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Magmatism and Metamorphism of the Proterozoic in the Northeastern Part of Korea: Petrogenetic and Geochemical Characteristics of the Okbang Amphibolites

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ABSTRACT: The Okbang amphibolites occurring as sill-shaped bodies within the Precambrian Wonnam Group have been studied in terms of geochemical characteristics for their tectonomagmatic environments. The amphibolites fall in the ortho-amphibolite fields in Ni and Cr versus Cu diagrams. They belong to subalkaline and tholeiitic series in total alkali versus silica and ternary AFM diagrams, respectively. They show the compositional variation corresponding to the differentiation trend of tholeiitic suites. In discrimination diagrams using high-field-strength elements such as Ti, Zr, Nb and Y, the amphibolites show geochemical affinities to both of volcanic-arc tholeiites and normal (depleted) mid-oceanic ridge tholeiites. The REE patterns of the amphibolites are nearly flat and extremely similar to those of back-arc tholeiites. $(La/Yb)_{CN}$ ratios vary from 0.89 to 2.02 with an average value of 1.23. Such low light-REE abundances in the amphibolites suggest that they were derived from the upper mantle source depleted in these elements.

In view of geochemical characteristics showing strong enrichments of incompatible elements such as K and Rb, distinctive negative Nb anomalies, depletions of light-REE observed also in normal (depleted) mid-oceanic ridge tholeiites, and unfractionated immobile elements such as Y and Yb, the tholeiitic magmas, from which the parent rocks of the amphibolites were formed, would be generated from a depleted upper mantle source and contaminated by continental crustal materials en route to surface. Tectonomagmatic environment for the amphibolites can be assumed to be continental back-arc basin.

INTRODUCTION

The Okbang amphibolites in the Socheon-meon, Bonghwa-gun, Gyungsangbuk-do occur as sill-shaped bodies within the Precambrian Wonnam Group. The amphibolites are included as xenoliths in the Buncheon gneissic granite. The amphibolites extend almost 3 km and vary with the range from 20 to 120 m in thickness.

In the Okbang tungsten mine, the amphibolites are closely associated with scheelite-bearing pegmatite veins. Previous works for the study area were mainly concentrated on the studies for the exploration of ore deposits (Lee, 1967; Kim, 1969; Ahn, 1969; Kim, 1986).

Lee (1967) has described the geology and ore deposits of the Okbang scheelite mine in some detail. Scheelite-bearing pegmatite veins, which are fissure-filling types along the bedding slippages and fractures, occur only within the amphibolites, but not within the gneissic granite or the schist surrounding the amphibolites. On the basis of petrographic features, Lee (1967) recognized that the scheelite deposits have been formed by the metasomatic reaction of the tungsten-bearing and alkaline fluid of pegmatites with the calcium, which could be derived from the hydrothermal alteration of plagioclase and hornblende constituting the amphibolites.

With regard to amphibolites, their petrogenesis are still controversial, although both Lee (1967) and Kim (1986) assumed that these rocks would be metamorphosed hornblendites or basic intrusive rocks. Furthermore, the genetic relationship between amphibolites and the associated Buncheon gneissic granite is not clear. The aim of the study is to investigate the tectonomagmatic characteristics of the amphibolites, which seems to be particularly important for understanding their origin and tectonic setting in the Taebaeksan area of the Proterozoic age.

GEOLOGIC SETTING

The geology of the area has been described in the Samgunri Sheet (1:50,000 scale) published by Geological Survey of Korea (Kim et al., 1963). The detailed geology of the vicinity of the Okbang mine was

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presented in Lee (1967).

In brief, the geology of the study area consists mainly of the Precambrian Buncheon gneissic granite and metasedimentary rocks such as the Yulli series, the Wonnam Group, and quartzite.

The Yulli series are metasedimentary rocks conformably overlying the Wonnam Group and they comprise arenaceous and argillaceous schist or gneiss. The Wonnam Group is composed of biotite gneiss, biotite-garnet gneiss, schist, and interbedded quartzite and limestone. These rocks show the tightly bedded crenulation. The strike and dip of main foliation is N50-76E and 36~88NW. In places, the biotite-garnet gneiss often shows porphyroblastic texture and shows the alteration of biotite to muscovite and of muscovite to atoll garnet. The metasedimentary rocks above mentioned were intruded by the Okbang amphibolites, the Buncheon gneissic granite, and pegmatites.

The Okbang amphibolites occur as sill-shaped within the Wonnam Group in southern part of the area, and were included as xenoliths in the gneissic granite in northern part.

The Buncheon gneissic granite, which is distributed in northern half of the area, intruded metasedimentary rocks and the amphibolites. The gnessic granite shows augen and banded structures due to regional deformation. The foliations are N62-80E and 52~80 NW in the Okbang mine area, and N10-20W and 50~58NE in the Ssangjeon area. Major constituent minerals are quartz, microcline, plagioclase, and biotite with minor amounts of epidote, zircon, and apatite. Coarse-grained quartz and plagioclase show mortar texture surrounded by small cataclastic quartz and plagioclase. The augen and mortar textures seem to be due to cataclastic deformation.

