Evidences of the presence of old continental basement in Cheju volcanic Island, South Korea, revealed by radiometric ages and Nd-Sr isotopes of granitic rocks

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Major and trace element and Nd-Sr isotopic data are presented on the granitic rocks known as a basement in the Cheju volcanic island, together with CHIME age data on porphyritic hornblende-biotite granite xenolith from the Byeoldobong area.

The CHIME ages from zircon and allanite grains of porphyritic hornblende-biotite granite were determined to be 169 ± 29 Ma and 183 ± 40 Ma, respectively, which are corresponding to a Jurassic age. It is concordant with a K-Ar age of 172.4 ± 5.2 Ma of a biotite granite in the same area, which is comparable to the Daebo granite in the Korean peninsula.

Granitic xenoliths from the Byeoldobong area have Nd-Sr isotopic compositions (initial ratio ($^{143}\text{Nd}/^{144}\text{Nd}$)_i = 0.51156~0.51158, ϵ_{Nd} = -19~-14 and ($^{87}\text{Sr}/^{86}\text{Sr}$)_i = 0.7156~0.7164, ϵ_{Sr} = 101~179) which are close to those of Jurassic Daebo granite (ϵ_{Nd} = -21~-14, ϵ_{Sr} = 104~171). On the other hand, the micrographic granite from the drilling core in the Hadeokcheon area gives initial ratio ($^{143}\text{Nd}/^{144}\text{Nd}$)_i = 0.51218 and ($^{87}\text{Sr}/^{86}\text{Sr}$)_i = 0.7077, which are comparable to the Cretaceous Bulguksa granite ranging from 0.51184 to 0.51268 in $^{143}\text{Nd}/^{144}\text{Nd}$ and 0.7055 to 0.7167 in $^{87}\text{Sr}/^{86}\text{Sr}$. The $T_{\text{DM}}^{\text{Nd}}$ model ages of 1.0 to 1.7 Ga from the Mesozoic granitic plutons in the Cheju island suggest that the source materials of the plutons in the island have evolved since mid-Proterozoic time as those of the peninsula.

In combination with the basement geology and petrochemistry, Nd-Sr isotopes, and radiometric and model ages of granitic rocks, our results imply that the Okchon zone is continuously extended to the Cheju volcanic Island of the southeastern end of the continental margin of the Eurasian plate.

INTRODUCTION

The Cheju Island is a typical shield volcano located on the continental margin at the southern end of the Korean peninsula. The alkali volcanic rocks of the Cheju Island erupted between Pleistocene (1.2 Ma) and Holocene (AD 1570) (Won *et al.*, 1986; Yun *et al.*, 1987; Lee *et al.*, 1988; Min *et al.*, 1988).

The volcanic succession consists mainly of basaltic lava flows and pyroclastic rocks. No basement rock crop out on the surface. The basement

rock has previously been assumed to be made of volcanic and granitic rocks of the Cretaceous which lie at *ca.* 250~300 m below sea level (Lee, 1982; Yoon, 1997). It has been thought to be an extension of the Kyoungsang sedimentary basin in the peninsula (Haraguchi, 1929; Lee, 1982; Yoon, 1997). The age and kind of the concealed basement rocks in Cheju volcanic island provide useful information on the geotectonic division of the Korean peninsula and characteristics of continental margin occurred intensive igneous activities including the Mesozoic plutonism and the

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Fig. 1. Sampling sites of granitic rocks in the Cheju volcanic island. Geological map after Lee (1982). Drilling sites in which granite is encountered in the drilling core are included (Koh, 1997; Son, 1997; Yun *et al.*, 1998). (K: Yeondong, ROS: Hadeokcheon, D: Jongdal, J: Jungmun, JS: Jeongshil, HD: Hamdeok, Ch: Cheonjiyeon, S: Seongeup, SJ: Shin-Cheju). CH-1, CH-2 and C-1200 indicate sample numbers.

Cenozoic volcanism including the Tertiary Cheju volcanism of the southeastern part of the Eurasian plate. In particular, to elucidate the Cheju volcanogenic processes, the magma has been proposed to be normal oceanic alkalic basalt magma (Lee, 1982), and the basement rock has been assumed to be continental and/or oceanic crust (Lee, 1982; Won *et al.*, 1986; Min *et al.*, 1988). The isolated Quaternary volcanic events in Cheju island represent intraplate hot spots (Lee, 1982; Won *et al.*, 1986; Chough *et al.*, 2000). Until recently, very little was known about the basement geology and the origin of alkali basaltic magma in the volcanic island.

As shown in Figs. 1 and 2, recently, several deep and hundreds of shallow holes drilled to exploit hot spring and groundwater have revealed that the volcanic rocks are present only above ca. 100 m below sea level and are underlain by a few hundreds of meter thick sedimentary rocks and unconsolidated sediments of the Plio-Pleistocene lying on the Cretaceous volcanic and granitic rocks

(Yun and Kim, 1984; Koh *et al.*, 1982, 1993; Yoon *et al.*, 1995b).

The purpose of this paper is to examine geochemical and isotopic characteristics and radiometric age and evolution of concealed granitic basement rocks beneath the Cheju volcanic island and to correlate the basement geology between the island and the Korean peninsula.

We report K-Ar and CHIME ages of granitic rocks from the drill cores and of granite xenoliths from the Byeoldobong pyroclastic deposits, and correlate chemical (REE), Nd-Sr isotopic compositions and model ages for granitic rocks in the petrochemical view point with that those of the Korean peninsula. K-Ar ages for alkali volcanic rocks were also included to discuss the evolution of the basement rock and alkali volcanic rocks.

GEOLOGIC SETTING

In a tectonic sense, the Cheju Island is situated in the continental margin and belongs to the

Fig. 2. Correlation of a tuff layer and granite in the drilling cores which are known as basement rocks in the Cheju volcanic island (Son, 1997; Koh, 1997; Yun *et al.*, 1998). Abbreviations are the same as in Fig. 1.

Cenozoic alkali rock province (Lee, 1982; Kim *et al.*, 1999). The volcanic island consists mainly of Cenozoic alkali basaltic lava flows, pyroclastics and marine fossiliferous sedimentary formations known as Seoguipo and Shinyangri Formations. Geological, geochemical and Nd-Sr isotopical characteristics of these volcanic rocks have been reported in detail by previous researchers (Lee, 1982, 1989; Park and Kwon, 1993; Lee *et al.*, 1994; Park *et al.*, 1996; Kim *et al.*, 1999).

The volcanic history of the Cheju island comprises the following three stages: (1) lava plateau stage (2) shield volcano stage and (3) scoria cinder cone stage (Lee, 1982). Based on the existing K-Ar age data for the volcanic rocks (Appendix), the age spectrum of volcanic activity is found to be composed of three substages of 2.2~1.2 Ma, 1.0~0.8 Ma and 0.2~0.03 Ma (Fig. 3).

