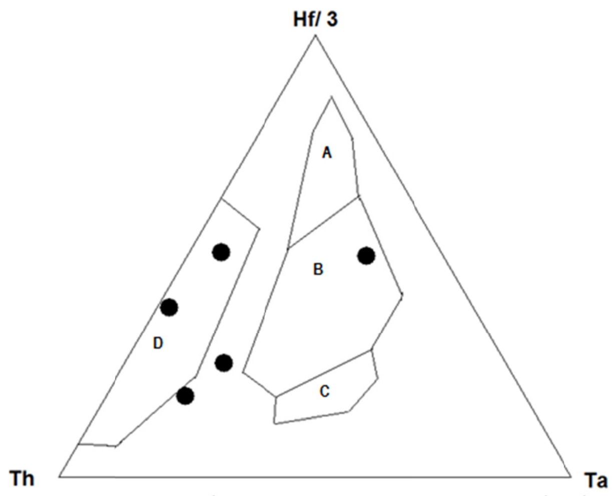

Figure 9. The Th-Hf/3-Ta discrimination diagram (after Wood, 1980)

A: N-type MORB, B: E-type MORB and within-plate tholeiites, C: Akaline within- plate basalts, D: Volcanic-arc basalts

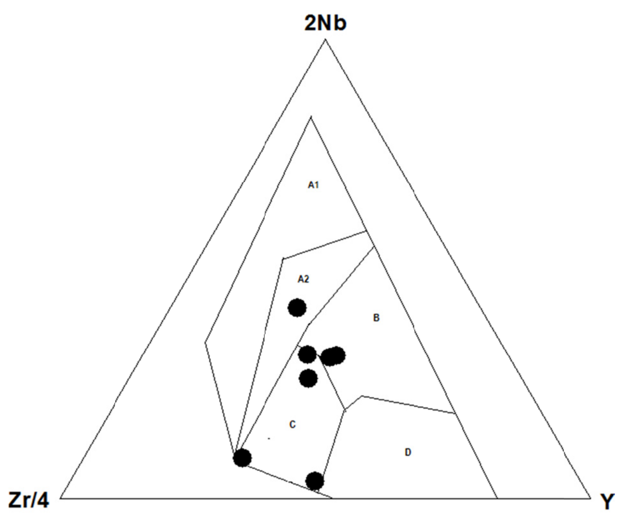

Figure 10. The Zr-Nb-Y discrimination diagram for basalts (after Meschede, 1986).

A1: Within-plate alkali basalts, A2: Within-plate alkali basalts and within-plate tholeiites, B: E-type MORB, C: Within-plate tholeiites and volcanic-arc basalts, D: N-type MORB and volcanic-arc basalts.

4. Conclusions

The amphibolites of the Ifewara area in the Ife-Ilesha schist belt belong to the Precambrian basement complex of southwestern Nigeria, which consist of Archean to Early Proterozoic migmatite gneissic-quartzite complex that bear the imprint of early to late Precambrian metamorphic episodes. Petrographic and petrochemical data were used to constrain the nature and genesis of the Ifewara amphibolites. Geochemical data showed that the protoliths of the amphibolites were tholeiitic basalts which were emplaced in a rifted crust within an environment of active sedimentation. The Ifewara amphibolite in the Ilesha schist belt has been shown to mark possible site of an oceanic basin, although there is no evidence for a mantle-derived magmatic arc, such that any subduction, if present, must have been short lived and failed to generate calc-alkaline magmas (Bother & Grobler, 1979). The geochemical data agrees with derivation of the magmas of the amphibolites from upper mantle melting. The observed shearing of the amphibolites is not unconnected with the Ifewara fault which provided the pathway for the magma. The fault could have been responsible for magma upwelling from the mantle and subsequent contamination and emplacement of the magma in a Within-plate tectonic setting.

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