GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 7, NO. 1 JANUARY 2001:85 - 90
 ISSN 1118-0579

THE GEOCHEMISTRY, TECTONIC SETTING AND ORIGIN OF THE MASSIVE MELANOCRATIC AMPHIBOLITE IN THE ILESHA SCHIST BELT, SOUTHWESTERN NIGERIA

AKINDELE O. OYINLOYE and IDOWU B. ODEYEMI

(Received 26 January, 2000; Revision accepted 7 July, 2000)

ABSTRACT

A massive melanocratic amphibolite, (MMA) occurs in Ilesha schist belt within a series of muscovite schists and amphibolite gneiss. Though metamorphosed, MMA shows no obvious textural deformation. Actinolite, tremolite, hornblende and biotite constitute the major minerals in MMA. Minor minerals in MMA include calcite, plagioclase and pyroxene while monazite, zircon and apatite form the accessory minerals. Chemical studies revealed that MMA contains low K_2O and Na_2O. Its Mg[1], Cr and Ni contents are considerably lower than those of similar basalts derived from purely primitive mantle. Enrichment of LREE, negative Eu/Eu* anomaly and occurrence of monazite in its mineralogy are all indications that the precursor magma of MMA contains a sedimentary imput. The plots of immobile trace (Zr,Ti, Nb, Y) and rare earth elements during the greenschist-amphibolite metamorphic grade for MMA show that it was derived from a low-K-Tholeiitic magma in a volcanic geotectonic setting (back arc basin).

INTRODUCTION

The petrology and geochemistry of units within the schist belts have been well studied, especially the amphibolite complexes. Most workers were of the opinion that the amphibolites were derived from an igneous parentage (e.g Bafor and Karamata 1981, Ajayi 1981) rather than a sedimentary source. Olade and Elueze 1979, Klemm et al., (1979) and Ajayi (1981), further described the Ilesha amphibolite as metabasalts which are tholeiitic in nature and related to Ocean Floor Island Arc environment.

The Ilesha schist belt is separated into two dissimilar lithological units by the major Ifewara-Zungeru Fault system (IZF Fig 1). The massive melanocratic amphibolite (which is the subject of this paper) occurs at the western flank of the IZF sharing a common boundary with hornblende gneiss while a granite gneiss terrain occurs in the eastern part of the belt (Fig. 1). The amphibolite complex consists of massive melanocratic and leucocratic types.

Although these rocks have attracted some attention because of the associated alluvial gold, their origin is yet to be completely understood or satisfactorily explained.

In this study the petrology, geochemistry and tectonic setting of the massive melanocrattic amphibolite are examined to determine its magma type, origin and environment of deposition.

FIELD OCCURRENCE AND PETROGRAPHY

The massive melanocratic amphibolite (MMA) occurs in the western section of the Ilesha schist belt (Fig.1) as darkish green and fine grained rock with no obvious folds or foliations. In places thin quartz veins occur in outcrops. In thin section this amphibolite is composed mostly of actinolite, tremolite and hornblende. Plagioclase feldspar, biotite and pyroxene form minor components. The accessory minerals in the MMA include monazite, zircon, calcite and apatite. Polished

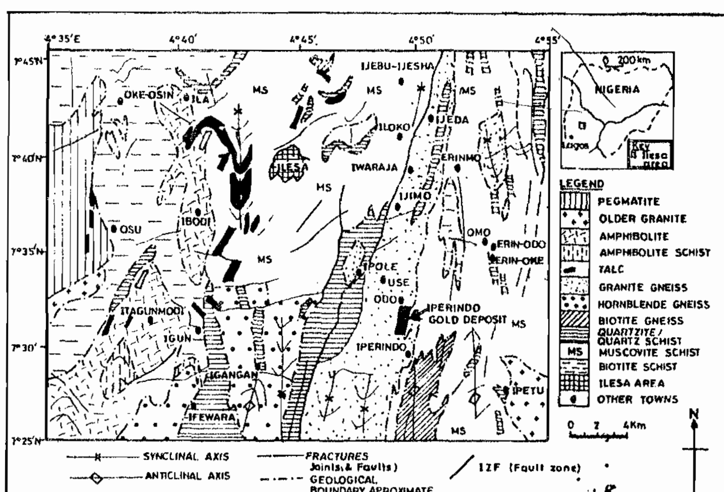

FIG. 1: Generalised geological map of Ilesa schist belt southwestern Nigeria (after Elueze 1982)

AKINDELE O. OYINLOYE, Department of Geology, University of Ado- Ekiti, Nigeria
IDOWU B. ODEYEMI, Department of Applied Geology, Federal University of Technology, Akure, Nigeria

thin section revealed that the opaque minerals in the MMA are mostly illmenite, magnetite, pyrite, chalcopyrite and pyrrhotite.