Occurrence of basement rocks

Granite xenoliths have been found at a few localities in Tertiary pyroclastic tuffaceous deposits, especially in the Byeoldobong area. Subangular granitic xenoliths of 5 to 20 cm in diameter are

dominated by medium grained biotite granite, porphyritic hornblende-biotite granite along with a subordinate amount of two mica granite. The porphyritic hornblende-biotite granites have a small amount of prismatic alkali feldspar phenocrysts of 0.5 to 5 cm in length. The granite is correlated to the pre-Cretaceous muscovite granite in the southwestern area of the peninsula (Yun *et al.*, 1998, 1999). Porphyritic hornblende-biotite granite contains quartz, microcline, plagioclase, hornblende, biotite with small amounts of magnetite, apatite, zircon, allanite and epidote. However rare granite gneiss fragments as well as granite fragments were also found in Tertiary tuffaceous formation of the Songacksan and Suwollbong areas (Son, 1997).

Based on the observations of cores from nine drilling sites except the Shin-Cheju area, a pyroclastic formation covers unconformably the granitic basement (Figs. 1 and 2) and is composed of volcanogenic sandstone and mudstone, trachytic welded tuff and tuff breccia. This volcanogenic formation can be correlated with the Yuchon group in the Kyoungsang sedimentary

Fig. 3. Distribution of K-Ar ages for volcanic rocks from the Cheju volcanic island based on the data of Appendix.

basin in the southern part of the Korean peninsula (Koh, 1997). K-Ar ages of the granitic rocks from the Hadeokcheon and Manjang tunnel areas have been reported to be the same as those for the Cretaceous Bulguksa granite (Ahn *et al.*, 1995; Lee, 1996).

A pink feldspar porphyritic granite in the Hadeokcheon area is composed mainly of quartz, plagioclase, alkali feldspar, biotite and a small amount of apatite. The granite is characterized by a micrographic texture, normally zoned plagioclase and a miarolitic texture which are commonly observed in the graphic granite called Masanite in the Kyoungsang basin.

Porphyritic hornblende-biotite granite (Sample No. CH-1) with feldspar phenocrysts sampled at -650 m level of the drilling core in the Seongeup (Site No. S) and -38m level of the drilling core in the Jeongshil (HD) show a quite lithologic character similar to the porphyritic hornblende-biotite granite xenoliths in the Byeoldobong area, suggesting that the granitic xenoliths from the Byeoldobong were originated from the former rock in the Cheju island.

The above facts suggest that the basement rock of the Cheju volcanic island consist mainly of granitic plutons of Jurassic and Cretaceous ages and Precambrian gneisses, which are typical continental crustal materials found in the peninsula which is particularly analogous to the rock types of basement in the Okchon zone.

ANALYTICAL PROCEDURES

The granitic rock samples were collected from the pyroclastic deposits in the Byeoldobong area and the drilling cores in the Hadeokcheon area. These were crushed to powder for chemical and isotopic analyses.

Major (quoted as weight percent oxides), trace (ppm element up to 5000 ppm) and REE (subppm level) element concentrations were determined on an inductively coupled plasma mass spectrometer (ICP-MS) at Kings College, University of London, England.

K-Ar age dating was carried out by the isotopic dilution method using ^{38}Ar spike on a VG 5400 mass spectrometer at Institute for Study of the Earth's Interior, Okayama University, Japan. K-concentrations were measured on an atomic absorption spectrophotometer with 2% analytical error at Nagoya University, Japan.

Zircon and allanite grains were selected in a thin section to analyze ThO_2 , UO_2 and PbO contents on a JXA-733 electron microprobe at Nagoya University. The analytical procedure and CHIME age calculation were those of Suzuki *et al.* (1994). The instrument conditions were 15 kV accelerating voltage, 0.25 μA probe current on a Faraday cage and 5 μm probe diameter. X-ray intensities are integrated for 300 seconds by means of 5 times cyclic stepping of spectrometer on individual peak and background positions. X-ray intensity data were converted into concentrations by the method of Bence and Albee (1968). The standards were used by Smellie *et al.* (1978) for Th and U, and synthesized glass (10.18 wt.% PbO , Suzuki and Adachi, 1998) for Pb. The detection limits 1σ confidence level are 0.007, 0.01 and 0.003 wt.% for ThO_2 , UO_2 and PbO , respectively. The relative

Table 1. CHIME and K-Ar ages of granitic rocks from the Cheju volcanic island

Method	Rock type	Specimen	Age (Ma)	Remark
CHIME	Porphyritic hornblende-biotite granite from the pyroclastic formation of the Beoldobong area	zircon	173 ± 31	this study
K-Ar	Biotite granite xenolith from the pyroclastic formation of the Beoldobong area	biotite	172.4 ± 5.2	this study
K-Ar	Feldspar granite from the Hadeokcheon area	alkali-feldspar	58.1 ± 1.4	Ahn <i>et al.</i> (1995)
K-Ar	Granite from the Deokcheon (Manjang tunnel) area	whole rock	66.4 ± 1.7	Lee (1996)

errors are *ca.* 30% for 0.01 wt.% of the PbO concentration, 6% for 0.3 wt.% of UO₂ concentration and 1% for 10 wt.% of ThO₂ concentration.

For Sr and Nd isotopic analyses, the conventional standard cation exchange technique using HCl elutant (Dosso and Murthy, 1980) was used to separate Sr and REE (Nd). α -hydroxy isobutyric acid (HIBA) was used to separated Nd from other REEs. Isotopic ratios were measured on a VG sector thermal ionization mass spectrometer at Nagoya University. $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were normalized to $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$ and $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$, respectively. Analysis of standard NBS987 yields a mean $^{87}\text{Sr}/^{86}\text{Sr}$ value of $0.7102530 \pm (10)$.

$^{143}\text{Nd}/^{144}\text{Nd}$ measurements of standard LaJolla and JNdi yielded $0.5118291 \pm (9)$ and $0.5121025 \pm (8)$, respectively. Within-run precision was always insignificant compared to reproducibility of the reference materials. The ϵ_{Sr} and ϵ_{Nd} values were calculated using the model parameters such as $^{87}\text{Sr}/^{86}\text{Sr} = 0.7045$, $^{87}\text{Rb}/^{86}\text{Sr} = 0.0827$, $^{143}\text{Nd}/^{144}\text{Nd} = 0.51264$ and $^{147}\text{Sm}/^{144}\text{Nd} = 0.1967$ (Jacobsen and Wasserburg, 1980; Wasserburg *et al.*, 1981). Depleted mantle parameters for $T_{\text{DM}}^{\text{Nd}}$ model age calculation were $^{143}\text{Nd}/^{144}\text{Nd} = 0.513114$ and $^{147}\text{Sm}/^{144}\text{Nd} = 0.222$ (Michard *et al.*, 1985).

RADIOMETRIC AGES OF THE GRANITIC ROCKS

Only two K-Ar ages for the granitic rock specimens from drilling cores in the Hadeokcheon and Manjang tunnel areas have been reported to be 58.14 ± 1.4 Ma (Ahn *et al.*, 1995) and 66.4 ± 1.7 Ma (Lee, 1996). On the basis of these ages and

lithology of the granitic rocks, previous researchers (Ahn *et al.*, 1995; Lee, 1996; Yun *et al.*, 1999) were led to conclude that the basement rock of the Cheju volcanic island comprises Cretaceous granitic rocks which are the same as those scatteredly distributed in the Kyoungsang sedimentary basin in the south of the Korean peninsula.

