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K-Ar ages and Geochemistry for Granitic and Volcanic Rocks in the Euiseong and Shinryeong Area, Korea

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ABSTRACT : Cretaceous sedimentary-volcanoclastic formations of the Kyeongsang Supergroup were intruded by granitic rocks in the late Cretaceous and early Tertiary. In the Euiseong and Shinryeong area, these intrusives have various compositions including gabbro, diorite, biotite granite and feldspar porphyry. Associated volcanic rocks consist of two chemically distinct types: the bimodal suite of basalt and rhyolite in the Keumseongsan caldera, and the felsic suite of andesite and rhyolite in the Sunamsan-Hwasan calderas. Most rocks are subalkaline, and follow a typical differentiation path of the calc-alkaline magma. The granitic rocks can be distinguished chemically from the volcanics by high Zr/Y ratios. Differences in Zr/Y and K/Y ratios between the two volcanic suites can be accounted for by mantle source and fractionation. Chondrite-normalized trace element abundances of granitic rocks are depleted in Th and K, whereas those of the Keumseongsan rhyolites are depleted in Sr and Ti. Rb, La and Ce is enriched in rhyolites of the Sunamsan-Hwasan calderas. Rb-SiO_2 and Rb-Y+Nb discrimination diagrams suggest that the intrusives and volcanics have a volcanic arc setting. K-Ar ages indicate four plutonic episodes : diorite (89 Ma), granite (66~62 Ma), granite and porphyry (55~52 Ma) and gabbro (52~45 Ma), and two volcanisms : bimodal basaltic and rhyolitic volcanism (71~66 Ma) in the Keumseongsan caldera, and felsic andesitic and rhyolitic volcanism (61~54 Ma) in the Sunamsan-Hwasan calderas. Geochemical and age data thus suggest that the igneous rocks are related to several geologic episodes during the late Cretaceous to early Tertiary.

INTRODUCTION

The Kyeongsang basin, southeast Korean Peninsula, is an area which has attracted considerable attention in the geologic literature, due to extensive Cretaceous-early Tertiary igneous activity and related mineralization. The igneous activity is calc-alkaline in nature, and is thought to represent an arc related to subduction of the Kula-Pacific plate (Lee, 1974; Jin, 1981; 1985; 1986; Min *et al.*, 1982; Lee *et al.*, 1987; Kim *et al.*, 1992). Intrusives which formed part of this activity are thought to have been drived from lower crust or upper mantle. In the Kyeongsang basin, these intrusives contain numerous genetically related Cu, Pb, Zn, Au, Ag, Mo and W base metal deposits (Jin *et al.*, 1981; Shimazaki *et al.*, 1981; Min *et al.*, 1982). Associated volcanic caldera also formed in the area. Most of the late Cretaceous-early Tertiary calderas in South Korea are 60~82 Ma in age, except for the Mageumsan caldera, which is dated at 84~104 Ma (Cha, Yun, 1988).

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Numerous petrological and geochemical studies have been carried out in the Keumseongsan and Sunamsan-Hwasan calderas in the Euiseong and Shinryeong area (Park, 1986a; 1986b; Yun, 1987; 1988; 1993; Lee *et al.*, 1993). The volcanic rocks in the calderas are correlated largely on stratigraphic groups, and are accompanied with plutonic equivalents. Geochemical studies generally agree that these rocks are subalkaline series, and originated from calc-alkaline magma (Yun, 1987; 1988; 1993; Lee *et al.*, 1993). Geochronological data is not available in the study area, except for basalt (71 Ma) and rhyolite (67 Ma) from the Keumseongsan caldera (Lee *et al.*, 1993). Lee *et al.* (1993) suggested that Cu, Pb and Zn mineralizations around the Keumseongsan caldera were related to the volcanism. Because the volcanic rocks of the Sunamsan-Hwasan calderas have been correlated without geochronological data, some problems in correlation are remained.

To address this problem, we have conducted geochemical and geochronological studies on igneous rocks in the area. In this paper, we describe the geochemical characteristics of igneous rocks in the study area, and infer the relationship between mineralization and igneous activity. Especially, this paper is aimed at eatablishing the timing of plutonism and volcanism in the Euiseong and Shinryeong areas.

GEOLOGIC SETTING

A geological map of the area is shown in Fig. 1 (Kweon, Lee, 1973; Oh, Jeong, 1975; Chang *et al.*, 1977; 1978; 1981; Won *et al.*, 1980; Jeong *et al.*, 1981). Basement in the study area consists of Cretaceous sedimentary-volcanoclastic sediments of the Kyeongsang Supergroup, which were intruded by granitic rocks in the late Cretaceous to early Tertiary. The Kyeongsang Supergroup is divided into the Shindong, Hayang and Yucheon groups (Chang, 1975, 1977, 1978). The study area only consists of the Hayang and Yucheon group. The Hayang group consists of six Formations : Iljik formation (Khi; conglomerate, sandstone and shale), Hupeongdong formation (Khh; chert bearing conglomerate, sandstone and shale), Jumgog formation (Khj; black or grey shale, and sandstone), Sagog formation (Khs; purple shale and sandstone), Chunsan formation (Khc; black or greenish grey shale) and Shinyang-dong formation (Khsy; black shale) in order of decreasing age.