METHODS OF ANALYSIS

Major and trace elements were analysed using conventional X-Ray Fluorescence glass beads and rock powder pellets for the trace elements. The detection limits for the XRF used for these analyses vary from 0.0008% (Ca) to 0.03% (Mg) for the major elements and from 2 ppm(Ni) to 27-ppm(Ba) for the trace elements. REE analyses were carried out at the Department of Geology, Royal Holloway and Bedford New College, University of London, Surrey. The analyses were carried out using the Inductively Coupled Plasma Source Spetrometry (ICPSS). The procedures followed for the analyses are as outlined by Walsh et al., (1982) with precisions between ± 5% to ± 10% (Walsh pers. comm, 1991).

RESULTS AND DISCUSSIONS

Major and trace elements in the MMA are reported in Tables 1A and 1B. It is observed that (unlike other rocks in this belt) elements in the MMA samples vary little even between samples collected from outcrops almost one kilometre apart. Some trace elements considered immobile during metamorphism are used in determining the tectonic setting of the melanocratic massive amphibolite in Ilesha schist belt. The total alkaline composition of the MMA is very low (about 1%) and Na_2O concentrations are consistently higher than the K_2O in the MMA suggesting that plagioclase (albite) appears to be the dominant feldspar. Mg' i.e. MgO/Fe_2O_3 + MgO' ratios vary between 0.45 to 0.48 with a mean of 0.46 (Table 1B). This is considerably lower than that of a primitive upper mantle which has a range of 0.68-0.75 and a mean of 0.70 according to Wilson (1991).

Geotectonic Setting.

An amphibolite can be of igneous or sedimentary in origin. Zr/Ti ratios versus Ni plot can be used to discriminate between amphibolite from sedimentary and igneous sources. The Zr/Ti ratios calculated for the MMA in this study are nearly constant and plot the igneous field (Fig.2), implying an igneous source or at least contains a major igneous precursor. Distinguishing tectonic environment of igneous rocks are often based on fresh samples of volcanic rocks. The application of this method, though valid for medium grade metamorphic rock, should be interpreted with caution. It has been observed that metamorphism often lead to mobilisation of major elements and many trace elements. However Zr, Ti, Nb, Cr, Ta, Ni, Hf, Y and the REE are considered immobile under the green schist to amphibolite grades, Strong and Sanders (1988), which are grades of

Table 1A. Major (wt.%) and trace element (ppm) chemical analyses for the melanocratic massi amphibolite (MMA) from the Ilesha schist belt southwestern Nigeria.