K-Ar age

A K-Ar biotite age for a porphyritic hornblende-biotite granite xenolith is obtained to be 172.4 ± 5.2 Ma, corresponding to a Jurassic age (Table 1). This is the first finding of the Jurassic granite and gives constraint for events of plutonism on the island. Particularly in the Jurassic, voluminous syntectonic granitic plutons known as the Daebo granite were widely emplaced during the Daebo orogeny along with the Sinian direction in the Precambrian basement of the peninsula.

Nine alkali volcanic rock samples from the island were taken for radiometric dating. K-Ar ages of the volcanic rocks range from 0.06 to 0.45 Ma, corresponding to the Pleistocene (Table 2). Compilation of the exsisting 43 K-Ar dating results is listed in Appendix and shown Fig. 4. The radiometric age spectrum of the volcanic rocks covers a wide range from 2.2 to 0.03 Ma with periodic intensities of volcanic activities as shown in Fig. 3. The age gap between the plutonism and volcanism in the island is about 60 Ma.

CHIME age

Zircon, monazite and allanite minerals in granitic rocks have their high blocking temperatures

Table 2. K-Ar ages of alkali volcanic rocks and biotite granite from the Cheju volcanic island, Korea

Sample No.	Rock type	K (wt.%)	^{36}Ar (10^{-10} cc/g)	$^{40}\text{Ar}(\text{rad})$ (10^{-8} cc/g)	K-Ar age (Ma)	Atm. ^{40}Ar (%)
JB7	Basaltic trachyandesite	1.84	6.58 ± 0.11	0.89 ± 0.03	0.13 ± 0.01	95.6
JB18	Basalt (Hawaiite)	1.13	4.39 ± 0.09	0.40 ± 0.02	0.09 ± 0.01	96.9
JB26	Basalt (Hawaiite)	1.09	4.18 ± 0.08	1.92 ± 0.05	0.45 ± 0.01	86.5
JB4	Trachybasalt	1.57	4.96 ± 0.97	1.87 ± 0.05	0.31 ± 0.01	88.6
JT19	Basalt	1.10	3.15 ± 0.07	0.35 ± 0.02	0.083 ± 0.004	96.3
CY8	Trachybasalt	1.19	4.17 ± 0.08	1.88 ± 0.05	0.41 ± 0.02	93.3
JS 14	Basalt	0.98	3.88 ± 0.08	0.79 ± 0.03	0.21 ± 0.01	93.3
JSK1	Trachybasalt	1.44	7.51 ± 0.11	0.31 ± 0.03	0.06 ± 0.01	98.5
JE2	Biotite granite (Biotite)	0.90	40.86 ± 0.66	4844.28 ± 48.88	172.36 ± 5.20	2.4

$^{40}\text{Ar}(\text{rad})$ indicates radiogenic argon.

Fig. 4. Location map of radiometric ages of volcanic rocks in the Cheju volcanic island (Lee *et al.*, 1994; Yoon *et al.*, 1995a; KIGAM, 1995; Kim *et al.*, 1999).

for Pb and high concentrations of Th and U (Scharer *et al.*, 1984; Suzuki *et al.*, 1994, 1996; Takeuchi and Suzuki, 2000). For this reason, an isochron age of the CHIME method is used as one suitable tool for radiometric dating (Suzuki and Adachi, 1991; Suzuki *et al.*, 1994). The porphyritic hornblende-biotite granite xenolith from the Byeoldobong pyroclastic formation have rare zircon, monazite and allanite grains. Zircon grains from the granitic rocks are euhedral and extremely small with about $0.2 \mu\text{m}$ across. Relatively clear

crystals were selected for U-Pb analyses.

The ThO_2 , UO_2 and PbO analytical results for zircon and allanite with apparent ages and calculated ThO_2^* or UO_2^* (Suzuki and Adachi, 1991) are listed in Table 3.

Zircon A total of twenty nine spots on six zircon grains from porphyritic hornblende-biotite granite (Sample No. CB-2) were analyzed. The ThO_2 and UO_2 contents range from 0.004 to 0.281 wt.% and from 0.015 to 0.583 wt.%, respectively. Zircons have a relatively low content of PbO and a large

Fig. 5. Plots of PbO vs. UO₂* for zircon and PbO vs. ThO₂* for allanite in the granite (Sample No. CB-2) from the Cheju volcanic island, Korea. Data designated by open circle are from another allanite grain which is not shown in this microphotography. Data expressed by cross marks confirmed that most analytical spots are closely related to cracks in allanite grain. UO₂*: sum of the measured UO₂ and UO₂ equivalent of the measured ThO₂ for zircon. ThO₂*: sum of the measured ThO₂ and ThO₂ equivalent of the measured UO₂ for allanite. Error bars in the figure represent 2 σ analytical uncertainty, and errors given to the age of 2 σ . MSWD: mean square of weighted deviates.

Table 3. Electron microprobe analyses of UO_2 , ThO_2 and PbO of zircon and allanite grains from porphyritic hornblende-biotite granite (Sample No. CB-2) in the Byeoldobong volcano pyroclastic sediments, Cheju volcanic island

	ThO_2 (wt.%)	UO_2 (wt.%)	PbO (wt.%)	Age (Ma)	UO_2^* (wt.%)
Z01-01	0.031	0.164	0.0045	192	0.173
Z01-02	0.100	0.223	0.0064	186	0.254
Z01-03	0.060	0.213	0.0055	176	0.232
Z01-04	0.159	0.448	0.0111	165	0.498
Z01-05	0.281	0.583	0.0164	181	0.670
Z02-01	0.017	0.139	0.0031	159	0.145
Z02-02	0.089	0.250	0.0069	184	0.278
Z02-03	0.050	0.181	0.0038	144	0.196
Z02-04	0.059	0.099	-1.0000	0	0.000
Z02-05	0.057	0.130	0.0033	166	0.147
Z03-01	0.019	0.136	0.0039	204	0.141
Z03-02	0.092	0.295	0.0071	163	0.324
Z04-01	0.008	0.270	0.0049	134	0.272
Z04-02	0.019	0.308	0.0088	207	0.313
Z04-03	0.010	0.266	0.0067	184	0.269
Z04-04	0.017	0.127	0.0039	217	0.133
Z04-05	0.023	0.350	0.0095	197	0.357
Z05-01	0.008	0.057	-1.0000	0	0.000
Z05-02	0.004	0.015	-1.0000	0	0.000
Z05-03	0.004	0.051	-1.0000	0	0.000
Z05-04	0.016	0.097	-1.0000	0	0.000
Z06-01	0.009	0.110	0.0031	204	0.112
Z06-02	0.052	0.112	0.0044	252	0.128
Z06-03	0.075	0.165	0.0050	197	0.188
Z06-04	0.027	0.148	0.0030	142	0.157
Z06-05	0.008	0.122	0.0030	179	0.124
Z06-06	0.029	0.179	0.0053	208	0.188
Z06-07	0.017	0.183	0.0045	177	0.188
Z06-08	0.026	0.158	0.0038	170	0.166

range from less than detection limit to 0.0164 wt.%. Therefore, apparent ages, to some extent, were obtained to be a wide range from 134 to 252 Ma (Table 3). However, all zircon analytical data lie on a line on the PbO versus UO_2^* diagram, and give a well defined isochron age of 169 ± 29 Ma (MSWD = 0.44) (Fig. 5).