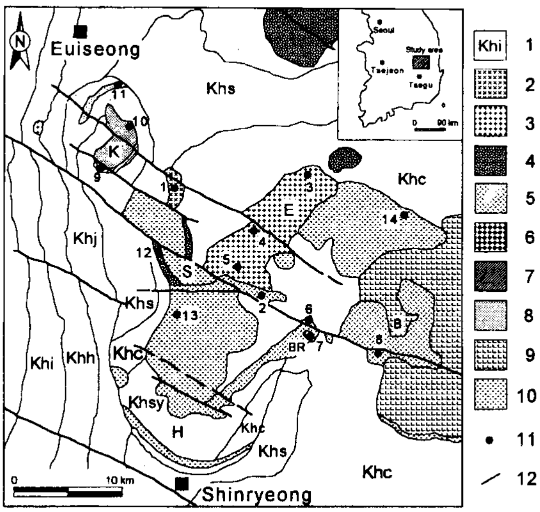

Fig. 1. Geologic map and sample locations in the study area. 1; Cretaceous sedimentary rocks, 2; late Cretaceous diorite, 3; late Cretaceous granitic rocks, 4; late Cretaceous quartz porphyry, 5; early Teriary granitic rocks, 6; early Tertiary gabbro, 7; late Cretaceous basalt, 8; late Cretaceous rhyolite, 9; early Tertiary andesite, 10; early Tertiary rhyolite, 11; sample location, 12; Fault. Khi; Iljik formation, Khh; Hupeongdong formation, Khj; Jumgog formation, Khs; Sagog formation, Khc; Chunsan formation, Khsy; Shinyangdong formation, K; Keumseongsan, S; Sunamsan, H; Hwasan, E; Eobongsan, BR; Bongrimsan, B; Bohyunsan.

The Yucheon group consists of pyroclastics with lesser lava, and unconformably underlies the Hayang group. The volcanics can be divided into two groups : 1) a bimodal basalt-rhyolite suite in the Keumseomgsan caldera, 2) a felsic suite (andesite-rhyolite) in the Sunamsan-Hwasan calderas. Volcanics in the Keumseongsan caldera include basaltic lava, rhyolitic pyroclastics and rhyolitic lava. Volcanic rocks in the Sunamsan and Hwasan calderas consist of andesite lava and rhyolitic pyroclastics. Volcanism in the Keumseongsan caldera is apparently correlated with that of the Sunamsan and Hwasan calderas by stratigraphic unit and petrology (Yun, 1987). Lee *et al.* (1993) have reported K-Ar ages for basalt (71 Ma) and rhyolite (67 Ma) from the Keumseongsan caldera. However, no other geochronological data is available for volcanic rocks from the Sunamsan-Hwasan calderas, or from plutonic rocks in the same area.

The late Cretaceous and early Tertiary intrusives of the study area are mainly gabbro, diorite, biotite granite, quartz porphyry and feldspar porphyry. Gabbro, which intruded biotite granite in the Hwasan caldera, is mostly composed of plagioclase, pyroxene, and hornblende, with small amounts of biotite, olivine and opaque minerals. Diorite also occurs as a stock in the northern part of the Sunamsan caldera, and contains plagioclase, quartz, biotite, orthoclase with miner hornblende, pyroxene and opaque minerals. Biotite granites are medium- to fine-grained, consisting mostly of quartz, microcline, orthoclase, plagioclase, biotite and opaque minerals. Biotite granite is partly changed to leucocratic granite and aplite. Feldspar porphyry, which intruded biotite granite in the Hwasan caldera, consists of phenocrysts of orthoclase and plagioclase, and groundmass feldspar and quartz. Quartz porphyry occurs as a stock, and is composed of phenocrysts of quartz, orthoclase and plagioclase, with groundmass feldspar and biotite.

GEOCHEMISTRY

Bulk chemical analyses of eight samples were made by ICP and INAA at Activation Laboratories LTD of Canada, and some analytical data were cited from previous studies (Lee *et al.*, 1993; Yun, 1987; 1988). Representative whole rock compositions are given in Table 1.

Major elements

The SiO_2 contents of the intrusives vary from 46.93 to 70.96 wt.% (gabbro; 46.93 wt.%, diorite; 58.27 wt.%,

Table 1. Representative chemical compositions of igneous rocks in the study area.