The Rb/Sr age of the Buncheon gneissic granite around the Buncheon area was determined as 2,107 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7056± 0.0006 (Choo and Kim, 1985) and 2,097± 4 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7082± 0.0007 (Hong, 1985). However, Ri (1988) determined a different Rb/Sr age for the Buncheon granitoids of 1,863± 103 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.72446.

PETROLOGIC CHARACTERISTICS

The amphibolites vary with the range from less than 30 to 120 m in thickness. The rocks are dark grey to grey and medium-grained rocks with leucocratic lineation. They show ptygmatic folds in some places. This means that the parent rocks of the amphibolites were affected by regional and cataclastic movements.

The amphibolites intruded by the Buncheon gneissic granite are observed in the vicinity of the Okbang primary school. The K/Ar age of the hornblende in scheelite bearing-pegmatite of the Okbang mine is 2,006.99± 28.7 Ma (Park et al., 1988). Considering that the scheelite mineralization resulted from metasomatic reaction between tungsten-bearing fluid of pegmatites and amphibolites, the age of the parent rocks of the amphibolites seems to be early Proterozoic or late Archean, which are also in good agreement with pre-Buncheon gneissic granite and post-Wonnam Group. The strike and dip of the foliations in the amphibolites are N40-88E and 33~80NW, respectively. They are concordant with those of the Wonnam Group.

Amphibolites are mainly composed of amphibole and plagioclase, and minor accessary minerals such as apatite, magnetite, biotite, and quartz. The amphibole shows generally pristmatic and metablastic texture. Occasional biotitization of hornblende and aggregates of coarse biotites are observed near to pegmatite veins. Amphibole and plagioclase in amphibolites were analysed using the electron probe microanalyser JXA-733, Seoul National University.

Plagioclase compositions vary from An_{53} to An_{39} in the area, but individual grains show nearly constant composition from core to rim. Amphibole compositions vary from magnesio-hornblende to actinolitic hornblende in places but chemical compositions of their individual grains show nearly constant like those of plagioclases. This means that although compositional variations of minerals were resulted from magma differenciation processes, the chemical compositions of individual grains have been homogenized by re-equilibration due to regional metamor phism.

Amphibole-plagioclase pairs yield metamorphic temperature with 530± 20℃ on the empirical model for plagioclase-hornblende exchange equilibria of Spear (1980). Brown's geobarometer (1977), which is based on the exchange of Al and NaM4 in tetrahedral site of amphibole, indicate that the parents of amphibolites were metamorphosed below about 3 kbar.

P-T conditions for the regional metamorphism in the area have been assumed for garnet-biotite pairs in the Buncheon gneissic granite and pelitic assemblages in the Weonnam formations. They are 530~570 ℃ at 3.5 kbar (Kim, 1991). These values nearly correspond with those assumed for amphibole-plagio-

