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Geology and Geochemistry of Some Crystalline Basement Rocks in Ilesha Area, Southwestern Nigeria: Implications on Provenance and Evolution

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Abstract. Geological and geochemical study of the basement complex rocks in Ilesha schist belt revealed that amphibolite, hornblende gneiss and granite gneiss are the major constituents. The gneisses are composed of similar rock forming silicates with variations in abundance. The amphibolite being a mafic rock has different compositions, containing abundant pyroxene, actinolite and tremolite. Monazite is present in the mineralogy of all these rocks. Chemical composition of these rocks revealed that they are petrogenetically related. Geochemical diagrams, plotted from chemical composition of these rocks, REE fractionation trends and presence of monazite in their mineralogy reveal that all these rocks were derived from a mixed magma source which did not originate from a pure upper mantle, but possibly from a back arc tectonic setting. The pattern of the REE, progressively increasing negative Eu/Eu* anomaly, La_N/Yb_N from the amphibolite to the granite gneiss and marked Eu depletion tend to implicate evolution through fractionation of a mixed basaltic magma to form the precursor of these rocks. The amphibolite probably represents the sample of the original basaltic magma.

Keywords: basement complex, Petro-genesis, magma, tectonic setting, fractionation, precursor Ilesha

Introduction

Geology of Nigeria and Ilesha area have been well documented (Oyinloye, 2005, 2004, 2002, 2001, 2000 and 1988; Rahaman *et al.*, 1988; Ajibade *et al.,* 1987; Elueze, 1982; Ajayi, 1981), Briefly, Nigeria lies approximately between latitude 4° N and 15° N and longitudes 2° E and 14° E within the Pan African (600 ± 150 Ma) mobile belt, between the West African and Congo Cratons (Akande, 1991; Odeyemi, 1981). The two major rock groups in Nigeria are the Precambrian - Phanerozoic crystalline rocks and Cretaceous to recent sedimentary rocks, both occurring almost in equal proportions (Rahaman *et al.,* 1988). The Precambrian rocks occur in the western half of the country, while the Phanerozoic rocks occur in the eastern and north central parts of Nigeria. The Precambrian rocks consist of migmatite - gneiss - complex and ancient metasediments dated Archean - Early Proterozoic (Ajibade *et al.,* 1987).

In Ilesha area, the Precambrian basement complex is made up of crystalline rocks which are amphibolite, hornblende gneiss, granite gneiss and the Pan-African granite. Other rocks include schistose metasediments which are biotite schist, quartzite, and quartz-muscovite schists (Fig.1).

On the basis of geological, petrological and geochemical studies, the following evolutionary models have been put forward for the Precambrian basement complex in Ilesha area of southwestern Nigeria:

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i. Evolution through accumulation of ensialic continental processes (Olade and Elueze, 1979).
ii. Evolution in ocean floor and Island arc (Rahaman *et al.,* 1988; Ajayi, 1981).
iii. Evolution in a back arc basin (Oyinloye, 2002).

The present study focuses attention on the geology and geochemistry of the crystalline rocks in Ilesha area with a view to explaining their provenance and evolution.

Geological setting. In Ilesha area, the basement complex rocks of interest for the purpose of this study include, amphibolite (AMP), hornblende gneiss (HBN) and granite gneiss (GRN). The amphibolite complex, which consists of the massive melanocratic and the foliated types, and the hornblende gneiss, occurs in the western section of the Ilesha schist belt (Fig. 1). The granite gneiss and older granite occur in the eastern section of the belt. An older granite intrusion and pegmatite also occur in the western section of the belt. The belt is separated by the NE trending Ifewara- Zungeru Fault (IZF) system (Fig. 1).

The massive amphibolite is a basic rock which is fine grained without any visible deformation fabric except thin colourless quartz veins in places. This amphibolite is composed of hornblende, actinolite and tremolite. In thin section, this rock is composed of (apart from the above) sphene, plagioclase, quartz, biotite, calcite, pyroxene and titanomagnetite; apatite, zircon and monazite occur as trace minerals.