SPL	MMA1	MMA2	MMA3	MMA4	MMA5	MMA6	MMA7	MMA8	MM
SiO_2	49.50	48.95	48.80	48.81	48.85	49 51	48.27	49.06	48.
TiO_2	0.76	0.91	0.95	0.77	0.96	0.79	0.86	0 10	0
Al_2O_3	14.94	14.61	14.66	14.94	14.83	15.12	14.49	14.34	13.
Fe_2O_3	10.61	11.20	10.92	10.74	11 58	10.83	11.98	11.63	12.
MnO	0.16	0.17	0.17	0.16	0.17	0.16	0.16	0.17	0
MgO	9.65	9.63	9.81	9.63	9.48	9.35	9.70	9.49	9
CaO	12.21	12.16	12.31	12.29	11.87	12.22	12.09	12.1(	12
K_2O	0.85	0.67	0.01	0.85	0.95	0.65	0.65	0.60	0.
Na_2O	0.16	0.15	0.16	0.16	0.16	0.15	0.14	0 15	0.
P_2O_5	0.09	0.09	0.07	0.07	0.09	0.08	0.09	0.10	0
LOI	0.76	0.93	0.95	0.95	0.81	0.90	0.82	0.92	0
Total	99.69	99.47	99.81	99 37	99.75	99.76	99.25	98.72	100.
Ba	17	26	152	22	14	39	38	12	2[illegible]
Ni	106	111	101	105	103	100	111	102	10
Cr	80	81	102	71	82	.81	60	96	7(
V	212	215	223	245	218	235	220	247	23
Co	46	57	51	58	46	45	59	55	5[illegible]
Rb	15	9	9	12	10	7	10	12	9
Sr	176	194	166	121	173	160	171	139	152
Y	19	21	19	15	15	20	17	19	21
Zr	55	54	60	49	58	66	54	55	66
Nb	nd	nd	1	1	1	3	nd	nd	nd
Ta	nd	2	3	nd	2	6	nd	nd	nd
Th	nd	2	nd	nd	1	nd	nd	1	2
Mg'	0.48	0.46	0.47	0.47	0.45	0.46	0.45	0.45	0.45
K/Na	0.20	0.22	0.20	0.20	0.20	0.23	0.22	0 30	[illegible]
Na+K	1 01	0.82	1.17	1 01	1.11	0.80	0 79	0 75	1 03

MMA - massive melanocratic amphibolite: Fe_2O_3 = total Fe as Fe_2O_3 ,
LOI = Los on ignition: SPL = Samples:

Table 1A. Contd. Major (wt.%) and trace element (ppm) chemical analyses for the melanocratic mass amphibolite (MMA) from the Ilesha schist belt southwestern Nigeria.

SPL	MMA10	MMA11	MMA12	MMA13	MMA14	MMA15	MMA16	MMA17	M
SiO_2	49 35	49.38	48.91	49.38	50.01	48.97	49.45	49.13	4
TiO_2	0.81	0.88	0.77	0.87	0.69	0.90	0.79	0.79	
Al_2O_3	13.70	14.04	14 82	14.69	14.95	14.67	15.48	15.03	1
Fe_2O_3	12.15	11.58	10.90	11.43	10.56	11.30	10.33	10.95	1
MnO	0.18	0.17	0.16	0.17	0.16	0.17	0.16	0.17	
MgO	10 12	9.92	9.58	9.58	9.29	9.65	8.85	10.06	
CaO	11.95	12.06	12.09	12.15	12.14	12.17	12.19	12.23	1
K_2O	0.64	0.72	0.92	0.99	1.17	0.78	0 95	0.70	
Na_2O	0.07	0.16	0.17	0.18	0.18	0.16	0.16	0.16	[illegible]
P_2O_5	0 83	0.08	0.08	0.09	0.01	0.10	0.09	0.07	[illegible]
LOI	1 08	1.00	0.96	0.92	0.82	0.84	0.76	0.86	[illegible]
Total	100.38	99.99	99.36	100.45	99.98	99.71	99.21	100.15	10[illegible]
Ba	24	14	29	14	34	149	31	4	3
Ni	109	101	103	92	101	95	97	96	1[illegible]
Cr	73	84	101	74	78	77	59	72	1[illegible]
V	207	216	213	223	236	261	249	219	2[illegible]
Co	52	50	51	48	64	50	55	54	7
Rb	19	11	11	10	10	9	10	14	1
Sr	189	185	225	172	174	154	133	174	18
Y	18	17	19	22	22	23	22	18	17
Zr	52	54	57	62	57	68	58	51	59
Nb	nd	nd	nd	nd	nd	nd	nd	nd	nd
Ta	2	nd	nd	nd	nd	nd	nd	nd	nd
Th	2	nd	nd	nd	nd	5	nd	6	1
Mg'	0.45	0.47	0.46	0.42	0.46	0.46	0.48	0.47	0.4
K/Na	0.11	0.22	0.20	0.20	0.15	0.21	0.20	0.23	0.2
Na+K	0.7	0.88	1.09	1.17	1.35	0.94	1.11	0.86	0.9

MMA - massive melanocratic amphibolite: Fe_2O_3 = total Fe as Fe_2O_3 ,
LOI = Los on ignition: SPL = Samples:

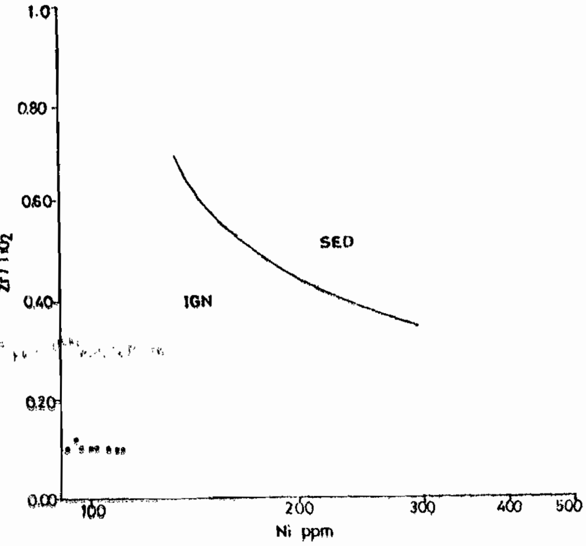

Fig. 2. Plot of Zr/TiO_2 against Ni for the massive melanocratic amphibolite ir Ilesha schist belt Southwestern Nigeria.

IGN = IGNEOUS FIELD
SED = SEDIMENTARY FIELD

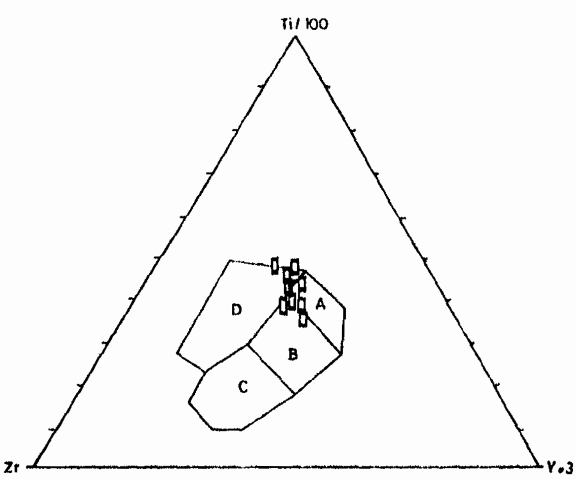

Fig. 3. Discrimination diagram using Ti, Zr and Y for the massive melanocratic amphibolites in Ilesha Schist Belt Southwestern Nigeria
B = Ocean floor basalt field, A & B = Island arc basalts fields
B & C = Calk-alkali basalt fields, D = Within plate field (i.e. Ocean Island or Continental basalts, after Pearce and Cann 1973).

metamorphism in the Ilesha schist belt. In this study therefore, a combined Ti, Zr, Y, Nb and Ni discrimination diagrams and REE fractionation trends were used to identify magma type and tectonic setting for the MMA.

Figure 3, shows the $Ti(10^{-2})$, Zr and Y(x3) tenary plot for the MMA. The samples plot in the A,B, and D fields (overlapping Island Arc Within Plate fields of Pearse and Cann (1973). In the Ti versus Zr plot (Fig.4) all MMA samples plot in the A field. Igneous rocks plotting in fields A and B in this diagram belong to the Tholeiitic magma group Pearce and Cann 1973), Ti/100 versus Zr diagram has been used for discrimination of magma types. The MMA samples plot in the A and B fields (Fig.5), which also suggests a low K tholeiitic magma for this rock. The plot of MMA samples on a Ti versus Zr diagram shows that all except one sample plot in the Arc Lava Field (Fig.6). These plots suggest a volcanic Island Arc tectonic setting for the MMA. Figure 7 shows triangular plot of $Px10^{-1}$ Zr and Yx2 for the MMA. These samples plot in the high Zr field which implies that the amphibolite is from a volcanic Arc of Low-K-Tholeiitic magma rich in zircon. On the plot of Ti versus Cr (Fig.8) all the amphibolite samples plot in the Island Arc Tholeiitic field (IAT) implying once more that the MMA originated from an island Arc/back Arc tectonic setting and that the precursor magma was a low-K-Tholeiite.