	Intrusives						
	Gabbro	Diorite	Biotite granite				K-fd porphyry
	L1	921212-1	KDCB1	921214-6	95831-8	95712-11	921214-4
SiO_2	46.93	58.27	66.31	66.74	67.55	69.27	70.96
TiO_2	0.43	0.92	0.51	0.50	0.51	0.40	0.34
Al_2O_3	16.04	18.01	15.23	15.34	15.52	14.46	14.17
FeO*	10.04	7.77	4.63	4.55	4.11	2.78	3.05
MnO	0.15	0.13	0.09	0.07	0.09	0.04	0.06
MgO	14.81	2.76	1.73	1.45	1.26	0.61	0.47
CaO	9.71	5.80	2.95	2.73	3.09	1.55	1.25
Na_2O	1.29	4.25	4.13	4.37	3.83	4.58	4.18
K_2O	0.34	2.43	3.49	3.53	3.58	4.09	4.79
P_2O_5	0.11	0.28	0.14	0.15	0.14	0.08	0.09
LOI	0.14	0.33	1.63	1.49	0.97	0.80	0.72
Total	100.00	100.96	100.84	100.92	100.64	98.64	100.10
Ba	91	575	800	696	28974	573	500
Sr	455	415	398	332	323	228	129
Rb	-	50	85	96	94	123	181
Y	11	28	22	23	26	24	31
Zr	18	197	187	210	192	276	268
V	96	106	54	49	45	29	15
Co	54	31	9	7	8	7	3
Cr	216	124	20	14	14	8	22
Ni	131	23	30	18	8	4	51
Cu	61	28	12	5	8	10	8
Pb	-	18	14	13	16	16	19
Zn	193	68	42	28	53	44	49
Hf	-	3.9	4.0	4.3	5.0	7.1	4.0
Th	-	4.1	7.3	7.3	8.6	-	17.8
La	5.61	19.9	25.0	25.8	30.0	29.0	39.5
Ce	15.69	39	46	48	53	5.7	67
Nd	3.06	18	19	19	23	24	26
Sm	2.07	4.3	3.5	3.6	4.3	4.2	5.4
Eu	0.71	1.2	1.0	0.9	1.2	0.8	0.7
Tb	-	0.5	0.5	0.5	0.8	0.9	0.5
Yb	0.80	2.5	2.1	2.2	2.9	2.2	3.0
Lu	0.14	0.41	0.29	0.37	0.40	0.35	0.49

biotite granite; 66.31~69.27 wt.% and feldspar porphyry; 70.96 wt.%). The SiO_2 content of volcanic rocks ranges from 48.47 to 76.12 wt.% (basalt; 48.47~53.87 wt.% and rhyolite; 71.87~76.12 wt.%) in the Keumseongsan caldera, and from 63.82 to 72.36 wt.% (andesite; 63.82 wt.% and rhyolite; 70.96~72.36 wt.%) in the Sunamsan and Hwasan calderas. As shown in Table 1, the volcanic rocks can be classified into two types : 1) the bimodal suite of basalt-rhyolite composition lacking andesite in the Keumseongsan caldera and 2) the felsic suite of andesite-rhyolite composition in the Sunamsan-Hwasan calderas.

Oxide-SiO_2 variation diagrams are shown in Fig. 2. K_2O increases with increasing SiO_2, whereas, TiO_2, Al_2O_3, FeO*, MnO and CaO show negative correlations, and Na_2O is scattered. On a SiO_2-(Na_2O+K_2O) diagram, the igneous rocks in the Euiseong and Shinryeong area belong to the subalkaline series (Fig. 3). On an AFM diagram, samples are mostly classified as calc-alkaline (Fig. 4).

Trace and rare earth elements

Variations of Sr, Rb, and V with SiO_2 are shown in Fig. 2. Sr and V show negative correlation, but Rb is positively correlated with SiO_2. Trace element ratios show that the intrusives are clearly distinguished from the volcanics by the higher Zr/Y ratios. Volcanics

Table 1. Countinued.