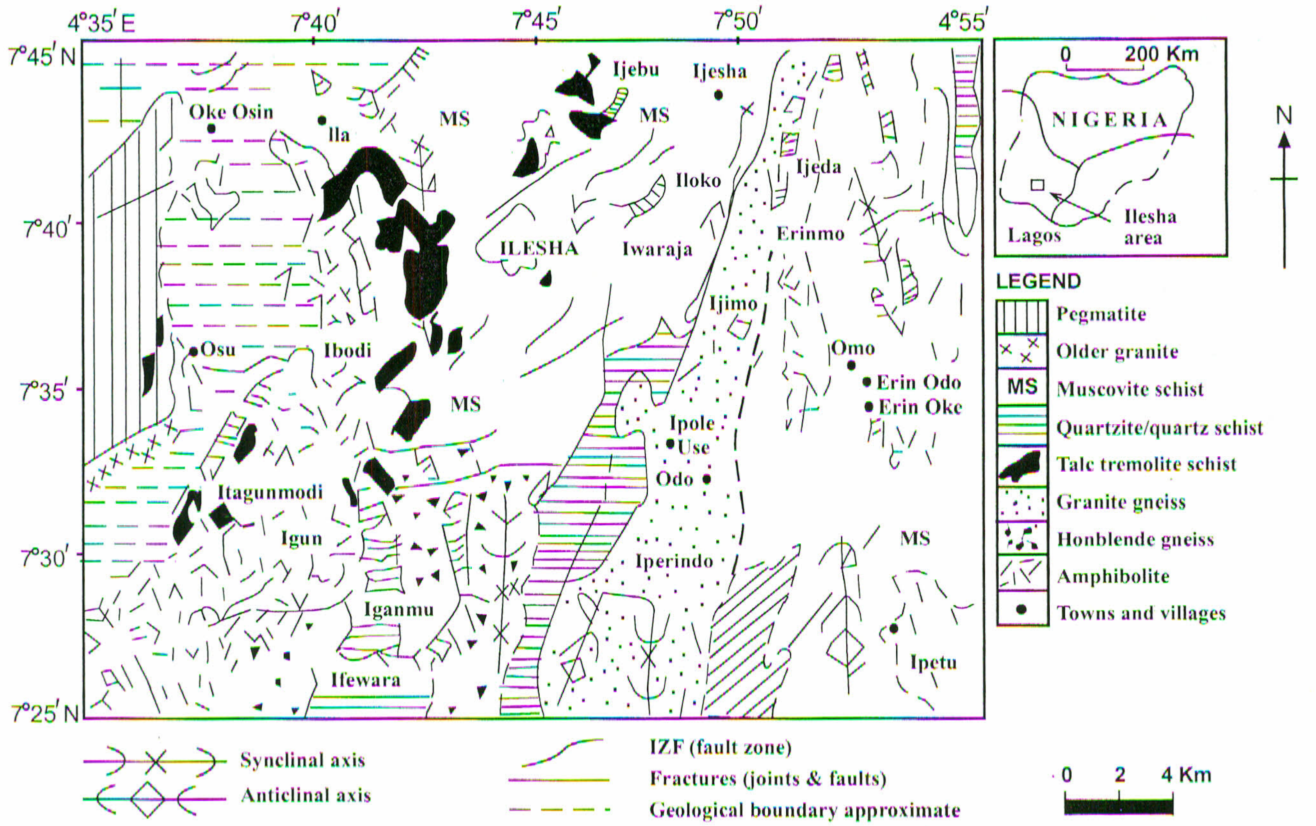

Fig. 1. Geological map of Ilesha schist belt Southwestern Nigeria (modified from Elueze, 1982).

The hornblende gneiss shares a common boundary with the massive melanocratic amphibolite (Fig. 1). This rock occurs as low lying outcrop and is composed predominantly of porphyroblastic plagioclase and hornblende phenocryst, almost in equal proportions. Deformation is depicted by prominent foliations, folds and faults on the rock. Outcrops of the hornblende gneiss trend towards North East-South West direction and dip to the west at an average angle between 50° and 70°. The apparent character of this rock is intermediate. Microbands of foliations rich in plagioclase and K-feldspar alternate with bands rich in amphiboles. In thin section, this rock is composed of hornblende and plagioclase porphyroblasts in a groundmass of ilmenite, recrystallised quartz and pyroxene fragments. Epidote, apatite, sphene and zircon constitute the accessory minerals in the hornblende gneiss. Garnet monazite, calcite, zircon and microcline occur as traces in this rock.

In Ilesha area, granite gneiss occurs to the east of the Ifewara-Zungeru Fault (Fig. 1). This is an acid rock that had been deformed by the prevalent cyclic metamorphism in the region. Major deformation fabrics on this rock group are foliations, and folds with their prominent synformal and antiformal axes. The general strike of the granite gneiss is North East-South West; it dips to the west at about 75° W on the average. At outcrop scale, the granite gneiss is composed of quartz, K-feldspar, biotite, and garnet. In thin sections, (apart from the above) zircon, hornblende, apatite, monazite, magnetite, distorted garnet, ilmenite and sphene are present.