Allanite Forty nine spots on three allanite grains from the granite (Sample No. CB-2) were analyzed. The ThO_2 content ranges from 0.897 to 1.705 wt.%, and the UO_2 content from 0.009 to 0.082 wt.% and the PbO content from 0.0039 to 0.0162 wt.%. On the PbO - ThO_2^* diagram, the data of thirty eight analytical spots define an isochron age of 183 ± 40 Ma (MSWD = 0.24) (Fig. 5). Some data designated by cross marks on the allanite grain and on PbO - ThO_2^* diagram were plotted

scatteredly as shown in Fig. 5. The lead loss of allanite grain during the hydrothermal alteration processes can be considered. These scattered analytical spots located in the vicinity of cracks in the allanite grain can cause more easily lead loss during the alteration processes. Therefore, this kind of EPMA analytical data on the allanite grains failed to give an isochron.

Even though above CHIME ages from two different minerals have a wide range, the ages are overlapped within analytical errors, suggesting age of Jurassic. These CHIME ages coincide with the K-Ar age of 172.4 ± 5.2 Ma. This new radiometric age provides us an important information for the evolution of the basement in the Cheju volcanic island.

Table 3. (continued)

	ThO ₂ (wt.%)	UO ₂ (wt.%)	PbO (wt.%)	Age (Ma)	ThO ₂ *
A01-01	1.130	0.009	0.0095	195	1.15
A01-03	1.010	0.019	0.0068	150	1.07
A01-04	1.330	0.013	0.0095	164	1.37
A01-05	1.030	0.018	0.0079	171	1.09
A01-06	0.956	0.035	0.0061	135	1.07
A02-01	1.030	0.020	0.0079	171	1.09
A02-02	1.000	0.016	0.0075	168	1.05
A02-03	0.897	0.021	0.0093	228	0.97
A02-04	1.020	0.030	0.0067	142	1.12
A02-05	1.040	0.019	0.0082	176	1.10
A03-01	1.450	0.056	0.0059	86	1.63
A03-02	1.413	0.055	0.0110	164	1.59
A03-03	1.423	0.037	0.0129	198	1.54
A03-04	1.010	0.061	0.0084	165	1.21
A03-05	1.043	0.064	0.0089	168	1.25
A03-06	1.511	0.031	0.0116	170	1.61
A03-07	1.142	0.036	0.0068	128	1.26
A03-08	1.705	0.043	0.0162	208	1.84
A03-09	1.140	0.029	0.0089	171	1.23
A03-10	1.294	0.033	0.0093	157	1.40
A03-11	1.026	0.026	0.0039	83	1.11
A03-12	1.081	0.028	0.0054	109	1.17
A03-13	1.038	0.032	0.0084	174	1.14
A03-14	1.075	0.031	0.0080	161	1.17
A03-15	1.075	0.033	0.0057	114	1.18
A03-16	1.041	0.025	0.0081	171	1.12
A03-17	1.096	0.031	0.0103	204	1.20
A03-18	1.001	0.035	0.0090	191	1.11
A03-19	1.084	0.038	0.0041	80	1.21
A03-20	1.043	0.027	0.0069	145	1.13
A03-21	1.006	0.032	0.0091	194	1.11
A03-22	1.649	0.039	0.0129	172	1.78
A03-23	1.097	0.029	0.0094	187	1.19
A03-24	1.161	0.031	0.0053	99	1.26
A03-25	1.196	0.038	0.0094	169	1.32
A03-26	1.362	0.047	0.0114	178	1.51
A03-27	1.371	0.042	0.0092	145	1.50
A03-28	1.113	0.033	0.0090	175	1.22
A03-29	1.089	0.025	0.0079	160	1.17
A03-30	1.326	0.047	0.0103	165	1.48
A03-31	1.274	0.084	0.0130	199	1.54
A03-32	1.061	0.023	0.0074	154	1.13
A03-33	1.274	0.030	0.0106	183	1.37
A03-34	1.348	0.082	0.0139	204	1.61
A03-35	1.306	0.035	0.0102	170	1.42
A03-36	1.006	0.024	0.0080	175	1.08
A03-37	1.238	0.038	0.0049	85	1.36
A03-38	1.072	0.033	0.0095	191	1.18

Z: zircon, A: allanite, -1: less than detection limit.

UO₂*: Sum of the measured UO₂ and UO₂ equivalent of the measured ThO₂ for zircons.

ThO₂*: Sum of the measured ThO₂ and ThO₂ equivalent of the measured UO₂ for allanites.

Fig. 6. Plot of major oxides vs. SiO_2 for granitic rocks from the Cheju volcanic island. The dashed and shaded fields are the Bulguksa and Daebo granites, respectively, in South Korea (Kim et al., 1996). XB: granite xenolith from the Beoldobong area (this study), HG-1: Granite from the Hadeokcheon area (this study), JSG: Granite from the Jungshil and Seongeup area (this study), Granite from the Hadeokcheon area (Ahn et al., 1995; Yun et al., 1998).

Table 4. Major and trace elements of granitic rocks from the Cheju volcanic island

Sample No.	CB-1	CB-2	CB-3	CB-4	CB-5	CB-6	CB-9	CH-1	CH-2	CH-3	M-C	C-1350	C-1200
SiO ₂ (wt.%)	72.35	66.08	67.79	69.29	73.02	69.01	69.25	70.54	73.36	69.75	75.54	76.32	75.26
Al ₂ O ₃	14.36	18.21	16.83	15.67	14.16	16.04	16.44	15.40	13.92	14.72	13.15	12.92	13.32
Fe ₂ O ₃	2.95	2.83	3.25	2.92	2.47	2.71	2.86	3.09	2.11	3.53	1.29	1.13	1.65
MgO	0.98	0.91	1.00	0.80	0.72	0.91	0.81	0.79	0.45	1.18	0.20	0.16	0.17
CaO	2.55	3.21	3.55	3.22	3.07	2.45	3.66	3.14	1.83	1.86	0.70	0.42	0.77
Na ₂ O	3.84	5.20	4.50	3.87	3.83	4.92	4.12	3.90	3.47	3.31	1.06	4.26	4.39
K ₂ O	1.66	2.20	1.63	2.75	1.33	2.63	1.50	1.60	3.68	4.31	4.14	3.36	4.24
TiO ₂	0.42	0.42	0.50	0.52	0.45	0.41	0.44	0.47	0.37	0.48	0.15	0.15	0.14
P ₂ O ₅	0.16	0.18	0.20	0.22	0.20	0.15	0.19	0.16	0.10	0.13	0.04	0.03	0.04
MnO	0.05	0.08	0.07	0.06	0.07	0.09	0.05	0.03	0.03	0.05	0.05	0.04	0.05
LOI	0.60	0.70	0.40	0.72	0.58	0.58	0.68	0.72	0.50	0.60	1.60	1.20	0.59
Total	99.20	100.20	99.72	100.40	99.90	99.90	100.00	100.40	99.82	99.92	98.00	99.99	100.60
Ba (ppm)	434	550	374	831	294	678	360	534	742	727	886	1067	801
Co	7	8	9	8	7	9	3	4	3	5	1	4	1
Cr	18	14	13	22	20	20	10	4	3	29	25	14	7
Cu	3	4	2	6	3	3	5	4	3	7	2	6	9
Li	14	14	17	14	13	10	19	28	66	15	20	n.d.	n.d.
Nb	8	8	9	9	9	9	n.d.	n.d.	n.d.	n.d.	8	17	15
Ni	20	16	18	21	17	21	9	6	6	19	14	4	77
Sc	4	3	4	3	3	3	3	3	2	7	3	3.6	2.6
Sr	517	834	718	674	561	830	603	580	413	370	110	188	140
V	31	26	31	27	24	26	21	22	18	53	5	3.2	2
Y	7	6	7	6	6	6	8	9	11	20	11	27	20
Zn	56	74	75	56	63	78	82	83	65	58	20	98	118
Zr	13	13	11	10	9	12	16	15	26	34	24	107	n.d.
Rb	57	67	58	79	47	71	67	54	193	180	144	260	135