	Keumseongsan caldera								Sunamsan-Hwasan caldera			
	Basalt			Rhyolite					Andesite	Rhyolite		
	30-39	30-40	30-46	30-30	30-33	501-2	501-21	ES4	831-5	214-2	L4 (7)	L5 (10)
SiO_2	51.12	53.87	48.47	73.54	71.87	73.85	75.39	76.12	63.82	70.96	72.36	71.48
TiO_2	1.30	1.05	1.14	0.30	0.32	0.21	0.09	0.08	0.77	0.34	0.38	0.43
Al_2O_3	19.09	15.65	16.70	13.45	13.92	13.52	13.05	12.76	16.08	14.17	13.78	14.19
FeO*	8.64	9.32	7.37	2.18	2.90	1.81	1.65	0.42	5.49	3.05	1.94	1.75
MnO	0.12	0.16	0.15	0.04	0.06	0.04	0.02	–	0.17	0.06	0.06	0.07
MgO	3.99	3.45	5.35	0.78	0.98	0.40	0.13	0.10	2.27	0.47	0.50	0.69
CaO	6.37	7.18	8.01	0.83	0.84	0.93	0.37	0.04	4.59	1.25	0.78	0.40
Na_2O	4.23	3.02	2.41	3.03	3.82	0.79	3.39	2.20	4.35	4.18	3.57	3.92
K_2O	1.92	1.14	1.06	4.58	4.06	5.00	5.16	5.24	1.55	4.79	4.69	5.04
P_2O_5	0.52	0.46	0.46	0.14	0.14	0.03	0.06	0.06	0.19	0.09	0.08	0.12
LOI	2.22	3.94	9.09	1.74	1.86	2.90	0.91	0.91	1.48	0.72	1.80	1.88
Total	100.52	99.24	100.21	100.65	100.77	99.48	100.12	97.70	100.75	100.10	99.95	99.97
Ba	1532	612	388	495	552	845	953	216	313	800	533	436
Sr	609	575	251	123	151	70	43	4	410	398	146	126
Rb	22	27	24	140	130	150	110	130	32	181	–	–
Y	34	26	26	24	26	16	14	14	19	22	27	30
Zr	225	80	192	156	147	116	93	100	103	187	49	42
V	120	90	100	20	68	22	–	2	45	15	18	14
Co	23	22	22	2	5	7	2	–	13	3	4	4
Cr	180	140	150	9	31	14	3	5	17	22	23	22
Ni	80	70	60	30	30	140	–	4	9	51	11	10
Cu	40	25	20	25	30	95	20	2	14	8	21	18
Pb	–	–	–	–	–	650	10	–	20	19	–	–
Zn	120	80	110	20	15	785	45	18	150	49	450	383
Hf	5.3	2.9	4.0	4.0	4.5	3.1	3.3	4.0	2.9	6.2	1.3	1.1
Th	3.6	4.3	2.5	14	11	8.8	8.6	9.6	6.6	18.8	–	–
La	39.3	31.1	28.1	30.5	37.0	31.7	29.6	35.3	17.7	39.5	32.95	64.72
Ce	85	67	62	60	75	57	52	68	36	67	62.88	115.40
Nd	40	32	30	23	31	18	17	29	19	26	26.94	40.98
Sm	7.1	5.5	5.5	4.2	5.3	3.0	3.0	4.8	3.5	5.4	4.71	5.96
Eu	1.7	1.4	1.5	0.6	0.7	0.6	0.4	0.3	1.0	0.7	0.71	0.72
Tb	1.0	0.8	0.7	0.7	1.0	0.5	0.5	0.8	0.7	0.5	–	–
Yb	2.8	2.2	2.26	2.45	2.88	1.55	1.7	2.77	1.8	3.0	2.31	2.51
Lu	0.4	0.32	0.34	0.37	0.44	0.27	0.29	0.43	0.28	0.49	0.37	0.38

Keumseongsan caldera data by Lee *et al.* (1993), Sunamsan-Hwasan calderas rhyolite (L4 and L5) by Yun (1987).

from the Sunamsan and Hwasan calderas show low Zr/Y ratios. Based on Ti/Zr-Ti/Y and K/Y-Ti/Y diagrams(Fig. 5), volcanic rocks of the Keumseongsan caldera can be divided into two bimodal groups such as a high Ti/Y group and a low Ti/Y group.

Chondrite-normalized REE abundances are shown in Fig. 6. Nearly lined patterns are evident in the basic rocks (gabbro, diorite, basalt and andesite), and negative Eu anomalies occur in the acidic rocks (granite, feldspar porphyry and rhyolite). The igneous rocks in the study area are characterized by enrichments in LREE. Especially, rhyolites of the Sunamsan-Hwasan calderas have smaller negative Eu anomalies relative to rhyolites of the Keumseongsan caldera. Chondrite-normalized trace element abundances are shown in Fig. 7. Granites are characterized by a depletion in Th and K relative to the rhyolites. Keumseongsan caldera rhyolites are depleted in Sr and Ti relative to the granites, whereas equivalents in the Sunamsan-Hwasan calderas are enriched in Rb, La and Ce, and depleted in Zr.

Tectonic setting

Ignoeus rocks can be categorized in terms of

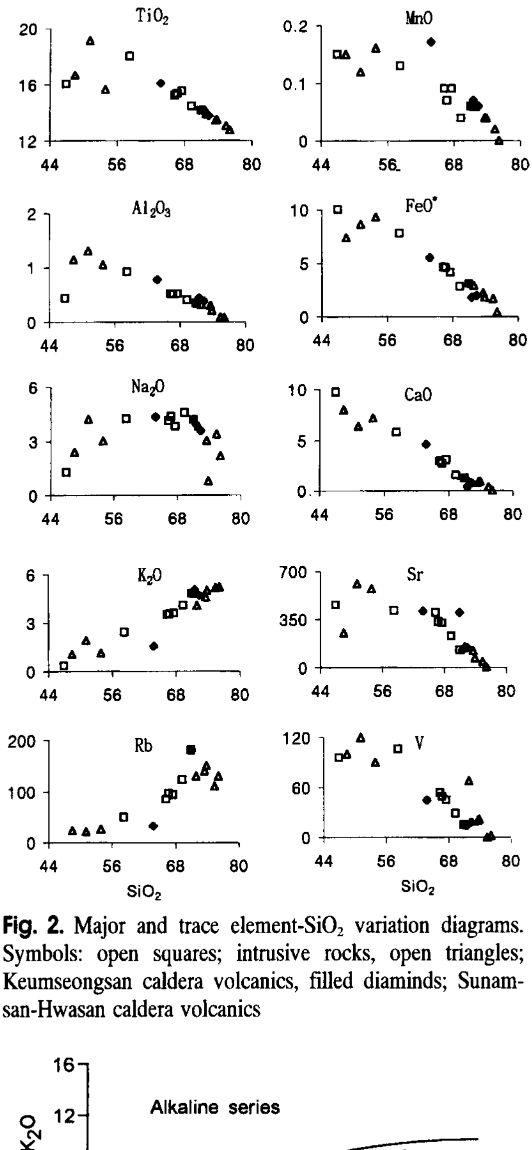

Fig. 2. Major and trace element-SiO_2 variation diagrams. Symbols: open squares; intrusive rocks, open triangles; Keumseongsan caldera volcanics, filled diaminds; Sunamsan-Hwasan caldera volcanics