Materials and Methods

Samples of each type of rocks, under study, were selected, crushed and milled into powder. Major and trace elements in each sample were determined, using X-ray fluorescence (XRF). Major elements were analysed on computerised XRF making use of beads prepared from the powdered rock samples. The trace elements were analysed on computerised XRF making use of pellets prepared from the powdered rock samples. The detection limits of the XRF vary from 0.009% (CaO) to 0.03% (MgO) for the major elements and from 2 ppm (Ni) to 27 ppm (Ba) for the trace elements. Rare earth elements (REE) were determined using the inductively coupled plasma source spectrometer (ICPSS). Rock samples (0.5 g of powdered rock) were first dissolved in HCl and then in HF ClO_4 (Oyinloye, 2002). The undissolved residue was fused with NaOH. Chromatographic glass columns were used for the REE separation. 20 g of resin was loaded on to columns giving a settled height of 10 cm. The REE were held quantitatively on the resin and were eluted with 500 ml of dilute HCl. The solution was then filtered and evaporated to dryness. The ICPSS used was Philips model PV8210 1.5 -m capable of evaluating spectral lines and measuring the REE concentration in each sample. Precision level attained was better than 1%.

Results and Discussion

As it is known, metamorphism often leads to mobilization of major and many trace elements. However, Zr, Ti, Cr, Ta, Rb, Ni, Hf, Y and the REEs are considered immobile under the green schist to amphibolite metamorphic grades (Kerrich, 1990; Strong and Saunders, 1988; Pearce *et al.,* 1984). In Ilesha area the grade of metamorphism is green-schist to lower amphibolite, hence some of these key trace elements and REE were used to unravel the tectonic setting and evolution of the Precambrian crystalline basement rocks in Ilesha area.

Results of the geochemical analysis of various constituents of the rocks have been summarised in the tables. Percentage share by weight of major elements and parts per million share of trace elements of melanocratic amphibolite are out-lined in Table 1, those of hornblende gneiss in Table 2 and of granite gneiss in Table 3. Absolute data for rare earth elements of the basement rock of Ilesha area is presented in Table 4.

Table 1. Major elements and trace elements in the melanocratic amphibolite of Ilesha area

SPL	AMP 1	AMP 2	AMP 3	AMP 4	AMP 5	AMP 6	AMP 7	AMP 8	XAMP
Major elements: wt%									
SiO_2	48.70	50.18	49.01	48.97	49.07	49.05	50.05	49.10	49.27
TiO_2	0.81	0.18	0.79	0.73	0.89	0.95	0.79	0.89	0.83
Al_2O_3	14.35	13.05	15.12	13.09	13.05	14.47	14.04	14.03	13.90
Fe_2O_3*	11.15	10.85	11.90	11.53	1.66	12.30	11.83	11.05	11.53
MnO	0.10	0.16	0.17	0.17	0.18	0.19	0.17	0.19	0.17
MgO	9.95	10.72	10.48	10.58	10.29	10.65	9.05	10.06	10.35
CaO	1.12	12.09	12.64	11.75	11.74	10.97	11.19	11.63	11.64
Na_2O	0.74	0.92	1.02	0.89	1.08	0.98	0.85	0.90	0.92
K_2O	0.14	0.16	0.15	0.16	0.17	0.18	0.17	0.17	0.16
P_2O_5	0.87	0.09	0.09	0.09	0..08	0.10	0.19	0.09	0.09
LOI	1.08	1.00	0.86	0.82	0.92	0.04	0.96	0.96	0.83
Total	99.01	100.60	100.44	99.78	99.13	99.70	99.29	99.07	99.75
Trace elements: ppm									Mean
Ba	22	12	30	15	30	49	31	18	26
Ni	119	107	100	102	91	85	90	80	97
Cr	72	91	108	99	85	97	79	92	90
V	200	215	210	218	230	255	264	220	227
Co	62	50	61	58	74	55	50	65	59
Rb	20	19	22	21	20	9	10	15	17
Sr	199	175	184	170	178	164	143	184	175
Y	28	27	19	20	21	20	22	20	22
Zr	54	52	60	63	67	64	48	56	58
Nb	nd	nd	nd	nd	nd	nd	nd	nd	nd
Th	2	nd	nd	nd	nd	nd	nd	nd	0.25
Ta	2	nd	nd	nd	nd	3	Nd	4	1.13
Mg^1	0.47	0.36	0.47	0.48	0.47	0.46	0.43	0.48	0.45
NCOR	11.52	11.83	12.76	12.49	12.51	11.98	12.39	11.24	12.09
K/Na	0.19	0.17	0.15	0.18	0.16	0.18	0.20	0.17	0.18
Na^+K	0.88	1.08	1.17	1.05	1.25	1.16	1.07	1.08	1.09

Mg^1 = $MgO/(Fe_2O_3+MgO)$; XAMP = mean of samples calculated with one standard deviation; LOI = loss on ignition; nd = not detected; SPL = sample

Table 2. Major elements and trace elements in the hornblende gneiss of Ilesha area