CB-1: Feldspar porphyritic medium grained biotite granite, CB-2: Porphyritic hornblende-biotite granite, CB-3: CB-4: Medium grained hornblende granite, CB-5: Medium grained biotite granite, CB-6: Pink feldspar porphyritic hornblende granite, CB-9: Biotite granite, CH-1: Medium grained feldspar porphyritic hornblende-biotite granite, CH-2: Fine grained biotite granite, CH-3: Granophyre, M-C: Micrographic granite (Yun et al., 1998), C-1350: Micrographic granite, C-1200: Micrographic granite (Ahn et al., 1995), n.d.: not determined.

GEOCHEMISTRY OF THE GRANITIC ROCKS

Detailed petrographic descriptions of granite xenoliths and some drilled core samples were given by Ahn *et al.* (1995) and Yun *et al.* (1999). Based on concentrations of major elements including SiO_2 , Al_2O_3 , CaO , MgO , Na_2O , K_2O and P_2O_5 , granitic rocks from the Cheju island are grouped into two groups: a high SiO_2 -low oxides and vice versa. In terms of silicate and oxides, Al_2O_3 , Fe_2O_3 , CaO , MgO , TiO_2 and P_2O_5 show a negative trend. However, K_2O shows a reverse trend.

These trends are characterized by Mesozoic granites such as Daebo and Bulguksa granites in the peninsula (Fig. 6, Table 4). The SiO_2 content of the Bulguksa granite (avg. 74.58%) is higher than those of the Daebo granite (avg. 68.12%) (Kim, 1992; Hong, 1987). Granitic rocks from the Hadeokcheon drilling core (Sample Nos. M-C, C-1350 and C-1200) have high SiO_2 contents ranging from 75.26 to 76.32 wt.%, similar to those of the Cretaceous Bulguksa granite ($\text{SiO}_2 = 67.03\sim 79.43$, Kim, 1992). On the other hand, several granitic xenoliths from the Byeoldobong area

Fig. 7. Relationship between SiO_2 and trace elements for granitic rocks from the Cheju volcanic island. Symbols are the same as in Fig. 6.

Table 5. Data of rare earth element (REE) for granitic rocks in the Cheju volcanic island

	CB-1	CB-2	CB-3	CB-4	CB-5	CB-6	CB-9	CH-1	CH-2	CH-3	M-C	C-1350	C-1200
La (ppm)	60.02 (181.9)	43.1 (130.6)	41.63 (126.2)	46.25 (140.1)	53.56 (162.3)	26.91 (81.6)	48.00 (145.5)	43.00 (130.3)	40.00 (121.2)	42.00 (127.3)	43.18 (130.9)	51.19 (155.2)	33.20 (100.6)
Ce	110.95 (128.3)	80.05 (92.5)	78.34 (90.6)	86.69 (100.2)	102.35 (118.3)	51.75 (59.8)	84.00 (97.1)	77.00 (89.0)	70.00 (80.9)	78.00 (90.2)	82.22 (95.1)	101.12 (116.9)	58.00 (67.1)
Pr	12.74 (104.4)	9.36 (76.7)	9.22 (75.6)	10.32 (84.6)	11.66 (95.6)	6.27 (51.4)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	9.17 (75.2)	10.51 (86.2)	n.d. (n.d.)
Nd	45.05 (71.5)	33.83 (53.7)	32.83 (52.1)	35.71 (56.7)	40.52 (64.3)	22.24 (35.3)	33.00 (52.4)	35.00 (55.6)	32.00 (50.8)	37.00 (58.7)	29.24 (46.4)	33.81 (53.7)	18.00 (28.6)
Sm	6.34 (31.2)	4.81 (23.7)	4.79 (23.6)	4.98 (24.5)	5.76 (28.4)	3.38 (16.7)	5.70 (28.1)	5.20 (25.6)	4.70 (23.2)	5.80 (28.6)	4.14 (20.4)	5.62 (27.7)	3.40 (16.8)
Eu	1.27 (16.5)	1.32 (17.1)	1.30 (16.9)	1.25 (16.2)	1.29 (16.8)	1.24 (16.1)	1.10 (14.3)	1.30 (16.9)	0.90 (11.7)	1.00 (13.0)	0.76 (9.9)	0.87 (11.3)	0.50 (6.5)
Gd	3.56 (12.9)	2.96 (10.8)	3.04 (11.1)	3.01 (10.9)	3.25 (11.8)	2.28 (8.3)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	2.93 (10.6)	5.07 (18.4)	n.d. (n.d.)
Dy	1.76 (5.1)	1.64 (4.8)	1.78 (5.2)	1.58 (4.6)	1.62 (4.7)	1.38 (4.0)	1.80 (5.3)	1.80 (5.3)	2.10 (6.1)	3.30 (9.6)	2.41 (7.0)	3.61 (10.5)	n.d. (n.d.)
Ho	0.26 (3.4)	0.26 (3.4)	0.29 (3.8)	0.25 (3.3)	0.28 (3.7)	0.21 (2.8)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	0.48 (6.3)	0.74 (9.7)	n.d. (n.d.)
Er	0.55 (2.5)	0.62 (2.8)	0.73 (3.2)	0.63 (2.8)	0.61 (2.7)	0.55 (2.4)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	1.53 (6.8)	2.26 (10.1)	n.d. (n.d.)
Yb	0.41 (1.9)	0.46 (2.1)	0.58 (2.6)	0.38 (1.7)	0.42 (1.9)	0.39 (1.8)	0.40 (1.8)	0.50 (2.3)	0.60 (2.7)	1.60 (7.3)	1.46 (6.6)	2.45 (11.1)	1.90 (8.6)
Lu	0.05 (1.6)	0.06 (1.8)	0.07 (2.1)	0.05 (1.6)	0.09 (2.6)	0.04 (1.3)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	n.d. (n.d.)	0.22 (6.6)	0.36 (11.0)	0.3 (8.8)
(Eu/Sm) _a	0.20	0.27	0.27	0.25	0.22	0.37	0.19	0.25	0.19	0.17	0.18	0.16	0.15
ΣREE	242.96	178.47	178.6	191.1	221.41	116.64	174.0	163.8	150.3	168.7	177.74	218.65	115.8
LREE/HREE	16.11	13.71	12.88	14.75	15.62	11.32	18.33	17.61	17.11	13.42	11.76	9.37	16.55