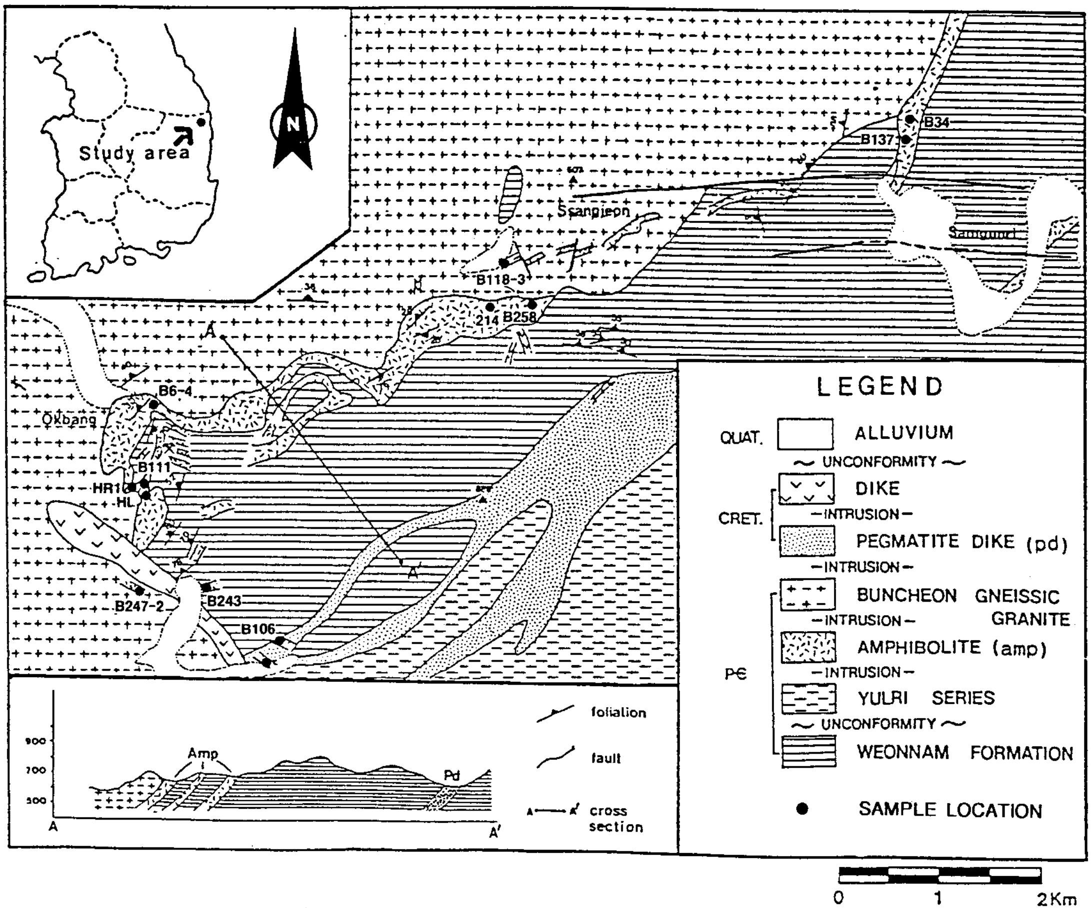

Fig. 1. Geologic map of the Okbang area.

clase pairs in amphibolites.

GEOCHEMICAL CHARACTERISTICS

Sampling and Analytical Procedure

Thirteen samples were selected from fresh and massive parts of amphibolites, away from pegmatite veins, mineral veinlets such as biotite and calcite, and other metamorphic alterations. Samples B34 and B137 were collected from the Samgunri area and samples HL and HR1 near from scheelite-bearing pegmatite. The others were collected from the main amphibolite sill in the central part of the area (Fig. 1).

Major and trace elements except SiO_2 have been analysed using inductively coupled plasma mass spectrometer at Inter-University Center for Natural Science Resource Facilities at Seoul National University. SiO_2 have been analysed on fused glass beads, using X-ray fluorescence spectrometer at Korea Mining Promotion Corporation. Rare earth elements (REE) are extracted and pre-concentrated using cation-exchange procedure for the precision of the analysis.

Major and trace element analyses are given in Table 1 and REE in Table 2.

Major and Trace Elements

In terms of the immobility of Ti during metamorphism, Ti contents can be used to discriminate igneous origin from sedimentary origin for the amphibolites. In Ni and Cr versus Cu diagrams considered by Engle and Engle (1962) (Fig. 2), most of samples except two samples fall in the ortho-amphibolite fields, with a widely scattering pattern of elements. Cu contents in the amphibolites range from 4 to 312 ppm. Ni and Cr contents vary with a wide range from 57 to 107 ppm and from 91 to 492 ppm, respectively (Table 1). In general, these compatible element contents are strongly affected by fractional crystalli-

Table 1. Major and trace element data for the Okbang amphibolites.

wt.%	B34	B118-3	B6-4	B247-2	B105	B106	B137	B111	B214	B243	B258	HL	HR1	Average
SiO_2	51.30	49.70	51.80	52.60	48.20	44.30	50.00	49.30	49.90	49.60	50.40	52.60	52.50	50.1
Al_2O_3	14.40	13.64	13.37	13.50	12.63	13.67	14.69	14.50	13.37	13.04	9.26	12.23	14.15	13.2
Fe_2O_3	2.71	3.02	4.04	3.08	4.29	4.75	2.37	3.81	3.30	2.31	2.12	3.37	3.45	3.3
FeO	7.56	8.70	10.14	8.38	12.40	13.32	6.69	9.88	9.63	7.73	6.16	9.93	8.35	9.1
MgO	8.18	7.69	4.80	6.37	6.98	6.33	8.14	6.85	6.54	8.17	5.52	6.51	5.03	6.7
CaO	10.95	11.01	8.63	7.55	9.47	9.28	11.80	9.32	10.20	11.72	6.75	8.11	8.80	9.5
Na_2O	1.84	1.73	2.45	1.07	1.52	1.77	1.50	2.17	1.77	0.85	1.58	0.90	2.56	1.7
K_2O	0.45	0.43	0.59	1.33	0.69	0.90	0.78	0.76	0.27	0.30	0.46	0.92	0.77	0.7
TiO_2	0.54	0.70	1.08	0.86	2.05	1.32	0.51	0.95	0.84	0.55	0.47	0.92	1.24	0.9
P_2O_5	0.08	0.09	0.13	0.09	0.19	0.09	0.07	0.10	0.10	0.08	0.07	0.08	0.17	0.1
MnO	0.15	0.19	0.20	0.15	0.25	0.39	0.15	0.29	0.20	0.18	0.14	0.20	0.17	0.2
Total	98.99	97.86	98.36	95.91	100.05	98.00	97.44	98.02	97.19	95.69	83.61	96.87	97.12	
ppm														Average
Ti	3236	4195	6472	5154	12285	7910	3056	5693	5034	3296	2817	5513	7431	5545.5
K	3736	3570	4898	11041	5728	7471	6475	6309	2241	2490	3819	7637	6392	5223.8
P	349	393	567	393	829	393	306	436	436	349	306	349	742	449.9
Rb	12	20	23	98	26	110	39	46	19	14	51	80	44	44.8
Ba	44	41	32	118	86	74	60	36	56	31	56	45	185	66.5
Co	34	41	40	35	49	49	34	43	42	37	29	33	37	38.7
Cr	258	282	201	298	260	91	308	136	164	492	136	443	190	250.7
Cu	49	94	312	37	13	9	18	4	143	111	42	13	107	73.2
Li	18	26	14	60	42	128	15	14	13	38	23	19	31	33.9
Nb	1	1	3	22	9	2	1	2	2	1	2	3	7	2.8
Ni	107	92	57	94	102	85	119	81	88	106	77	106	52	89.7
Xc	44	44	40	48	44	48	42	40	43	44	28	51	35	42.4
Sr	107	93	103	130	116	63	75	89	97	110	75	43	273	105.7
V	241	271	312	326	475	943	225	307	298	232	187	349	264	340.8
Y	15	18	31	22	37	18	15	23	23	15	13	26	32	22.2
Zn	64	80	131	87	127	358	65	215	101	71	63	316	96	136.5
Zr	44	55	89	66	96	76	43	71	68	44	38	75	96	69.0
Ti/Zr	74	76	73	78	128	104	71	80	74	75	74	74	77	78.7
Zr/Y	2.9	3.1	2.9	3.0	2.6	4.2	2.9	3.1	3.0	2.9	2.9	2.9	3.0	3.10
K/Rb	311.3	178.5	213.0	112.7	220.3	67.9	166.0	137.2	118.0	177.9	74.9	95.5	45.3	155
K/Ba	84.9	87.1	153.1	936	66.6	101.0	107.9	175.3	40.0	80.3	68.2	169.7	34.6	97.1
Sr/Ba	2.43	2.27	3.22	1.10	1.35	0.85	1.25	2.47	1.73	3.55	1.34	0.96	1.48	1.59
Rb/Sr	0.11	0.22	0.22	0.75	0.22	1.75	0.52	0.52	0.20	0.13	0.68	1.86	0.16	0.56