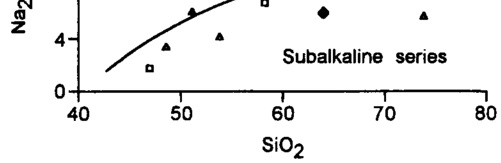

Fig. 3. Total alkali-SiO_2 diagram for igneous rocks in the study area. The discriminant line is that of Irvine, Baragar (1971). Symbols are the same as those in Fig. 2.

tectonic settings using SiO_2 and trace elements (Pearce *et al.*, 1984). Rb-SiO_2 and Rb-(Y+Nb) diagrams suggest that both the plutonic and volcanic

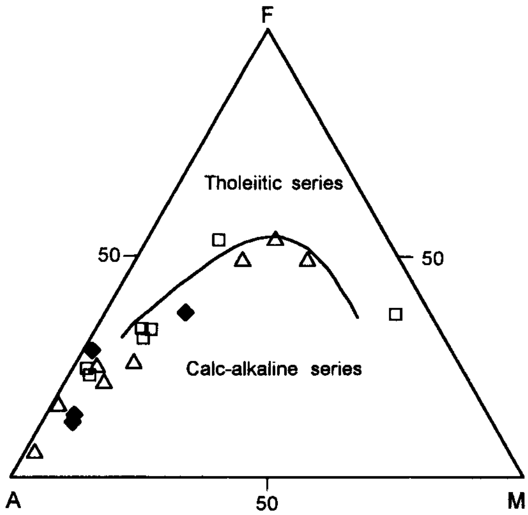

Fig. 4. AFM diagram for igneous rocks in the study area. The discriminant line is that of Irvine, Baragar (1971). Symbols are the same as those in Fig. 2.

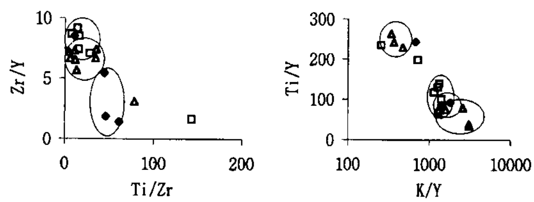

Fig. 5. Ti/Y-Zr/Y and K/Y-Ti/Y plots for igneous rocks in the study area. Symbols are the same as those in Fig. 2.

rocks were derived from volcanic arc magmatism (Fig. 8). This is consistent with other igneous rocks in the Kyeongsang basin (Min *et al.*, 1982; Jin, 1985, 1986). Most Cretaceous to early Tertiary granitic and volcanic rocks in the Kyeongsang basin are thought to have been generated from the thermal effects of the subducted Kula-Pacific Ridge beneath the southern part of the Korean continents (Lee, 1974; Jin, 1981; 1985; 1986; Min *et al.*, 1982, Lee *et al.*, 1987; Kim *et al.*, 1992).

K-Ar Age

Sample Preparation

K-Ar age determinations were made of eight intrusives (four granites and single samples of gabbro, diorite, and feldspar porphyry). Three volcanics were dated from the Sunamsan-Hwasan calderas (one andesite, and two rhyolitic tuff). The sample localities are shown in Fig. 1. K-feldspar, plagioclse, biotite and

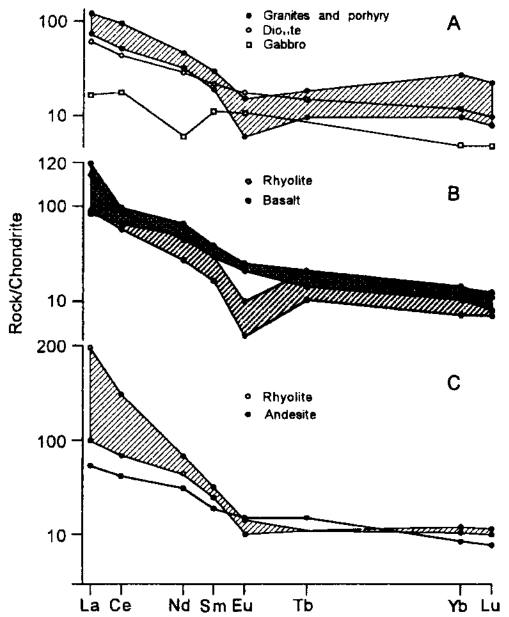

Fig. 6. Chondrite-normalized REE patterns of igneous rocks. Chondrite values are those of Haskin *et al.* (1968).