Numerical value in parenthesis is chondrite normalised value (Nakamura, 1974). Data for C-1350 and C-1200 after Ahn et al. (1995). n.d.: not determined.

and two drilling core samples (Sample Nos. JS and S) from the Jeongshil and Seongeup areas have rather low SiO_2 contents ranging from 66.08 to 73.36 wt.%. These are in a compositional range of the Jurassic Daebo granite ($\text{SiO}_2 = 55.30\sim 75.74$, Kim, 1992). Compared to Mesozoic granitoids, the granite xenoliths relatively scatter in trace element contents (Fig. 7). The Sr contents of these granitic rocks is 370~834 ppm. It is compared with 174~681 ppm of Sr in the Daebo granite not with the Bulguksa granite of 6~197 ppm (Kim, 1992). In general, granitic rocks in the Cheju island have peraluminous and calc alkalic characteristics which are commonly shown by Mesozoic granitic rocks in the peninsula.

Total concentrations of REE range from 115.8

to 242.9 ppm (Table 5). LREE/HREE ratios are 9.4~16.6 and show a relative enrichment in LREE. REE patterns of granitic rocks from the Byeoldobong, Joengshil and Seongeup areas resemble those of the Jurassic Daebo granite with HREE depletion and weak or lacking Eu anomaly, suggesting a deep seated crustal origin of the granitic magma. In addition, the Beoldobong granite xenoliths and the Hadeokcheon granite core samples show a relatively low $(\text{Eu}/\text{Sm})_n$ value of 0.15~0.37. Whereas, granitic rocks from the Hadeokcheon and Manjang tunnel areas have distinct Eu negative anomalies and also have REE patterns concordant to those of the Cretaceous Bulguksa granite (Fig. 8). As shown in Fig. 8, the Cretaceous Bulguksa granites have less depleted

Fig. 8. Chondrite normalised REE patterns of granitic rocks from the Cheju volcanic island. REE abundances were normalised by the data of Nakamura (1974). The shadow and hatched fields represent the Bulguksa granite and the Daebo granite, respectively, in South Korea (Hong, 1987).

REE patterns with marked Eu negative anomaly. This signature indicates the shallow emplacement of granitic magma which is originated from the mantle source materials (Kim *et al.*, 1996). Lee (1992, 1994) and Cho and Kwon (1994) also pointed out that the Cretaceous granites in the Kyongsang basin have emplaced at shallow depth based on the petrographical and petrochemical data. The similarity in chemical composition and lithology of two groups of granitic rocks from the Cheju Island and the peninsula favors an interpretation of the similar petrogenetic setting for the whole Korean peninsula together with the island.

Nd AND Sr ISOTOPES OF GRANITIC ROCKS

Strontium and neodymium isotopes have much information to offer about magmatic processes as well as source rocks (Farmer and Depaolo, 1983; Roden *et al.*, 1994; Kim *et al.*, 1996; Wilson and Shimron, 2000). Analytical results of Nd and Sr isotopes for granitic rocks from the Cheju Island are given in Table 6. Homogeneous strontium isotopic compositions of feldspar ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7174$), hornblende ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7167$) and the host whole rock ($^{87}\text{Sr}/^{86}\text{Sr} = 0.7171$) sample (Sample No. CB-1) indicate that the Nd-Sr system seems to be little affected by later isotopic exchange with sea and/or meteoric waters during post-magmatic alteration processes. As shown in Table 6, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of granitic rocks from the Cheju island vary widely from 0.7108 to 0.7229 (avg. 0.7162). Especially granitic rocks in the Byeoldobong area known as the Jurassic age are characterized by high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios ranging from 0.7116 to 0.7229 (initial ratio ($^{87}\text{Sr}/^{86}\text{Sr}$)_i = 0.7156 to 0.7164, $\epsilon_{\text{Sr}} = 101\sim 179$). These strontium isotopic compositions are very similar to those of the Jurassic Daebo granites (0.7111~0.7164, $\epsilon_{\text{Sr}} = 97\sim 170$, Kim *et al.*, 1996) in the peninsula. On the other hand, the Cretaceous granite from the Hadeokcheon area (Sample No. M-C) has a relatively low $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.7108 (initial ratio ($^{87}\text{Sr}/^{86}\text{Sr}$)_i = 0.7077). This value falls in the isotopic range of the Cretaceous Bulguksa granite (initial ratio ($^{87}\text{Sr}/^{86}\text{Sr}$)_i = 0.7042 to

Table 6. Sr and Nd isotopic compositions of some granitic rocks from the Cheju volcanic island

Sample No.	Age (Ma)	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	ϵ_{Sr} (T)	$^{87}\text{Sr}/^{86}\text{Sr}$ initial ratio	Sm (ppm)	Nd (ppm)	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$	ϵ_{Nd} (T)	$^{143}\text{Nd}/^{144}\text{Nd}$ initial ratio	$T_{\text{DM}}^{\text{Nd}}$ (Ga)
CB-1 (WR)	172.4	57	517	0.3193	0.71714	179.4	0.71636	6.34	45.05	0.0856	0.511653	-19.2	0.511556	1.6
CB-2 (WR)	172.4	67	834	0.2327	0.71652	170.6	0.71595	4.18	33.83	0.0752	0.511668	-18.9	0.511583	1.5
CB-3 (WR)	172.4	58	718	0.2339	0.71662	172.0	0.71605	4.79	32.83	0.0888	0.511668	-18.9	0.511568	1.7
CB-4 (WR)	172.4	79	674	0.3395	0.71698	177.1	0.71615	4.98	35.71	0.0849	0.511660	-19.1	0.511564	1.6
CB-5 (WR)	172.4	47	561	0.2426	0.71664	172.3	0.71605	5.76	40.52	0.0865	0.511668	-18.9	0.511570	1.6
CB-6 (WR)	172.4	71	830	0.2477	0.71622	166.4	0.71561	3.38	22.24	0.0925	n.d.	n.d.	n.d.	n.d.
M-C (WR)	58.14	144	110	3.7913	0.71083	89.9	0.70770	4.14	29.24	0.0862	0.512213	-8.3	0.512180	1.0
JE-1 (WR)	172.4	n.d.	n.d.	n.d.	0.72292	261.5	n.d.	n.d.	n.d.	n.d.	0.511715	-18.0	n.d.	n.d.
JE-2 (WR)	172.4	n.d.	n.d.	n.d.	0.71159	100.6	n.d.	n.d.	n.d.	n.d.	0.511904	-14.3	n.d.	n.d.
CB-1 (Fd)	172.4	n.d.	n.d.	n.d.	0.71748	184.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CB-1 (Hb)	172.4	n.d.	n.d.	n.d.	0.71674	173.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CB-8 (WR)	172.4	74	365	0.5872	0.71295	119.9	0.71151	6.12	33.49	0.1112	0.512291	-6.8	0.512166	n.d.