zation of mafic minerals such as ilmenite, magnetite, or pyroxene. Furthermore, the increase in TiO_2 is accompanied by the increase of total iron and P_2O_5 and the decrease of Al_2O_3 and MgO (Table 1), suggesting fractional crystallization processes. The amphibolites belong to subalkaline series on the total alkali-silica diagram of Irvine and Baragar (1971) (Fig. 3a), with a limited range from 1.15 to 3.33 wt.% total alkali (Na_2O+K_2O). The some scatter of analyses in this diagram may be due to fractional crystallization. K/Rb and Rb/Sr ratios range from 45 to 311 and from 0.11 to 1.86, respectively, and they also suggest fractional crystallization or crustal contamination. The subalkaline series are subdivided into a calc-alkaline series and a tholeiitic series. The amphibolites contains higher total ($FeO+Fe_2O_3$) and TiO_2, but lower K_2O, SiO_2, and MgO than the calc-alkaline series defined by Irvine and Baragar (1971). Al_2O_3 contents in amphibolites are less than 15 wt.%. They form a distinct group in the iron-rich tholeiitic field, on the ternary AFM diagram proposed by Irvine and Baragar (1971), and show the compositional variations corresponding to the differentiation trend of tholeiitic suites.

High-field-strength elements (HFSE) such as Ti, Zr, Nb, and Y are relatively immobile during weathering and are very useful for tectonomagmatic discrimination purposes. The abundances of these elements in the amphibolites range from 2,817 to 7,910 ppm for Ti, from 43 to 96 ppm for Zr, from 1 to 9 ppm for

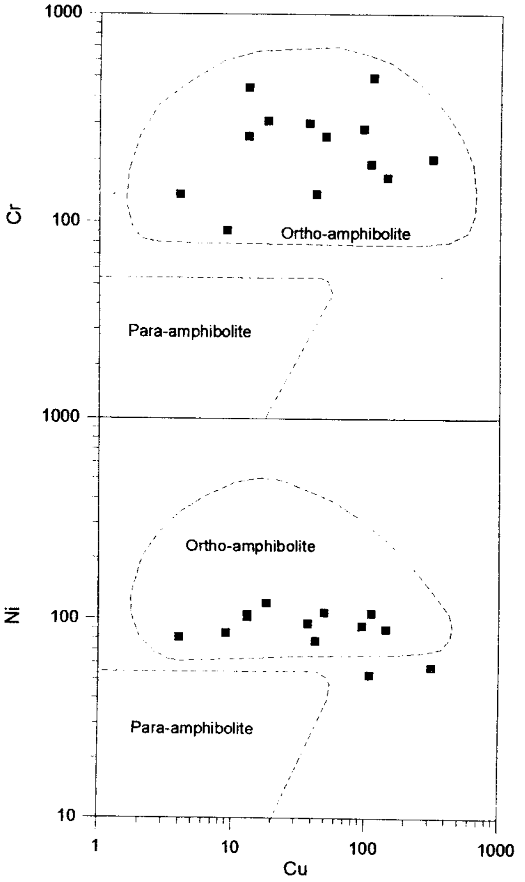

Fig. 2. Cr and Ni versus Cu diagrams for the Okbang amphibolites. The dashed line separates ortho-amphibolites from para-amphibolites (Engle and Engle, 1962).