SPL	HBN 1	HBN 2	HBN 3	HBN 4	HBN 5	HBN 6	HBN 7	HBN 8	XHBN
Major elements: wt%									
SiO_2	65.62	61.79	55.81	65.71	64.87	64.12	52.94	62.92	61.72
TiO_2	0.43	0.26	0.37	0.38	0.39	0.45	0.48	0.11	0.36
Al_2O_3	15.83	14.12	9.68	15.76	16.68	13.87	8.04	14.04	13.50
Fe_2O_3	3.71	4.68	8.11	3.65	3.60	5.37	9.70	3.38	5.28
MnO_4	0.08	0.13	0.24	0.09	0.07	0.11	0.28	0.12	0.14
MgO	1.71	2.58	4.53	1.73	1.32	2.59	5.12	1.50	2.64
Ca_2O	4.14	8.33	13.11	4.48	3.18	6.01	15.43	6.26	03.97
Na_2O	4.78	2.89	2.87	4.55	5.05	4.37	2.56	4.71	3.97
K_2O	3.57	3.60	2.19	3.88	3.83	3.10	1.64	3.85	3.21
P_2O_5	0.07	1.84	2.55	0.31	0.01	0.09	3.52	2.52	1.36
LOI	0.74	0.40	0.63	0.63	0.78	0.56	0.39	0.61	0.59
Total	100.68	100.62	100.09	101.17	99.78	100.64	100.10	100.02	100.39
Trace elements: ppm									
Ba	1417	1417	1240	1401	1573	1659	1448	1443	1457
Ni	21	19	20	17	36	33	38	30	27
Cr	60	69	9	8	44	72	83	22	46
V	47	50	46	35	41	44	63	77	50
Co	49	44	39	59	39	42	39	36	43
Rb	83	80	47	73	86	78	65	32	68
Sr	1331	1345	949	1060	1298	1455	1167	1158	1220
Y	16	19	51	42	21	14	21	68	32
Zr	57	64	122	84	89	74	123	146	95
Nb	12	8	16	30	27	16	nd	nd	14
Th	nd	nd	7	1	nd	1	1	nd	
Ta	1	7	nd	nd	4	5	4	nd	1
NCOR	1.31	1.03	nd	0.84	1.32	0.80	nd	nd	3
K/Na	0.75	1.25	0.76	0.85	0.76	0.71	0.64	0.82	0.7
Na^+K	8.35	6.49	5.06	8.43	8.88	7.47	4.20	8.56	7.18
Mg^I	0.32	0.36	0.36	0.32	0.27	0.33	0.35	0.31	0.33

XHBN = average concentration of elements in the samples; Mg^I = MgO /(Fe_2O_3+MgO); HBN = hornblende gneiss; LOI = loss on ignition; nd = not detected; SPL = sample

According to Pearce *et al.* (1981), Ti versus Zr diagram (Fig. 2) can be used to distinguish between mid-ocean-ridge basalts (MORB), volcanic arc larvas, and within plate basalts (WPB). When samples of the amphibolites are plotted on a Ti versus Zr diagram (Fig. 2), all samples plot in the arc lava field.

On the plot of Ti, Zr and Y (triangular plot) for the AMP, the samples plot between DB and A fields indicating that the AMP samples are island arc/back arc basalts formed within plate (ocean and continental side) (Fig. 3).

Fig. 4 shows the plot of Ti versus Zr for the massive melanocratic amphibolites in which majority of the samples plot in A field and few in the B field, indicating that the amphibolite is a low-potassium tholeiite of an ocean affinity. The plot of amphibolite on Ti versus Cr diagram shows that the amphibolite is an island/back arc tholeiite (Fig. 5). Fig. 6A shows the normative corundum versus mol.Al_2O_3/Na_2O +K_2O+CaO plot for classification of I-Type and S-Type of igneous rocks. The HBN samples and the GRN samples mostly plot in the S-Type field with few samples plotting in the I-Type field implying a sedimentary source for the precursor of these rocks. However Fig. 6B shows that both HBN and GRN plot in both S-Type and I-Type fields. The HBN samples plot has a mode in the I-Type field while the GRN has a mode at the