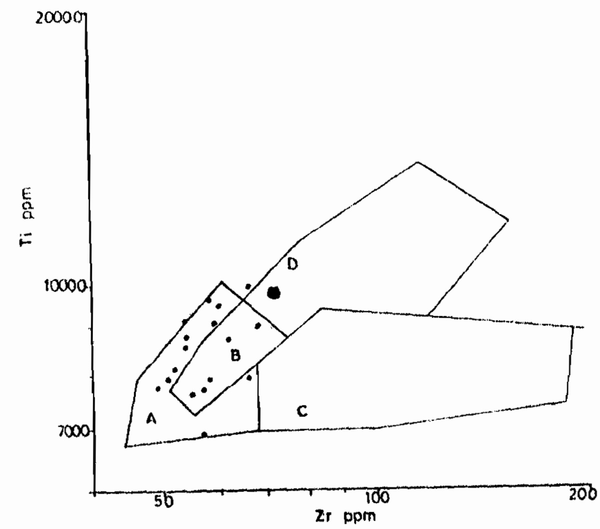

Fig. 4. Discrimination diagram using Ti, Zr plot for the massive melanocratic amphibolites in the Ilesha schist belt, Southwestern Nigeria.
D & B = Ocean floor basalts (OFB) fields
A & B = Low-potassium tholeiites (LKT) fields
C & B = Calk-alkali basalts (CAB) fields
(after Pearce and Cann 1973)

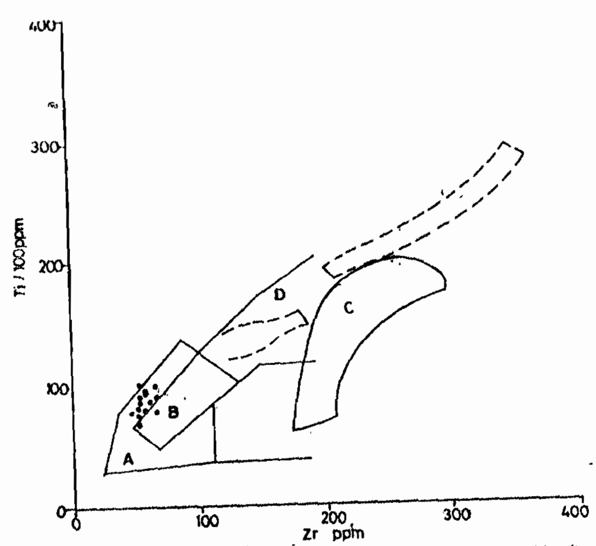

Fig.5. Plot of Ti/100 versus Zr for the massive melanocratic amphibolites in Ilesha schist belt, Southwestern Nigeria.
A & B = Low potassium tholeiites; D & B = Ocean basalt fields.
C & B = Calk-alkali basalts fields (after Pearce and Cann 1973)
Dash lines and solid curve line are after Strong and Saunders (1988).

Table 1B : Average major (Wt. %) and trace elements (ppm) chemical analyses for representative samples of the Massive Melanocratic Amphibolite (MMA) from Ilesha Area, Southwestern Nigeria.

Element	Mean	STD	No
SiO_2	49.00	0.10	18
TiO_2	0.81	0.05	18
Al_2O_3	14.69	0.11	18
Fe_2O_3	11.22	0.13	18
MnO	0.17	0.00	18
MgO	9.65	0.07	18
CaO	12.15	0.03	18
Na_2O	0.82	0.04	18
K_2O	00.16	0.01	18
P_2O_5	0.12	0.12	18
LOI	0.88	0.02	18
Total	99.77	0.12	18
Ba	37	10.38	18
Ni	102	1.32	18
Cr	18	3.23	18
V	227	3.73	18
Co	54	1.72	18
Rb	11	0.69	18
Sr	169	0.58	18
Y	19	0.58	18
Pr	58	1.29	18
Th	2	0.27	5
Ya	4	1.47	8
Nb	2	0.53	4
K/Na	0.20	0.04	18
Na+Ka	0.97	0.04	18
Ca+Na	13.13	0.05	18
Mg'	0.46	0.05	18