Table 2. Rare earth element abundances for the Okbang amphibolites.

	B34	B118-3	B6-4	B247-2	Average
(ppm)					
La	2.36	2.75	4.05	6.08	3.81
Ce	6.56	9.15	12.04	16.61	11.09
Pr	1.03	1.43	1.93	2.28	1.67
Nd	5.60	7.80	10.50	10.50	8.60
Sm	1.23	1.76	2.85	2.25	2.02
Eu	0.51	0.68	0.99	0.89	0.77
Gd	1.98	2.66	4.26	3.07	2.99
Dy	2.53	3.13	5.23	3.67	8.64
Ho	0.51	0.62	1.04	0.71	0.72
Er	1.52	1.46	3.07	1.84	1.97
Yb	1.61	1.76	3.04	2.01	2.11
Lu	0.26	0.28	0.49	0.32	0.34
ΣREE	45.7	33.48	49.49	50.23	44.73
ΣLREE	17.29	23.57	32.36	38.61	27.96
ΣHEEE	28.41	9.91	17.13	11.62	16.77
(CN)					
La	7.17	8.36	12.31	18.48	11.58
Ce	7.58	10.58	13.92	19.20	12.82
Pr	7.92	11.00	14.85	17.54	12.83
Nd	8.89	12.38	16.67	16.67	13.65
Sm	6.06	8.67	14.04	11.08	9.96
Eu	6.62	8.83	12.86	11.56	9.97
Gd	7.17	9.64	15.43	11.12	10.84
Dy	9.17	9.13	15.25	10.70	25.19
Ho	6.62	8.05	13.51	9.22	9.35
Er	6.76	6.49	13.64	8.18	8.77
Yb	7.32	8.00	13.82	9.14	9.57
Lu	7.67	8.26	14.45	9.44	9.96
$(La/Sm)_{CN}$	1.18	0.96	0.88	1.67	1.17
$(La/Yb)_{CN}$	0.98	1.04	0.89	2.02	1.23
Eu/Eu*	1.00	0.96	0.87	1.04	0.97

ΣLREE; La to Eu and ΣHREE; Gd to Lu.
CN; Chondrite-normalized values using chondrite abundance data from Sun(1980).

Nb, and from 13 to 37 ppm for Y. Such a wide range of variations in element abundances can be appropriate for discrimination diagrams.

According to a series of discrimaination diagrams such as Ti-Zr diagram (Fig. 4), Ti/100-Zr-3Y (Fig. 5a), and 2Nb-Zr/4-Y (Fig. 5b) proposed by Condie (1990), Pearce & Cann (1973), and Meschede (1986), respectively, the tectonomagmatic environment of the amphibolites can be discriminated from within-plate tholeiites (WPT), calc-alkaline basalts (CAB), enriched mid-ocean ridge basalts (E-type MORB), and volcanic-arc basalts (VAB). However, the amphibolites plot within both of modern volcanic-arc tholeiite (VAB) and normal (depleted) mid-ocean ridge tholeiite (N-type MORB). The compositional field of N-type MORB is overlapped with that of volcanic-arc basalts (VAB), because volcanic-arc basalts (VAB) can not be distinguished from N-type MORB in these diagrams (Fig. 5a, 5b).

Rare Earth Elements

The rare earth element (REE) distribution patterns in the amphibolites, normalized to chondrite (Sun, 1980), are presented in Fig. 6, for comparison with those of island-arc tholeiites (IAT) and back-arc tholeiites (BAT).

The amphibolite patterns are nearly flat from La to Lu, with a slight depletion and enrichment of light-REE. $(La/Yb)_{CN}$ ratios vary from 0.89 to 2.02 with an average value of 1.23. These REE patterns quite differ from typical fractionated patterns with strong enrichment of light-REE produced by fractional crys-