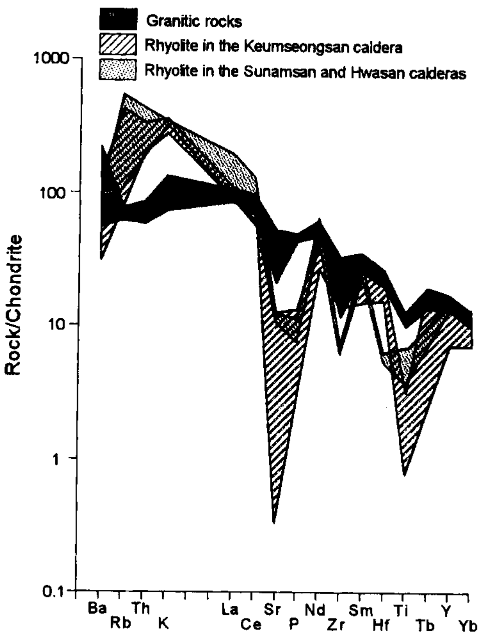

Fig. 7. Chondrite-normalized trace element abundances of acidic igneous rocks in the study area. Trace element and chondrite values are those of Haskin *et al.* (1968).

hornblende were separated from the intrusives, whereas the volcanic rock age determinations were made on whole-rock samples.

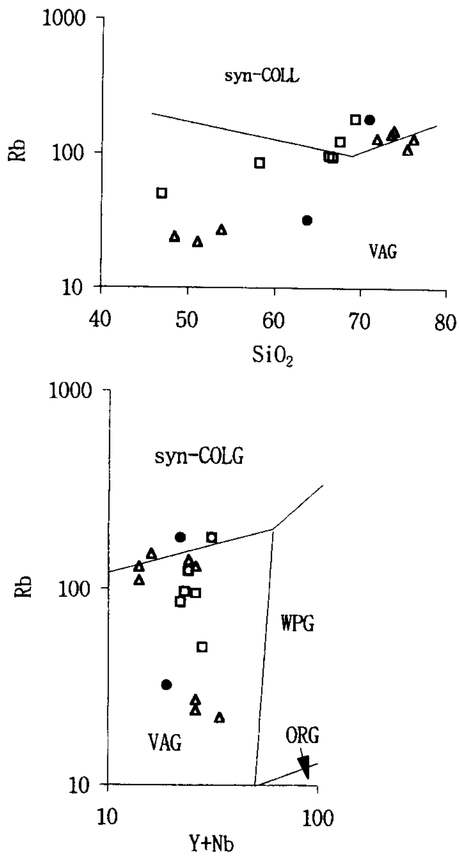

Fig. 8. Rb-SiO_2 and Rb-(Y+Nb) discriminant diagrams (after Pearce *et al.*, 1984). Syn-COLG; syn-collision granite, WPG; within plate granite, ORG; ocean ridge granite, VAG; volcanic arc granite. Symbols as in Fig. 2.

The intrusives were crushed and sieved, and the 60~80 or 150~200 mesh size fraction retained for separation of K-feldspar, plagioclse, biotite and hornblende. Volcanic rock samples were crushed and sieved, and the 60~80 mesh fraction was used for whole rock dating. The sieved fractions were washed with distilled water to eliminate powder residue, and then dried in an oven (80°C). K-feldspar and plagioclase was separated using by heavy liquids, and biotite and hornblende separated by a combination of Frantz magnetic seperation and heavy liquids.

Analytical procedure

Potassium was analyzed by flame photometry using a 2000 ppm Cs buffer (Nagao *et al.*, 1984). Powder samples were digested by HF and HNO_3 in teflon beakers. Multiple runs of chemical standards show that the errors in this method are $<2\%$.

Averaged values of duplicate analyses were used for age calculation.

Argon was analyzed by isotope dilution, with a ^{38}Ar spike on a 15 cm radius sector type mass spectrometer with a single collector system at Okayama University of Science (Nagao and Itaya, 1988). Physical constants used in the calculation of K-Ar ages are λ_e=0.581×10^{-10}/y, λ_β=4.962×10^{-10}/y, and $^{40}K/K$= 0.0001167 (Steiger and Jager, 1977).

Results

K-Ar ages of separated minerals from the intrusives, and whole-rocks data from volcanic rocks are listed in Table 2. Age of diorite is 89.1±2.0 Ma for biotite in the Sunamsan. Feldspar porphyry is 55.0±1.3 Ma for K-feldspar in the Sunamsan. The ages of biotite granite determined from biotite and K-feldspar are 63.6 ±1.5 Ma and 65.8±1.5 to 61.5±1.6 Ma in the Eobongsan, respectively. Leucocratic granite in the Hwasan is 53.8±1.3 Ma for K-feldspar. The ages of gabbro determined from hornblende and plagioclase are 51.6±2.8 Ma and 45.1±2.3 in the Bongrimsan, respectively. Biotite granite is 52.3±1.3 Ma for K-feldspar in the Bohyunsan.

K-Ar age of andesite lava is 61.1±1.5 Ma for whole rock in the Sunamsan. Rhyolitic tuff is 54.5± 1.2 Ma for whole rock. Rhyolilic breccia is 54.0±1.5 Ma for matrix minerals.