Fd: Feldspar, Hb: Hornblende, WR: Whole rock, JE-1: Pink-feldspar porphyritic hornblende-biotite granite, JE-2: Biotite granite, CB-8: Andesite, n.d.: not determined. Data of Rb, Sr, Sm and Nd concentrations were from Tables 4 and 5.

Fig. 9. $\epsilon_{Sr}(t)$ vs. $\epsilon_{Nd}(t)$ of isotope correlation diagram of granitic rocks in the Cheju volcanic island. Isotope data for Daebo granite (dashed area) and Bulguksa granite (shaded area) (Kim *et al.*, 1996) and volcanic rocks, Cheju island (Kim *et al.*, 1999). Symbols are the same as in Fig. 6. Diamond symbol indicates andesite (Sample No. CB-8).

0.7067, Kim *et al.*, 1996). Rb and Sr in the Jurassic granitic rocks from the Cheju Island varies from 47 to 79 ppm and 561 to 834 ppm, respectively. According to Kim *et al.* (1996), the Jurassic Daebo granites from the peninsula show large range in Rb (56.8 to 182.4 ppm) and Sr (18 to 762.7 ppm). The Cretaceous granite from the Hadeokcheon area have 144 ppm of Rb and 110 ppm of Sr, which are fall in the range of the Cretaceous Bulguksa granite in the peninsula (Rb = 89.7~314.4 ppm, Sr = 44.4~308.0 ppm, Kim *et al.*, 1996).

The $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of the Jurassic granites from the Byeoldobong area range from 0.51165 to 0.51190 ($\epsilon_{\text{Nd}} = -19 \sim -14$), and fall in the range of the Daebo granite ($\epsilon_{\text{Nd}} = -19 \sim -10$, Kwon and Tilton, 1992; $\epsilon_{\text{Nd}} = -21 \sim -14$, Kim *et al.*, 1996) (Fig. 9). Meanwhile the Cretaceous granite from the Hadeokcheon area has $^{143}\text{Nd}/^{144}\text{Nd}$ value = 0.51221 (initial ratio ($^{143}\text{Nd}/^{144}\text{Nd}$)_i = 0.51218, $\epsilon_{\text{Nd}} = -8.3$). This value is compared to the Cretaceous equivalent ($\epsilon_{\text{Nd}} = -6.6$ to 0.4) in the Okcheon zone. The Jurassic Byeoldobong granites have slightly higher concentrations of Nd (22.2~45.05 ppm) and Sm (3.38~6.34 ppm) than those of the Cretaceous Hadeokcheon granite (Nd = 29.24 ppm, Sm = 4.14 ppm). However, the Sm and Nd contents of the Daebo granites (Sm = 3.7~13.8

ppm, Nd = 18.0~34.0 ppm) have roughly the same range as those of the Bulguksa granites (Sm = 1.7~7.1 ppm, Nd = 7.0~34.0 ppm) (Kim *et al.*, 1996).

Based on the plots of ϵ_{Sr} versus ϵ_{Nd} , Kim *et al.* (1996) suggested that the Cretaceous granitic rocks in the Kyoungsang basin were derived from a mantle source. On the other hand, the Jurassic ones were interpreted as partial melting products of lower crustal material and/or material with significant crustal contribution in mantle derived components (Kim *et al.*, 1996). The Nd-Sr isotopic and Rb-Sr concentration data of granitic rock from the Cheju island provides a similar source regime of calc alkaline magma in the peninsula.

Calculated $T_{\text{DM}}^{\text{Nd}}$ model ages are given in Table 6. The $T_{\text{DM}}^{\text{Nd}}$ model ages from Jurassic granites in Cheju island range from 1.1 to 1.7 Ga (avg. 1.5 Ga), corresponding to middle Proterozoic age. Inferred model ages agree with those of Jurassic granites (1.5 to 2.3 Ga, Kwon and Tilton, 1992; 1.7 to 1.9 Ga, Kim *et al.*, 1996) in the Okchon zone in the peninsula. On the other hand, Cretaceous granite (Sample No. M-C) yielded a little younger model age of 1.0 Ga (Table 6). These model ages suggest that a Proterozoic basement exist beneath the Cheju volcanic island and the

Mesozoic plutons in the island have evolved since mid-Proterozoic time in accordance with those of the peninsula.

DISCUSSION

The basement of Cheju volcanic island has been considered to be made of Cretaceous volcanics and granitic rocks and to be the extension of the Kyoungsang sedimentary basin of the peninsula (Lee, 1982; Koh *et al.*, 1993; Sohn and Yoon, 1995). However, in this study, the Jurassic granites were firstly identified by K-Ar and CHIME dating of the granite xenoliths from the pyroclastic formation of the Byeoldobong area in the vicinity of Cheju city. This finding is very important in correlating the basement geology to that in the Korean peninsula. The ages of the granites in the Cheju island correspond to those of the Jurassic Daebo and Cretaceous Bulguksa granites. In addition, geochemical and Nd-Sr isotopic data for the granites in the Cheju island also evidently indicate the presence of two groups which correspond to above two (Figs. 6 and 9).

The Korean peninsula located at the eastern margin of the Sino-Korean craton is widely underlain by a Precambrian metamorphic basement. Based on the geology and tectonic framework, South Korea is divided into five geological provinces: (1) Gyeonggi massif, composed mainly of Precambrian metamorphic rocks and Jurassic granites, (2) Okchon zone composed mainly of Precambrian to Cretaceous metamorphic and sedimentary rocks and Jurassic to Cretaceous granitic rocks, (3) Ryeongnam massif composed mainly of Precambrian metamorphic rocks and Permian to Cretaceous igneous rocks, (4) Kyoungsang sedimentary basin, consisting of Cretaceous sedimentary and igneous rocks and (5) Tertiary sedimentary and volcanic basin, including the Cheju and Ulreung volcanic islands (Fig. 1).

Four plausible candidates for the basement rock of the Cheju volcanic island can be made. (1) Cretaceous sedimentary and igneous rocks of the Kyoungsang basin, (2) metasedimentary and igneous rocks of the Okchon zone (3) Precambrian

metamorphic rocks and Permian to Jurassic granitic rocks of the Ryeongnam massif and (4) oceanic basaltic rocks of the Tertiary volcanic basin.

(1) Many previous workers (e.g., Haraguchi, 1929; Ahn *et al.*, 1995; Lee, 1996; Koh, 1997; Yoon, 1997) proposed that the basement rocks of the Cheju Island could be Cretaceous volcanogenic sedimentary and igneous rocks in the Kyoungsang basin. This hypothesis has been strongly supported by the identification of Cretaceous granites in the Haduckcheon and Manjang tunnel areas, which have petrographic features quite similar to those of micrographic granites in the Kyoungsang basin. However, no Jurassic granite and/or Precambrian metamorphic rocks are present in this basin.