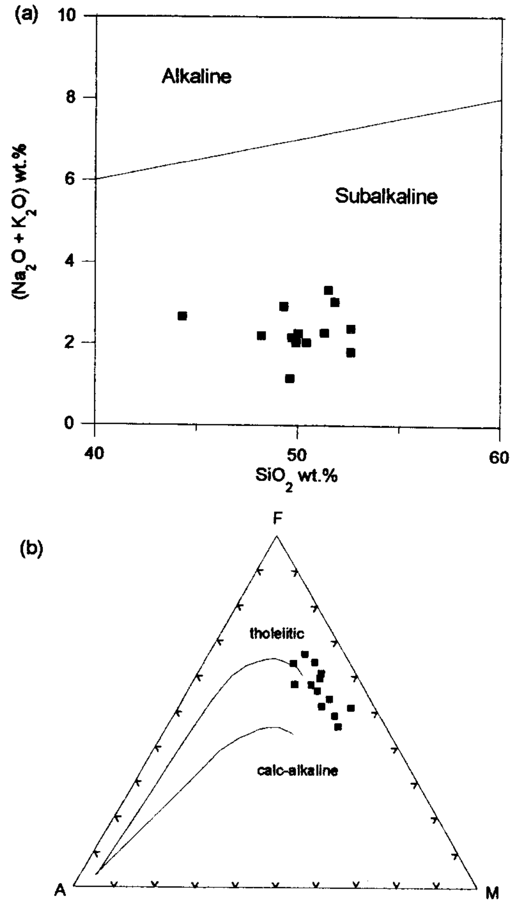

Fig. 3. (a) The variations of (Na_2O+K_2O) wt.% versus SiO_2 wt.% for the Okbang amphibolites. The solid line seperates alkaline from subalkaline suites (after Irvine and Baragar, 1971). (b) AFM diagram for the Okbang amphibolites. The solid lines show typical tholeiitic and calc-alkaline differentiation trends. A; Na_2O+K_2O, F; total FeO, and M; MgO (after Irvine and Baragar, 1971).

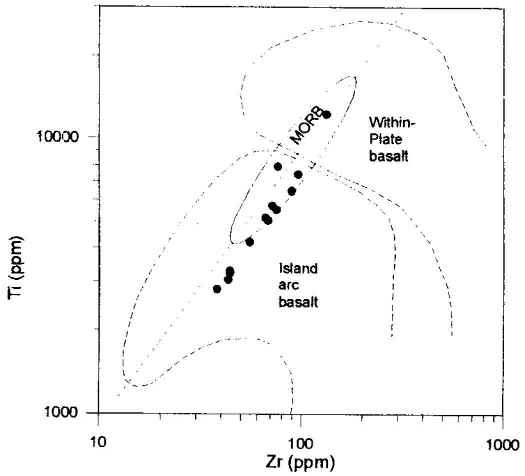

Fig. 4. Ti versus Zr for the Okbang amphibolite. Compsotional fields are from Condie (1990). The diagonal line (Ti/Zr=70) seperates primitive (to the left) from evolved (to the right) members.

tallization. Light-REE abundances range from 8 to 17 times chondrite and heavy-REE abundances from 8 to 24 times chondrite. The gradual enrichment from La to Nd observed in some samples may be due to accessary minerals such as apatite. The only one sample B247-2 have small negative Eu anomaly with Eu/Eu*=0.87, suggesting the fractionation of plagioclase and other samples show negligible positive or negative Eu anomalies with Eu/Eu*=0.96~1.04.

The REE patterns of the amphibolites are extremely similar to those of back-arc tholeiites from the East Scotia Sea rather than those of island-arc tholeiite from the associated South Sandwitch island-arc (Fig. 6). The upper and lower limits of the range for the amphibolite patterns completely accord with those for back-arc tholeiite patterns from the East Scotia Sea. Light-REE abundances for the amphibolites are similar to or slightly lower than those for the back-arc tholeiite from the East Scotia Sea (Hawkesworth et al., 1977). Furthermore, the light-REE abundances in the amphibolites are also similar to those in the N-type MORB but they are two-thirds of those in the E-type MORB reported by Humphris et al. (1985).

Such low light-REE abundances in the amphibolites suggest that they were derived from the upper mantle source depleted in these elements, distinct from those of enriched mantle source.

DISCUSSION

Geochemical characteristics of the Okbang amphibolites can be compared with those of tholeiitic basalts of which the tectonic settings are known at present. Incompatible element abundances for the Okbang amphibolite, normal mid-ocean ridge tholeiite (N-type MORB), enriched mid-ocean tholeiite (E-type MORB), initial rifting tholeiite (IRT), oceanic back-arc tholeiite (OBAT), continental back-arc tholeiites (CBAT) and island-arc tholeiite (IAT) are normalized to chondritic abundance, with the exception of K, Rb, and P, which are normalized the primordial mantle values (Thompson et al., 1984) (Fig. 7). Fig. 8 show incompatible element abundance patterns in