STD = Standard Deviation, No = Number of Samples

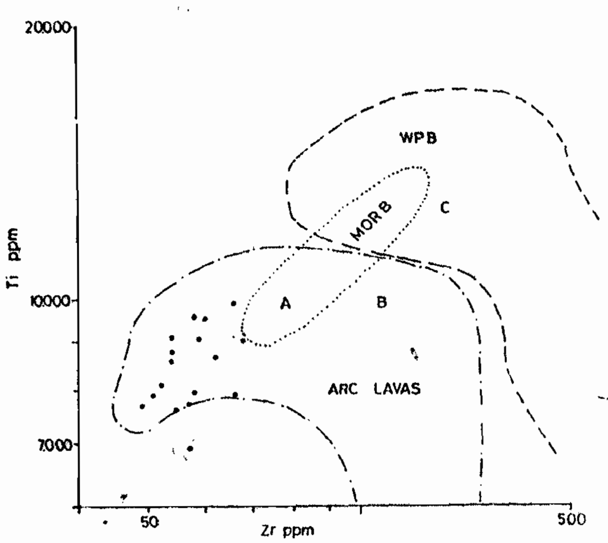

Fig.6. Plot of Ti against Zr for the massive melanocratic amphibolites in Ilesha schist belt southwestern Nigeria.
A = Mid-ocean ridge basalt (MORB) field, B = Arc lava field
C = Within plate basalt (WPB)(after Pearce et al, 1981).

Rare Earth Elements (REE).

The concentration of REE in the MMA are reported in Table 2. The Eu/Eu* negative anomaly was determined by interpolating the chondrite normalised Sm and Gd values. The extended trace elements for spiderdiagrams were normalised to the Mid-Ocean Ridge Basalts. The average total REE in the MMA is

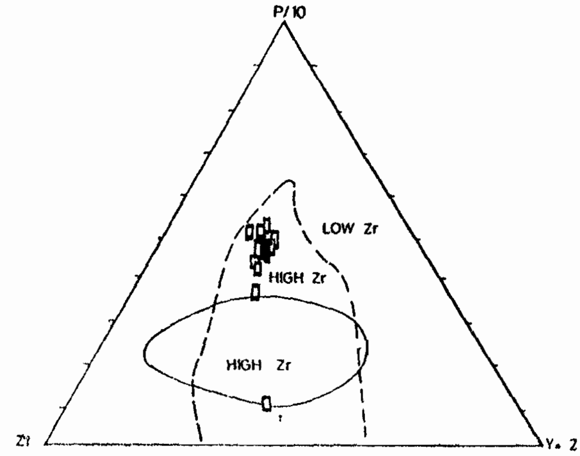

Fig. 7: Ti-Zr-Y Plot for discrimination of High & Low Zr for the massive melanocratic amphibolites in Ilesha schist belt Southwestern Nigeria. (after Strong and Saunders 1988).

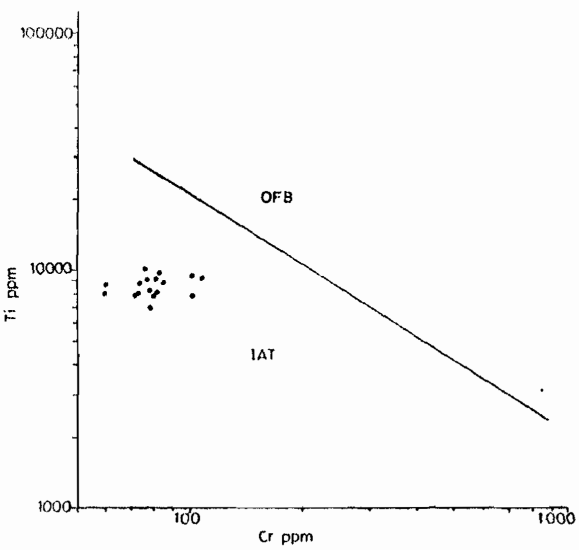

Fig.8 Plot of Ti versus Cr for the massive melanocratic amphibolites in Ilesha schist belt Southwestern Nigeria.
IAT = Island arc tholeiites, OFB = Ocean floor basalt.
(after Pearce et al 1981)

71ppm varying from 68-74ppm. Light RE (LREE) (La-Eu) have an average of 59 pp whereas the heavy REE (HREE), (Gd-Lu) ha an average concentration of 12ppm. Thus t average LREE/HREE ratio is 5 approximately