DISCUSSION

Geochemical Chracteristics

The geochemical data indicate that the intrusive and volcanic rocks in the study area originated from calc-alkaline magma (Fig. 3 and 4), which is consistent with previous studies. Using the tectonic discrimination diagram proposed by Pearce *et al.* (1984), the tectonic environment is identified as a volcanic arc, which is also the case for other igneous rocks in the Ky- eongsang basin. Vocanics can be classified into two types by their chemical characteristics. These are a bimodal suite of basalt-rhyolite composition lacking andesite composition in the Keumseongsan caldera, and a felsic suite of andesite-rhyolite composition in the Sunamsan-Hwasan calderas. Differences of Zr/Y and Ti/Y ratios, and Sr, Ti, Rb, La

Table 2. K-Ar ages for igneous rocks in the study area.

Location No.	Sample No.	Rock name (analyzed mineral)	K (wt.%)	Rad.^{40}Ar (10^{-8} ccSTP/g)	Age (Ma)	Non-Rad. ^{40}Ar(%)
Sunamsan						
1	ES921212-1	Diorite(bt)	5.84±0.12	2069.4±21.9	89.1±2.0	5.1
2	ES95831-7	Feldspar porphyry (k-f)	11.14±0.22	2412.5±34.7	55.0±1.3	5.1
Eobongsan						
3	ES921214-6	Biotite granite (k-f)	9.39±0.19	2442.7±26.8	65.8±1.5	5.8
4	KDCB-1	Biotite granite (bt)	4.26±0.09	1069.9±14.9	63.6±1.5	24.6
5	ES95831-8	Biotite granite (k-f)	9.72±0.19	2440.7±34.7	63.6±1.5	4.0
	ES95831-9	Aplite (k-f)	8.89±0.18	2156.9±39.4	61.5±1.6	23.2
Bongrimsan						
6	ES95831-6	Leucocratic granite (k-f)	8.02±0.17	1698.9±23.9	53.8±1.3	3.1
7	ES95831-10	Gabbro (hd)	0.34±0.02	68.1±1.6	51.6±2.8	32.2
		(pl)	0.09±0.01	16.1±0.7	45.1±2.3	59.4
Bohyunsan						
8	ES95712-11	Biotite granite (k-f)	8.67±0.17	1785.4±24.9	52.3±1.3	2.3
Keumseongsan caldera						
9	ES30-46	Basalt (w.r)	0.70±0.02	198.9±2.3	71.4±2.3	15.0
10	ES910501-21	Rhyolite (w.r)	3.48±0.07	918.6±9.2	66.8±1.5	3.2
11	ES4	Intursive rhyolite (w.r)	4.07±0.08	1083.2±10.6	67.3±1.5	2.8
Sunamsan-Hwasan caldera						
12	ES95831-5	Basaltic andesite (w.r)	2.10±0.04	507.0±7.7	61.1±1.5	9.0
13	ES921214-2	Rhyolitic tuff (w.r)	3.37±0.07	723.3±7.9	54.5±1.2	5.9
14	ES960111-10	Rhyolitic breccia (m)	1.43±0.03	302.9±6.1	54.0±1.5	28.9

Abbreviations: bt; biotite, hd; hornblende, k-f; k-feldspar, pl; plagioclase, m; matrix, w.r; whole rock and Ce contents in the volcanics can be explained by source magma of heterogenity and degree of fractional crystallization. However, trace elements (Rb, Zr and Y) and the rare earth elements behave similarly in the felsic rock types (granite, feldspar porphyry and rhyolite) suggesting that the felsic magmas have a common parent.

Relationship between trace elements and metallogenic provinces

Base metal mineralization is associated with igneous rocks of the Kyeongsang basin, metallogenic provinces are related to major and trace elements of igneous rocks. Thus, the metal deposits of the Kyeongsang basin are classified into various metallogenic provinces : zonal metallic provinces of copper-iron, lead-zinc and tungsten-molybedum (Kim, 1971; Sillitoe, 1977). These metallogenic provinces may be linked to the plutonism, which was responsible for the Jindong, Namhae, Onjeong and Eonyang-Yucheon granitic rocks. Some authors (Lee, 1984; 1989; Lee, Lee, 1992) reported that these granitic rocks show differences in rock types and chemical compositions between metallogenic provinces (Jindong; Cu province, Namhae; Pb-Zn province, Onjeong; Mo province, and Eonyang-Yucheon; Pb-Zn province). Thus, comparisons between granitic rocks of the Kyeongsang basin are necessary to infer possible relationships between mineralization and igneous activity (Lee *et al.*, 1994), Lee *et al.* (1994) found clearly difference in average contents of Cu, Pb and Zn among the granitic rocks in the Kyeongsang basin (Table 3). Cu (19 ppm), Pb (14 ppm) and Zn (68 ppm) contents of the granitic rocks in the study area are higher than those of equivalent rocks elsewhere in the Kyeongsang basin. Especially, Cu (26.5 ppm) and Zn (185 ppm) contents of volcanic rocks in this area are higher than those of volcanic rock (15 ppm, 78 ppm) in the southern Kyeongsang basin (Kim, Lee, 1993), they are also higher than those of the granitic rocks in the study area (Table 3). The granitic and volcanic rocks of the study area thus have higher Cu and Zn contents than those of similar rocks in the southern Kyeongsang basin, and might be associated with Cu and Zn mineralizations in the study area.