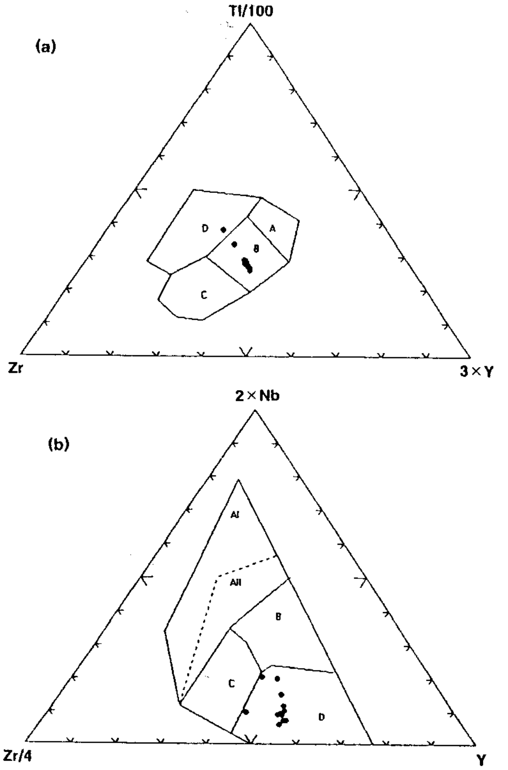

Fig. 5. Tectonomagmatic discrimination diagrams. (a) Ti/100-Zr-3Y diagram (after Pearce and Cann, 1973) for the Okbang amphibolites. Compositional fields are: A; island-arc tholeiite (IAT), B; mid-ocean ridge basalt (MORB) and IAT, C; calc-alkaline basalt, and D; within-plate basalt (WPB). (b) 2Nb-Zr/4-Y diagram(after Meschede, 1986) for the Okbang amphibolites. Compositional fields are: AI; within-plate alkalic, AII; within-plate tholeiite (WPT), B; enriched MORB (E-type MORB), C; volcanic-arc basalt (VAB) and WPT, and D; normal MORB (N-type MORB) and VAB.

the Okbang amphibolite, normalized to a range of tholeiitic basalts of which tectonic settings are well known at present.

In Fig. 7 and Fig. 8, elements are plotted in order of decrease of their immobile incompatibility from left to right, according to the method proposed by Sun (1980). The incompatible element abundance patterns can be used to discriminate the source of a magma, because the shape of trace element abundance patterns is not significantly affected by fractional crystallization or variable degrees of partial melting (Pearce, 1983).

The continental crustal rocks are generally enriched in K, Ba, and Rb relative to MORB types (N-type MORB and E-type MORB). Accordingly, mag-

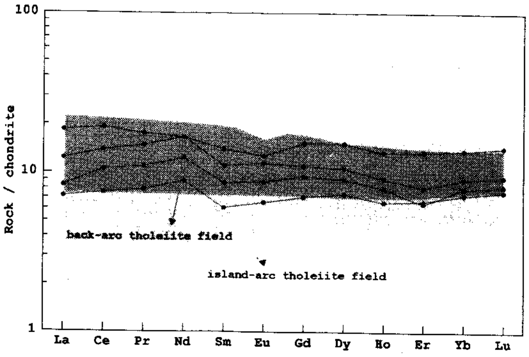

Fig. 6. Chondrite-normalized REE patterns for the Okbang amphibolites, compared to fields for island-arc tholeiite (IAT) from the South Sandwich island arc (after Hawkesworth et al., 1977) and for back-arc tholeiite (BAT) from the associated marginal basin, the East Scotia Sea (after Saunders and Tarney, 1979).

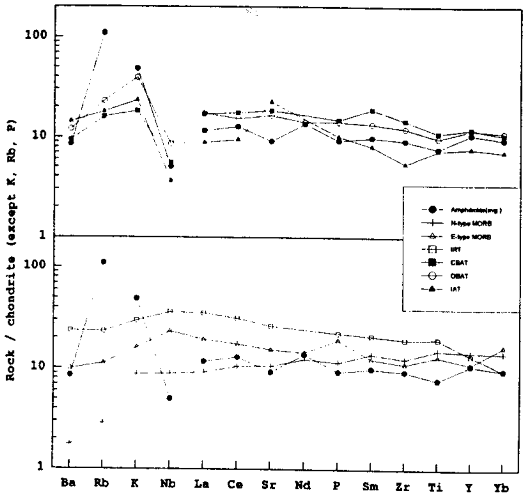

Fig. 7. Incompatible element abundance patterns, normalized to chondrite and primordial mantle values for K, Rb, and P (after Thompson et al., 1984), in the Okbang amphibolites, compared to those in tholeiitic basalts of modern tectonic settings. Data for N-type MORB and E-type MORB are from Sun (1980), OBAT from Saunders and Tarney (1979), and IAT, IRT and CBAT from Holm (1985).

mas, which are generated from a depleted mantle source (N-type MORB) and contaminated by crustal materials, generally show distinctive features having spiked anomaly patterns, as a consequence of the relative depletion of Nb and enrichment of Rb, Ba, and K. The relatively immobile incompatible elements such as Ti, Y, and Yb apppear nearly unmodified, even at significant degrees of contamination

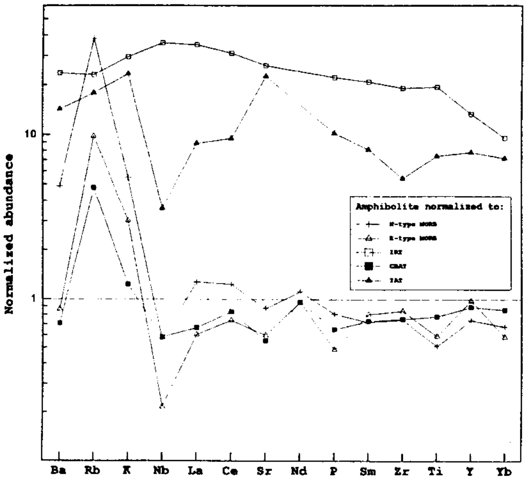

Fig. 8. Incompatible element abundance paterns of the Okbang amphibolites, normalized to a range of typical tholeiitic basalts of modern tectonic settings. Symbols are same as referred in Fig. 7.