The data indicate that this rock is slight enriched in LREE compared to a typical basa which implies that the MMA is not purely igneous origin as claimed by Bafor a Karamata (1981) and Ajayi (1981). This typ of relatively high LREE enrichment in a bas has been attributed to derivation from a m enriched by subduction of ocean lithosphe materials (Thompson et al., 1984). T occurrence of monazite as observed petrology suggests a sedimentary imput i the original magma from which the rock w

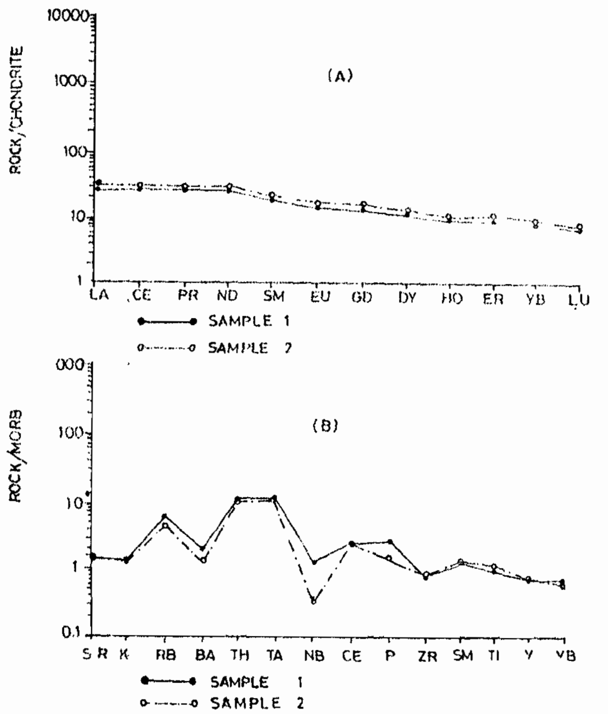

Fig.9: A= Chondrite normalized REE patterns for the massive melanocratic amphibolites (MMA).
B= Spidergram patterns for the MMA.

derived (Allan Bromley 1992 pers. comm.)

When chondrite normalised REE are plotted against their atomic numbers, the MMA shows an essentially flat pattern with very slight Eu depletion. On the average MMA has 30x. Chondrite normalized LREE level (La), 7x chondrite normalized HREE (Lu), (Fig. 9A). The MMA has a well developed Eu/Eu* negative anomaly of 0.45, with a range of 0.43-0.47 (two of the three REE samples were used for these plots to avoid clustering at a point because there is very little variation between the samples Table 2). These negative Eu/Eu* anomalies indicate that these rocks originated from a metasomatised mantle where sedimentary materials have been brought down and mixed with the mantle materials to form a heterogenous precursor magma. Ordinarily if the precursor magma was of pure mantle origin, the Eu/Eu* anomaly would be positive. The average $(La/Yb)_N$ ratios of 4.05 in the MMA is very low, which indicates derivation of rock from a source with very little differentiation, because of the mixed precursor source magma (igneous and sedimentary). This may account for the very little variation in the chemical composition of the MMA samples as observed earlier in this paper.

Spider Diagrams

Spider diagrams based on extended trace elements (incompatible trace elements including REE) is a useful petrogenetic indicator as it allows for comparison of abundance of elements in a particular rock with those of a specific geotectonic environment as a natural reference frame, e.g. comparisons with the primitive mantle and Mid Ocean Ridge (MORB) are possible. The spider diagrams for MMA are shown in Figure 9B. The MMA has marked through at Nb indicating derivation of rocks from a subduction related magma, (Thompson et al., 1984). The troughs at Zr shown by this rock (Fig. 9B) are also indications of silica saturated subduction related basalts. From the above results it appears that MMA has both igneous and sedimentary characteristics in which the mantle (igneous source) and marine materials, (sedimentary source) have been mixed together to produce the protolith material from which this rock was formed. This can occur in an environment where an ocean crust is brought down into the mantle by tectonic forces, ocean crust materials would be mixed with the mantle rocks (subduction). Wilson (1991), Oyinloye (1998); to produce the precursor magma from which the MMA was formed. This phenomenon can take place in a volcanic arc or a back arc environment. However, MMA spider diagrams are similar to those of a speading tectonic setting (e.g. MORB or a back arc setting) but none of the MMA samples plot on the MORB in all the discrimination diagrams. Also the development of negative Eu/Eu* anomaly, enriched LREE, low Cr, and Ni, Mg[1] less than 0.7, presence of monazite in the mineralogy of the MMA are all not consistent with a truely Mid Ocean Ridge Basalt (MORB). Therefore a back arc tectonic environment where an ocean slab had been subducted into the mantle will adequately account for all the chemical characteristics of MMA as described above.