Table 3. Major elements and trace elements in the granite gneiss of Ilesha area

SPL	GRN 1	GRN2	GRN 3	GRN4	GRN5	GRN6	GRN7	GRN 8	XGRN
Major elements: wt %									
SiO_2	74.40	73.45	74.62	74.50	75.36	74.60	74.72	75.50	74.64
TiO_2	0.09	0.45	0.08	0.10	0.11	0.12	0.12	0.10	0.15
Al_2O_3	14.75	14.40	14.50	13.35	14.01	14.15	14.62	13.85	14.20
Fe_2O_3	1.48	1.38	1.45	1.35	1.32	1.30	1.20	1.42	1.36
MnO	0.06	0.03	0.02	0.01	0.01	0.02	0.05	0.01	0.03
MgO	0.04	0.03	0.08	0.07	0.05	0.06	0.05	0.03	0.02
CaO	0.78	0.51	0.62	0.52	0.44	0.51	0.40	0.62	0.55
Na_2O	2.55	2.48	2.30	2.25	2.27	2.28	2.25	2.60	2.37
K_2O	5.24	6.00	5.61	6.75	5.82	6.35	5.55	4.98	5.79
P_2Q_5	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.02
LOI	0.40	0.52	0.30	0.64	0.38	0.79	0.54	0.83	0.55
Total	99.80	99.27	99.59	99.56	99.78	100.19	99.52	99.96	99.71
Trace elements: ppm									
Ba	215	249	130	151	285	147	176	200	194
Ni	10	13	19	15	10	11	11	10	13
Cr	12	10	15	11	20	21	22	21	17
V	40	10	14	10	15	11	10	10	15
Co	35	25	30	18	21	10	15	20	22
Rb	182	162	180	180	178	190	180	190	180
Sr	68	73	72	70	70	85	59	72	71
Y	19	20	19	21	25	26	27	21	22
Zr	110	135	113	112	108	118	120	121	117
Nb	6	4	5	20	21	22	23	36	17
Th	42	50	54	50	48	30	30	31	42
Ta	6	5	3	4	6	5	2	1	4
NCOR	1.70	2.54	1.61	1.15	0.64	1.91	1.93	1.46	1.62
K/Na	2.06	2.42	2.44	2.65	2.56	2.80	2.47	1.92	2.41
Mg^1	0.03	0.02	0.05	0.04	0.04	0.04	0.04	0.02	0.04

GRN = granite gneiss; SPL = sample; NCOR = normative corundum; Mg^1 = $MgO/(Fe_2O_3K+MgO)$; Fe_2O_3 = total iron as Fe_2O_3; XGRN = mean of samples calculated with 1 standard deviation; LOI = loss on ignition

S-Type field indicating a mixed magma source for the precursor of these rocks.

On the plot of AMP samples on a chondrite normalized REE against their atomic numbers (Fig. 7), the AMP shows an essentially flat pattern with a very slight Eu depletion. The Eu depletion is an evidence of feldspar fractionation however small. On the same plot (Fig. 7) hornblende gneiss REE chondrite normalized plots progressively decline towards Lu with a more pronounced Eu depletion. Both amphibolite and hornblende have a well developed negative Eu/Eu^* anomaly (Fig. 7), indicating fractionation of plagioclase. The seemingly smooth transition from basic to intermediate-acid plutonic rocks is reflected in the gradational increase in the negative Eu/Eu^* anomalies from the amphibolite to the hornblende gneiss and to the granite gneiss. The average La_N/Yb_N ratios vary from amphibolite to the hornblende gneiss (Fig. 7). According to Feng and Kerrich (1990) La_N/Yb_N ratios less than 5 is an evidence of derivation from a source with little differentiation while high values of this ratio signify differentiation; the higher the value of La_N/Yb_N ratio the higher the differentiation of the source. In Figure 7D, the La_N/Yb_N ratio has decreased to 9.62 in the GRN which indicates the last stage of differentiation.

Note that in the amphibolite La_N/Yb_N is less than 5 indicating derivation from undifferentiated source. Hence the amphibolite represents sample of the original basaltic magma. Gener-

Table 4. Absolute data of rare earth elements in the basement rocks of Ilesha area

SPL	AMP 1	AMP 2	AMP3	XAMP	HBN1	HBN2	HBN3	XHBN
La	15	12	13	13.33	550	760	870	727
Ce	14	15	15	14.67	970	1430	978	1126
Pr	13	14	15	14.00	90	1060	840	663
Nd	13	12	15	13.33	300	129	102	177
Sm	10	10	10	10.00	40	490	317	282
Eu	2.5	2.5	2.4	2.47	4.7	6.4	4.0	5.03
Gd	5	5	3	4.33	24	13	19	18.67
Dy	3	4	5	4.00	12	36	25	24.33
Ho	0.7	0.8	0.6	0.70	1.95	2.7	3.13	2.59
Er	1.9	2.0	1.8	1.90	6	3.45	2.8	4.03
Yb	1.7	1.8	1.7	1.73	3	10	15	9.33
Lu	0.2	0.3	0.2	0.23	2.11	4	3.11	3.07
Total	80.00	79.5	82.70	80.73	2003.76	3944.55	3204.24	3050.85
LREE	67.5	65.5	10.40	67.80	1954.70	3875.40	3111	2980.37
HREE	12.5	13.9	12.30	12.90	49.06	69.15	93.24	70.48
LREE/HREE	5.40	4.71	5.72	5.28	39.84	56.04	33.37	43.08

SPL = sample; AMP = melanocratic amphibolite; HBN = hornblende gneiss; GRN = granite gneiss; LREE = light rare earth elements; HREE = heavy rare earth elements; XAMP, XHBN = mean of samples calculated with one standard deviation

ally these data show that these rocks are petrogenetically related and derived from same mixed magmatic source.