(Wilson, 1989).

In Fig. 7, N-type MORB are strongly depleted in more incompatible elements such as K, Ba, and Rb. Compared to the N-type MORB, E-type MORB and initial rifting tholeiites (IRT) in continental settings show enrichments of the incompatible elements, positive Nb anomalies, and smooth patterns significantly unfractionated.

In contrast, volcanic-arc tholeiite such as island-arc tholeiite (IAT), oceanic back-arc tholeiite (OBAT) and continental back-arc tholeiites (CBAT) show distintive features having the marked negative Nb anomalies and positive anomalies spikes at Rb and K. These elements would be derived from continental crust, and added to the depleted mantle source (Fig. 7, Fig. 8).

The Okbang amphibolites also show these geochemical features strongly enriched in Rb and K with distinctive negative Nb anomaly. In subduction-related tholeiites, continental back-arc tholeiite (CBAT) and oceanic back-arc tholeiites (OBAT) are strongly enriched in the whole range of incompatible elements, relative to island-arc tholeiites (IAT) (Fig. 7, Fig. 8). The Okbang amphibolite patterns are extremely similar to those of the continental back-arc tholeiites (CBAT) and oceanic back-arc tholeiites (OBAT), in the whole range of incompatible elements. Back-arc basins, developed on the continental side of a volcanic arc, originate either in oceanic settings such as the Mariana Trough and the Scotia Sea or in continental settings such as Shikoku Basin. According to Holm (1985), the incompatible element patterns for oceanic back-arc tholeiite (OBAT) are extremely similar to those for continental back-arc tholeiite (CBAT). The only significant difference between these two back-arc basin tholeiites is the somewhat larger side of negative Nb anomaly for continental back-arc type (Holm, 1985). Negative Nb anomaly size observed in the Okbang amphibolite is similar to that in the continental back-arc tholeiites rather than in the oceanic back-arc tholeiites.

SUMMARY AND CONCLUSIONS

1. The Okbang amphibolites mainly consist of magnesio-hornblende, plagioclase (An_{53}~An_{39}), and minor accessory minerals such as pyroxene, apatite, magnetite, biotite and quartz. The chemical compositions of hornblendes and plagioclases vary in places but those of individual grains are nearly constant. This means that although compositional variations of minerals were resulted from magma differentiation processes, the chemical composition of an individual grain have been homogenized by re-equilibration due to regional metamorphism.

2. The Okbang amphibolites are classified into subalkaline series on the total alkali-silica diagram and tholeiitic series showing the differentiation trend on AFM diagram. Accordingly, the amphibolites are ortho-amphibolites be originated from basaltic rocks.

3. The REE patterns of the amphibolites are nearly flat with $(La/Yb)_{CN}$ ratios ranging from 0.89 to 2.02, and extremely similar to those of continental back-arc tholeiites rather than oceanic back-arc tholeiites or island-arc tholeiites. In incompatible element abundance patterns, the amphibolites show geochemical features having the marked negative Nb anomaly, positive Rb and K anomalies, depletion of light-REE, and unfractionated patterns of immobile incompatible elements such as Y and Yb.

4. The above-mentioned geochemical characteristics strongly suggest that the tholeiitic magma, from which the parent rock of amphibolites was formed, would be generated from a depleted upper mantle source and contaminated by continental crustal material. Tectonomagmatic environment for the amphibolites can be assumed to be continental back-arc basin where the Wonnam Group would be deposited at that time.

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韓國 北東部地域 原生代의 火成活動과 變成作用: 玉房 앰피볼라이트의 岩石成因과 地球化學的 特徵

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요 약: 경북 봉화군 소천면 소재 옥방 회중석광산 주변부에 분포하는 앰피볼라이트는 그 암석성인적 측면에서 많은 관심을 불러 일으켰다. 이 앰피볼라이트는 선캠브리아기의 원남층군내에 관입암상의 형태로 산출되며 옥방회중석광산의 모암이기도 하다. 주성분과 미량성분의 지구화학적 특징에 의하면, 이 앰피볼라이트는 정앰피볼라이트로서 비알카리 계열의 쏘레라이트 현무암질 암석으로 분류되며 쏘레라이트의 분화경향을 그대로 따르고 있었다. 희토류원소 및 친액상원소들의 지구화학적 특징에 의하면, 이 앰피볼라이트를 형성한 기원암의 마그마는 친액상원소들이 결핍된 상부맨틀로부터 유래되었으며 상승도중 대륙지각물질의 혼염이 있었고 이 마그마가 관입된 조구조적 환경이 대륙배호분지 (continental back-arc basin)임을 강력하게 시사하고 있다. 따라서 이 앰피볼라이트에 의해 관입된 원남층군이 퇴적된 조구조 환경 역시 대륙배호분지에 해당됨을 암시한다고 할 수 있다.