(2) Occurrence of the Jurassic granites in the Cheju volcanic island provides a significant constraint on this problem. These granites have Nd and Sr isotopic signatures, Nd model ages and geochemical characteristics similar to those of the Jurassic Daebo granite in the Korean peninsula. In contrast, Nd and Sr isotopic compositions of the Cretaceous granites in the island are similar to those of the Cretaceous granites in the peninsula. In the Cheju island, presence of Jurassic and Cretaceous granitoids with geochemical and isotopic characteristics comparable to those of Daebo and Bulguksa granites, respectively is a strong evidence for the correlation of the continental basement with the Okchon zone. The basement of Okchon zone consists mainly of metasedimentary rocks such as gneiss and schist of Precambrian age. The Jurassic and Cretaceous granitic rocks have emplaced in the metasedimentary rocks. Present geologic informations on basement rocks in Cheju volcanic island provide, to a large extent, a consistency of basement rock types in lithological and chronological aspects between the island and the Okchon zone.

(3) The Ryeongnam massif is represented by Precambrian gneiss and Permian to Jurassic granites (Lee *et al.*, 1997, 1998). Cretaceous volcanic and sedimentary rocks are limited. Thus the geology of this massif is different from the basement geology of the Cheju island.

(4) Oceanic basaltic crust in the Cheju island is discarded because of the occurrence of Mesozoic granitic rocks and Precambrian gneiss fragments in some volcanic sequences. Crust-mantle boundary was estimated to be at depth of *ca.* 40 km by the olivine-clinopyroxene geobarometer (Choi *et al.*, 2000).

On the basis of the geological and tectonic provinces, Kim (1975) reported that the Cheju island belongs to Tertiary basin as shown in Fig. 1. However, combined geochemical and Nd-Sr isotopical characteristics and radiometric ages of the granitic rocks from Cheju Island indicate that the basement of the island is correlated with the Okchon zone rather than the Kyoungsang sedimentary basin. In addition, calculated T_{DM}^{Nd} model ages ranging from 1.1 to 1.7 Ga for the Jurassic granites in the island are also comparable to those of Jurassic granites (1.7 to 1.9 Ga, Kim *et al.*, 1996) in the Okchon zone in the peninsula. Thus, it is suspected that the Okchon zone, known as a highly mobile belt (Kim, 1970; Cluzel, 1991), extends to the south China block through the Cheju island. Most Korean geologists (e.g., Lee, 1982; Won *et al.*, 1986; Park and Kwon, 1993; Park, 1994; Park *et al.*, 1996; Chough *et al.*, 2000) have believed that the Cheju alkali volcanism was originated from intraplate hot spots beneath the Tertiary sedimentary and volcanic basin. However, in the tectonic view point, we are led to conclude that the Cheju alkali volcanism occurred in close relation to the tectonism of the Okchon folded belt. Occurrence of Tertiary basalt flow with lots of lehrerite mantle xenoliths from the Jokokri in the Okchon zone (Kim *et al.*, 1988) can also support the above conclusion.

CONCLUSION

Granitic xenoliths including biotite granite, porphyritic hornblende-biotite granite and two mica granite from the pyroclastic formation of the Beoldobong area and granite core samples from the Hadeokcheon area were used to investigate the petrochemistry, evolution and age of emplacement of the plutonic rocks.

Dating of the porphyritic hornblende-biotite granites yielded a biotite K-Ar age of 172.4 ± 5.2 Ma and CHIME ages ranging from 169 ± 29 Ma to 183 ± 40 Ma. These are concordant with each other, and indicate the Jurassic plutonic activity during the Daebo orogeny.

Geochemical and Nd-Sr isotopic signatures of Jurassic granite xenoliths from the Beoldobong area are comparable to those of the Jurassic Daebo granites in the Korean peninsula. On the other hand, Cretaceous micrographic granites from the Hadeokcheon and Manjang tunnel areas, in terms of lithological, chronological, geochemical and isotopical characteristics, correspond to those of the Cretaceous granite in the peninsula. These suggest that the basement of Cheju volcanic island had experienced the same plutonic activities as those in the peninsula, especially in the Okchon zone. Furthermore, the Nd model ages for the granitic plutons in the island ranging from 1.0 to 1.7 Ga imply that the basement of the island has evolved since mid-Proterozoic time as in the Okchon zone of the peninsula. In the view of tectonic division, the Cheju volcanic island possibly belongs to the intraplate Okchon zone lying on the southeast continental margin of the Eurasian plate.

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APPENDIX

Table A1. Summary of K-Ar age data of volcanic rocks from the Cheju volcanic Island

Sample No.	Rock type		Age (Ma)	Reference
DH-1	Mugearite	wr	0.618 ± 0.017	Lee <i>et al.</i> (1994)
14-1	Benmorite	wr	0.711 ± 0.021	Lee <i>et al.</i> (1994)
26-2	Basalt	wr	0.121 ± 0.018	Lee <i>et al.</i> (1994)
P1	Basalt	—	2.22 ± 0.16	Yoon <i>et al.</i> (1995a)
C15	Basalt	wr	0.16	KIGAM (1995)
C39	Basalt	wr	0.16	KIGAM (1995)
C1	Trachyte	wr	0.025	KIGAM (1995)
C13	Basalt	wr	0.07	KIGAM (1995)
C14	Basalt	wr	0.47	KIGAM (1995)
C37	Basalt	wr	0.05	KIGAM (1995)
C26	Basalt	wr	0.27	KIGAM (1995)
C38	Basalt	wr	0.60	KIGAM (1995)
C12	Basalt	wr	0.63	KIGAM (1995)
C35	Basalt	wr	0.70	KIGAM (1995)
C17	Basalt	wr	0.31	KIGAM (1995)
C33	Basalt	Fd	0.11	KIGAM (1995)
C29	Basalt	wr	0.37, 0.51	KIGAM (1995)
C28	Basalt	wr	0.12, 0.15	KIGAM (1995)
C27	Basalt	wr	0.17, 0.18	KIGAM (1995)
C18	Trachyte	wr	0.50	KIGAM (1995)
C16	Basalt	wr	0.55	KIGAM (1995)
C3	Trachyte	wr	0.73	KIGAM (1995)
C4	Trachyte	wr	0.73	KIGAM (1995)
C6	Trachyandesite	wr	0.41	KIGAM (1995)
C20	Trachyte	wr	0.17, 0.19	KIGAM (1995)
C24	Basalt	wr	0.10	KIGAM (1995)
C19	Trachyte	wr	0.89, 0.92	KIGAM (1995)
C43	Basalt	wr	1.20	KIGAM (1995)
C9	Basalt	wr	0.6	KIGAM (1995)
C7	Basalt	wr	0.035	KIGAM (1995)
C8	Basalt	wr	0.07	KIGAM (1995)
C2	Trachyte	wr	0.75	KIGAM (1995)
C10	Trachyte	wr	0.87	KIGAM (1995)
C25	Basalt	wr	1.20	KIGAM (1995)
C44	Tachyte	wr	0.94	KIGAM (1995)
C15	Basalt	wr	0.52	KIGAM (1995)
C21	Basalt	wr	0.69, 0.71	KIGAM (1995)
C36	Basalt	wr	0.16	KIGAM (1995)
C42	Basalt	wr	0.17	KIGAM (1995)
C22	Basalt	wr	1.19, 0.12	KIGAM (1995)
SYU	Basalt	wr	0.07	Kim <i>et al.</i> (1999)
SYL	Basalt	wr	0.02	Kim <i>et al.</i> (1999)
SPU	Basalt	wr	0.84	Kim <i>et al.</i> (1999)

wr: whole rock, Fd: feldspar.