Provenance. The compatible elements' concentrations in these rocks (Ni, Cr, Co,) which are extremely lower than those from a pure primitive upper mantle source indicates that the protoliths of these rocks are from a metasomatised mantle. Occurrence of monazite in the mineralogy of the rocks amphibolite, hornblende gneiss and granite gneiss indicates that crustal/sedimentary materials were prominent in the original magma from which the protholiths of these rocks were formed. Enrichment of these rocks in REE is an indication that they are not pure mantle basalts. According to Thompson

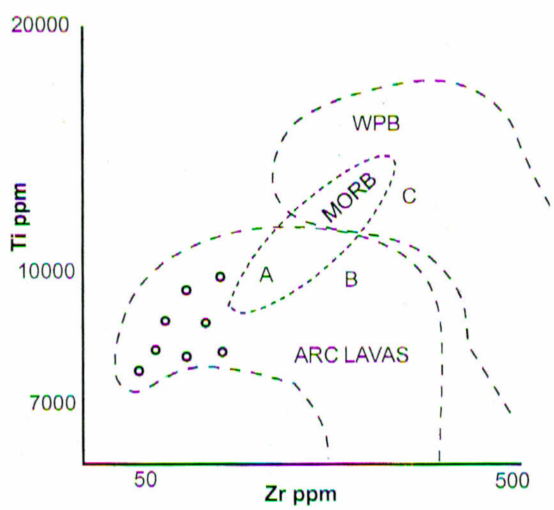

Fig. 2. Plot of Ti against Zr for the massive melanocratic amphibolite in Ilesha area. A = mid-ocean ridge basalt (MORB) field; B = arc lava field; C = within plate basalt (WPB) (Pearce *et al.*, 1981)

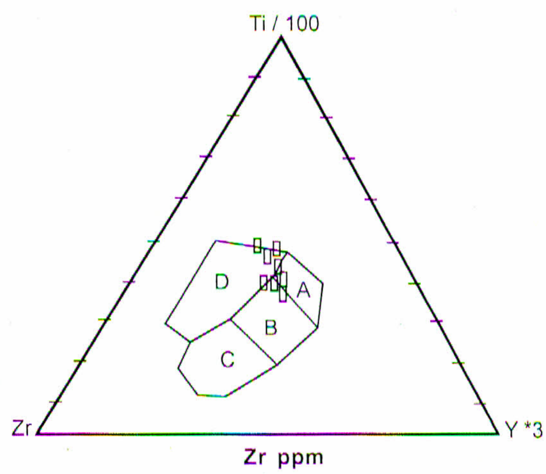

Fig. 3. Discrimination diagram using Ti, Zr and Y for the massive amphibolite (AMP); B = ocean floor basalt field; A and B = island arc basalts fields; Band C = calk alkali basalt fields; D = within plate basalt field (i.e. ocean island or continental basalts) (Pearce and Cann, 1973).

et al. (1984), LREE enrichment in basalt is attributed to a melt enriched by subducted ocean lithospheric materials. Disrimination diagrams (Fig. 2, 3, 4, 5 and 6) for these rocks show that these rocks are from a volcanic and subduction tectonic environment, possibly a back arc setting where an ocean slab had been subducted into the mantle to form a mixed magma

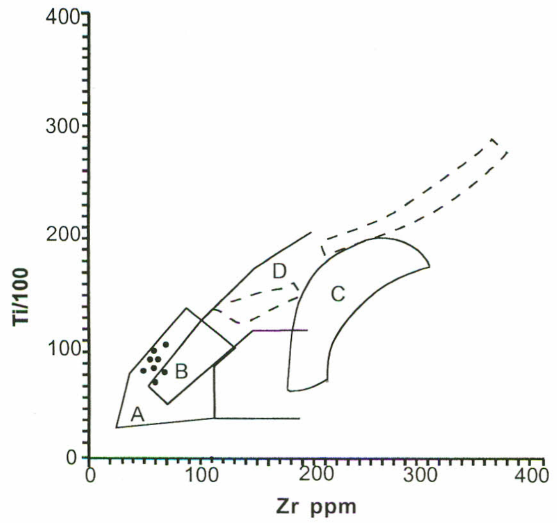

Fig. 4. Plot of Ti/100 versus Zr for the massive amphibolite. Fields A and B are for low potassium tholeiites; D and B are ocean basalt field; C and B are Calk-alkali basalts fields (Pearce and Cann, 1973). Broken line and solid line curves, according to Strong and Saunders (1988).