Table 2

Rare earth elements chemical data for the massive melanocratic amphibolites, (MMA)

Element	MMA1	MMA2	MMA3	Mean
La	10.00	10.20	9.50	9.90
Ce	24.58	24.97	23.15	14.23
Pr	3.35	3.35	3.06	3.25
Nd	17.43	16.82	15.96	16.74
Sm	4.06	3.75	3.54	3.78
Eu	1.17	1.17	1.10	1.15
Gd	4.16	4.05	3.62	3.94
Dy	3.98	4.12	3.55	3.88
HO	0.68	0.73	0.62	0.68
Er	1.95	2.19	1.73	1.96
Yb	1.58	1.85	1.46	1.63
Lu	0.23	0.27	0.21	0.24
Total	74	73	67	71
LREE	61	60	56	59
HREE	13	13	11	12
LREE/HREE	4.69	4.56	5.03	4.92

LREE = Light Rare Earth Elements
HREE = Heavy Rare Earth Elements.

CONCLUSIONS

On the basis of geology, petrology, and chemical studies of the massive melanocratic amphibotie in the Ilesha schist belt, it is concluded that

(1) The precursor magma of the amphibolite in Ilesha schist belt has both igneous and sedimentary characteristics.

(2) These characteristics are due to the formation of the amphibolite precursor magma by mixing ocean crust with those of mantle materials during a tectonic subduction episode in a back arc basin.

REFERENCES

Ajayi, T.R. 1981: On the geochemistry and origin of the amphibolites in Ife-Ilesha area southwestern Nigeria, Jour. Min. Geology. 17, (2):179-195.

Bafor B.E. and Karamata S.E. 1981. Geology and geochemistry of a metamorphosed volcano sedimentary assemblage in the Precambrian of northwestern Nigeria Annals of Geological Survey of Egypt X:665-688.

Eleuze, A.A., 1982. Geochemistry of the Ilesha granite gneiss in the basement complex of southwestern Nigeria. Precamb Res.19: 1167-1170.

Klemm., D.D., 1984. The Precambrian metavolcano - sedimentary sequence east of Ife - Ilesha southwestern Nigeria, A Nigerian greenstone belt? J. African Earth. Sci. 2: 161-176.

Olade M.A. and Elueze A.A. 1979. Petrochemistry of the Ilesha amphibolites basement crustal evolution, in the Pan-African domain of western Nigeria, Precambr. Res. p.303-318.

Oyinloye, A.O. 1998. Geology, geochemistr and origin of the banded and granite gneisses in the basement complex of the Ilesha area, southwestern, Nigeria Jour. African Earth Sci. 26 (4) : 633-641.

Pearce, J.A. and Cann, J.R. 1973. Tectonic setting of basic volcanic rocks determination using trace elements analyses. Earth Planetary Sci. Lett. 1 290-300.

Pearce, J.A. Albaster, T. Shelton, A.W. and Searle M.P. 1981. The Ophiolites an Cretaceous arc basic complex, evidenc and implications, Phill. Trans, R. Soc. London A 300: 299-317.

Strong, D.F., Saunders. C.M. 1988. Ophioli suphide mineralisation at Tit Cove, Newfoundland, controls by upper mant and crustal processes Econ. Geol. 2: 239-255.

Thompson R.N. Morrison M.A. Hendry G.I. ar Parry S.J. 1984. An assessment of relative roles of crust and mantle in magma genesis. An elemental approac Phil. Trans. Soc. A310: 549-590.

Walsh. J.N. Buckly F. and Baker J. 1982. Simultaneous Couple Plasma Source Spectrometary, Chemical Geol. 33: 141-153.

Wilson M. 1991. Igneous petrogenesis: A tectonic approach. Harper Collins Academy second impression, P. 227-241.