Table 4. Relationship of plutonism and volcanism in the study area.

	Age (Ma)	Plutonisum	Volcanism
Tertiary	50	Gabbro (52)	
		Granite/Porphy (55-52)	Rhyolite (55)
	60		Andesite (61)
Cretaceous		Granite (66)	Rhyolite (67)
	70		Basalt (71)
	80		
	90	Diorite (89)	

Timing of plutonism and volcanism

Based on the K-Ar ages, plutonism in this area can be divided into four stages (Table 4) : diorite (89 Ma), granite (66~62 Ma), granite or feldspar porphyry (55~52 Ma) and gabbro (52~45 Ma). These results indicate that plutonism of various compositions ccurred in this area during late Cretaceous to early Tertiary. Volcanic rocks in this area are reported as the products of a common coeval volcanism, but can be divided into two stages on the basis of age data and chemical characteristics as mentioned above : a bimodal basalt-rhyolite suite in the Keumseongsan caldera is dated at 71~66 Ma, and a felsic suite in the Sunamsan-Hwasan calderas was erupted from 61~54 Ma. Moreover, these results might support the possibility of different source of magma. Ages of granitic rocks (66~52 Ma) are similar to those of volcanic rocks (67~54 Ma) such as rhyolite and andesite, and

Table 3. Cu, Pb, Zn and Mo contents according to rock type (ppm)

Rock type	Cu	Pb	Zn	Mo	Province	Reference
Plutonic rocks						
Jindong	66.1	6.4	32.8	0.9	Cu	Lee *et al.* (1994)
Namhae	10.6	17.5	61.8	1.2	Pb-Zn	Lee *et al.* (1994)
Onjeong	11.3	9.0	34.8	7.2	Mo	Lee *et al.* (1994)
Yucheon-Eonyang	7.8	7.9	40.1	2.0	Pb-Zn	Lee *et al.* (1994)
Euiseong-Shinryeong	19	14	68	–	Cu-Zn	This study
Volcanic rocks						
South Kyeongsang basin	15	–	78	–		Kim, Lee (1993)
Euiseong-Shinryeong basin	26.5	–	185	–		This study

it might indicate that the magma was derived from the timely and spatially common source.

CONCLUSIONS

1. Intrusive and extrusive rocks in the study area originated from a calc-alkaline magma in a volcanic arc environment.

2. Geochemical data show that the igneous rocks of this area have slightly higher Cu and Zn contents than those of other igneous rocks in the Kyeongsang basin, suggesting a link between the magmatism and the mineralization in the study area.

3. Plutonism in the study area can be divided into four stages such as diorite (89 Ma), granite (66~62 Ma), granite or feldspar porphyry (55~52 Ma), and gabbro (52~45 Ma).

4. Volcanic rocks can be divided into two stages by age data and chemical characteristics : a bimodal basalt-rhyolite suite lacking andesite in the Keumseongsan caldera (71~66 Ma), and a felsic andesite-rhyolite suite in the Sunamsan-Hwasan calderas (61~54 Ma).

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의성-신령지역의 화강암류 및 화산암류에 대한 K-Ar 연대

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요 약 : 경상누층군이라 불리는 백악기 육성퇴적암-화산쇄설물들은 백악기 말-제3기초의 화강암류에 의해 관입되어 있다. 의성-신령지역의 화강암류는 다양한 암상과 화학조성을 갖는다 : 반려암; 46.9, 섬록암; 58.3, 흑운모 화강암; 66.3~69.3, 장석 반암; 71.0 wt.% SiO_2. 화산암류는 화학적으로 금성산 칼데라에서는 안산암질 성분이 결여된 현무암-유문암의 bimodal 유형과 선암산-화산 칼데라에서는 안산암-유문암의 felsic 유형으로 나뉜다. 대부분의 화성암류는 비알칼리 계열에 속하고, 칼크-알칼리 마그마의 분화 경로를 따른다. 화강암류는 높은 Zr/Y비에 의해 화산암류와 잘 구별된다. 화산암류에서 Zr/Y와 K/Y비의 차이는 맨틀기원 및 분별작용에서 불균질로 설명될 수 있다. 콘드라이트로 균질화된 희토류 원소량은 화강암류에서 Th와 K이 결핍되어 있고, 금성산 칼데라의 유문암에서 Sr 와 Ti의 결핍되어 있다. 선암산-화산 칼데라의 유문암은 Rb, La 및 Ce이 부화되어 있다. Rb-SiO_2와 Rb-Y+Nb의 관계도는 화강암류와 화산암류가 화산호 환경이었음을 암시한다. K-Ar 연대는 4회의 심성활동 (섬록암; 89 Ma, 화강암; 64~62 Ma, 화강암/반암류; 55~52 Ma, 반려암; 52~45 Ma)으로 나뉘고, 금성산 칼데라의 bimodal 유형 (71~66 Ma)과 선암산-화산 칼데라의 felsic 유형 (61~54 Ma)으로 특징지워지는 화산활동이 수반되었다. 지화학 및 연대측정 자료들은 화성암류가 백악기말-제3기초 동안 다양한 지질학적 에피소드의 결과로 형성되었슴을 암시한다.