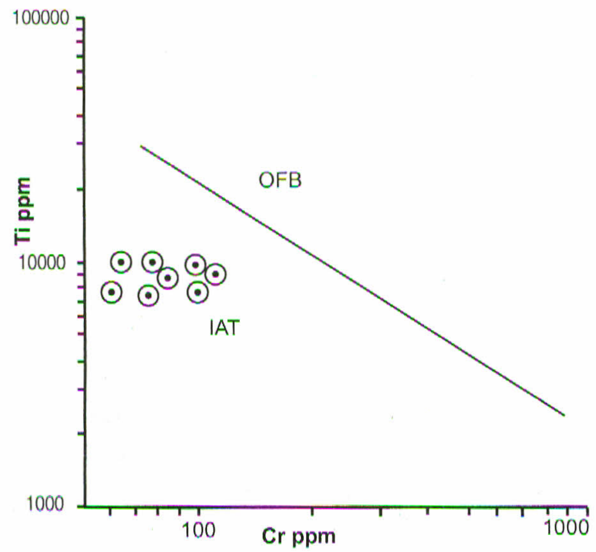

Fig. 5. Plot of Ti versus Cr for the massive amphibolite; IAT = Island Arc tholeiites; OFB = ocean floor basalts (Pearce and Cann, 1973).

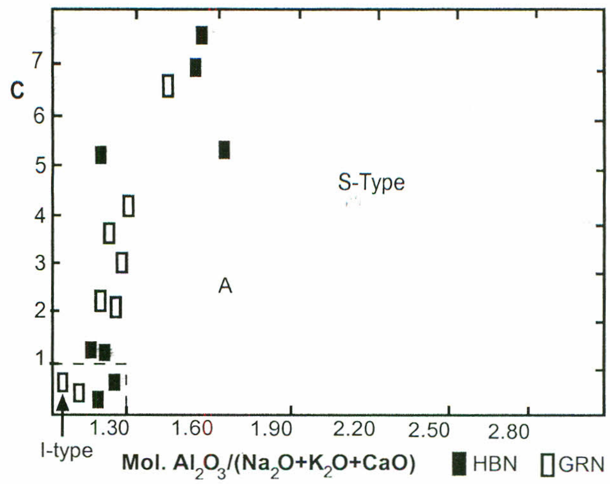

Fig. 6A. Normative corundum versus mol. $Al_2O_3/(Na_2O+K_2O+CaO)$ for classification of I-type and S-type igneous rocks.

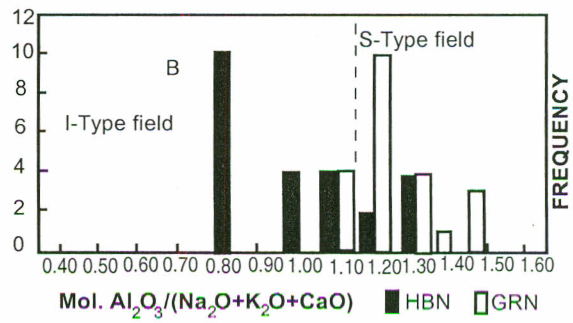

Fig. 6B. Histogram of mol. $Al_2O_3/(Na_2O+K_2O+CaO)$ distribution for the hornblende gneiss (HBN) and granite gneiss (GRN).

(Oyinloye, 2002). This is at variance with Olade and Elueze (1979) in which a crustal rifting graben was suggested as the tectonic setting of these rocks. Also from the above discussion, an ocean floor tectonic setting (primitive mantle), suggested by Rahaman *et al.* (1988) and Ajayi (1981) for the Ilesha crystalline rocks, is an unlikely scenario.

Evolution. Fig. 7 shows the chondrite normalized REE for the amphibolite (basic rock), hornblende gneiss (intermediate rock) and granite gneiss (acid rock). These REE curves show a progressively increasing negative Eu/Eu* anomaly from the amphibolite to the granite gneiss. The REE pattern shown by the AMP seems to reflect a transition from a flat volcanic REE pattern to stepped plutonic patterns. It appears therefore, that the granite gneiss (developed from S-type granites precursor rock) evolved from a basaltic magma, through progressive fractionation of the initial basaltic magma. The geotectonic environment was a volcanic setting probably a back arc. The

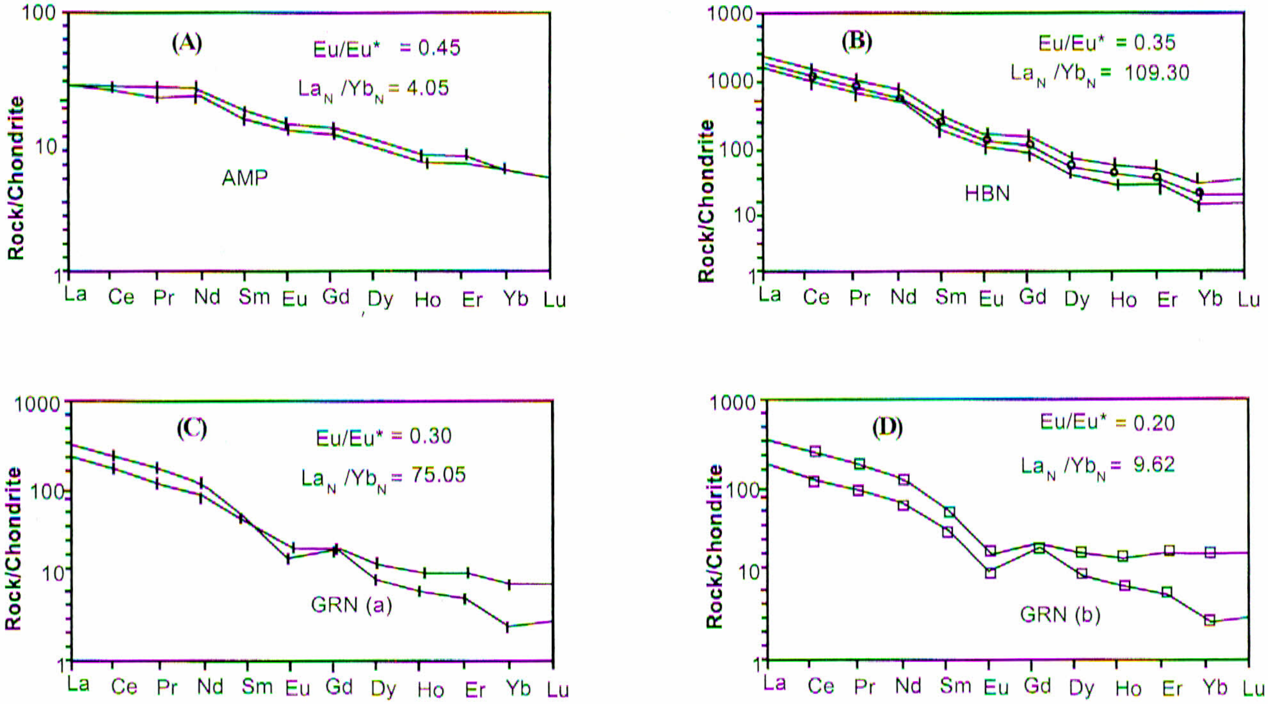

Fig. 7. Chondrite normalized REE patterns for AMP, HBN, GRN from the Ilesha schist belt southwestern Nigeria.
(**A**) AMP chondrite normalized REE patterns showing essentially flat patterns, slight Eu depletion and low La_N/Yb_N implying little or no differentiation.
(**B**) HBN chondrite normalized REE patterns showing high LREE, low HREE, stepped patterns and moderate Eu depletion and very high La_N/Yb_N showing high differentiation.
(**C**) GRN (a) chondrite normalized REE patterns showing high LREE, low HREE, pronounced Eu depletion and high La_N/Yb_N showing very high differentiation of the source.
(**D**) GRN (b) chondrite normalized REE pattern showing high LREE, low HREE, high Eu depletion and moderate La_N/Yb_N showing little differentiation (last magmatic phase). These rocks show a progressively increasing Eu depletion from AMP to GRN (A-D). La_N/Yb_N shows an increase from AMP to HBN, and decrease from HBN to GRN. These trends probably suggest a possible differentiation trend implicating evolution through magmatic differentiation of a basaltic magma.

amphibolite possibly represents a sample of the basaltic parental magma. The combined REE plots in Fig. 7 show a possible differentiation trend considering mineralogical sequence.

Conclusion

On the basis of geology, petrology and geochemistry of the amphibolite, hornblende and granite gneiss, the crystalline rocks in Ilesha area are genetically related. These rocks are formed in a back arc basin where a mixed initial magma (from crustal and mantle sources) was formed. The amphibolite precursor rock represents the parent basaltic magma. These rocks evolved by progressive differentiation of the parent basaltic magma to give rise to the protoliths of the hornblende gneiss and the granite gneiss as shown in Fig. 7. Postmagmatic transpresive forces operating in this region were responsible for turning the protoliths of these crystalline rocks into metamorphic rocks.

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