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The Geochemistry of Yuksipryeong Two-Mica Leucogranite, Yeongnam Massif, Korea

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영남육괴내 육십령 복운모화강암에 대한 지화학적 연구

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Abstract: Yuksipryeong two-mica granite presents strongly peraluminous characteristics in both mineralogy and geochemistry. It has high aluminum saturation index with 1.15~1.20 and high corundum with 2.20~2.98 wt% CIPW norm. As the color index is <16% and $FeO^T + MgO + TiO_2$ is average 1.9 wt%, it corresponds to leucogranite. Yuksipryeong two-mica leucogranite shows negative linear trend for TiO_2, Al_2O_3, FeO, Fe_2O_3, MgO, CaO, K_2O, P_2O_5, Rb, Ba, and Sr as SiO_2 increases, and the positive relation of Zr and Th, which result from feldspar, biotite, apatite and zircon fractionation. Pegmatitic dike has higher SiO_2 and P_2O_5, but lower another major elements. Yuksipryeong two-mica leucogranite has lower Rb, but higher Ba and Sr than Manaslu, Hercynian two-mica leucogranites, and S-type granites in Lachlan Fold Belt. Pegmatitic dike has higher Rb and Nb but lower Ba, Sr, Zr, Th, and Pb contents than Yuksipryeong two-mica leucogranite, resulting in removing or mobilizing for some trace elements from the granitic melt. Yuksipryeong two-mica leucogranite has total REEs with 95.7~123.3 ppm, and chondrite-normalized REE pattern is very steep ($(La/Yb)_N = 6.9$~24.8), light REEs (LREEs)-enriched and heavy REEs (HREEs)-depleted pattern with low to moderate Eu anomalies ($Eu/Eu^* = 0.7$~0.9). While pegmatitic dike has low total REEs with 7.0 ppm, and chondrite-normalized REE pattern is flat-pattern ($(La/Yb)_N = 2.1$) with strong negative Eu anomalies ($Eu/Eu^* = 0.2$). The melt compositions having formed two-mica leucogranites depend on not only the source rock but also the amounts of the residual remaining after melting of source rocks. The CaO/Na_2O and Rb/Sr-Rb/Ba ratios depend mainly on the composition of source rocks in the strongly peraluminous granite, that is, plagioclase/clay ratio of the source rocks. Yuksipryeong two-mica leucogranite has higher CaO/Na_2O and lower Rb/Sr-Rb/Ba ratios than Manaslu and Hercynian two-mica leucogranites (Millevaches and Gueret) derived from clay-rich, plagioclase-poor (pelite), which suggest that the probable source rocks for Yuksipryeong two-mica leucogranite is clay-poor, plagioclase-rich quartzofeldspathic rocks. As the concentrations of Al_2O_3 remain nearly constant but those of TiO_2 increases as increasing temperature in the strong peraluminous melt, the Al_2O_3/TiO_2 ratio may reflect relative temperature at which the melts have formed. Comparing the pelite-derived Manaslu and Hercynian two-mica leucogranites, Manaslu two-mica leucogranite has higher Al_2O_3/TiO_2 ratio than latter, and its melt have formed at relatively lower temperature (≤875°C) than Hercynian two-mica leucogranites. Likewise, comparing the quartzofeldspathic rock-derived granites, Yuksipryeong two-mica granite has higher Al_2O_3/TiO_2 ratio than S-type granites in Lachlan Fold Belt (>875°C). The melt formed Yuksipryeong two-mica leucogranite are considered to have been formed at temperature at below the maximum 875°C.

Key words: Yuksipryeong two-mica granite, Peraluminous, Leucogranite, REE, Petrogenesis

요 약: 육십령 복운모화강암은 광물학 · 지화학적으로 과알루미나 성질을 특징적으로 나타낸다. 육십령 화강암체는 1.15~1.20 범위의 높은 알루미나 포화 지수와 2.20~2.98wt% 범위의 높은 CIPW norm 강옥 함량을 나타낸다. 색지수는 <16%이고, $FeO^T+MgO+TiO_2$는 평균 1.9 wt%로서 우백질화강암에 해당한다. 육십령 복운

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모 우백질화강암은 SiO_2성분이 증가함에 따라, TiO_2, Al_2O_3, FeO, Fe_2O_3, MgO, CaO, K_2O, P_2O_5, Rb, Ba, Sr은 감소하는 경향을 나타내는 반면, Zr과 Th는 증가하는 경향을 나타내는데, 이는 장석, 흑운모, 인회석, 저어콘의 분별경정작용에 기인한 것으로 해석된다. 거정질 암맥에는 SiO_2, P_2O_5는 높게, 그 외의 주원소는 결핍되어 나타난다. Manaslu, Hercynian 복운모 우백질화강암, Lachlan습곡대의 S-형 화강암과 비교해 보면, 육십령 복운모 우백질화강암은 낮은 Rb, 높은 Ba, Sr을 나타낸다. 거정질 암맥의 지화학적 특징은 육십령 복운모 화강암을 형성했던 멜트로부터 일부 원소들의 제거 혹은 유동성에 의해 높은 Rb, Nb와, 낮은 Ba, Sr, Zr, Th, Pb 함유를 나타낸다. 육십령 복운모 우백질화강암은 총 휘토류 함량이 95.7~123.3 ppm 범위를 나타내며, 운석에 대해 표준해보면, 저 내지 중정도의 Eu 이상(Eu/Eu* = 0.7~0.9)을 가지면서 경희토류원소가 풍부하고 중희토류원소가 결핍된 매우 경사가 져 있는($(La/Yb)_N = 6.9\sim24.8$) 변화를 보여준다. 반면에 페그마틱 암맥은 총 휘토류원소의 함량이 7.0 ppm으로 운석에 대해 표준화하면, 강한 부의 Eu 이상(Eu/Eu* = 0.2)을 가진 편평한 양상을 나타낸다. 복운모 우백질화강암을 형성했던 멜트의 성분은 기원암 뿐만 아니라 기원암이 녹은 후의 잔류물질의 양에도 의존한다. 특히 CaO/Na_2O의 비와 Rb/Sr-Rb/Ba의 비들은 강한 과알루미나질 화강암에서는 기원암의 성분에, 즉, 기원암의 사장석과 점토 함량 비에 주로 의존한다. 육십령 복운모 우백질화강암은 사장석 성분보다 점토 성분이 풍부한 암석에서 기원한 Manaslu와 Hercynian 복운모 우백질화강암들(예를 들면 Millevaches와 Gueret)보다는 더 높은 CaO/Na_2O의 비와 더 낮은 Rb/Sr-Rb/Ba비를 나타내고 있는데, 이러한 지화학적 특징은 점토 성분보다는 사장석이 풍부한 석영장석질 암석으로부터 기원했던 것으로 사료된다. 강한 과알루미나질 멜트에서는 온도가 상승함에 따라 Al_2O_3 성분은 거의 일정하게 유지되는 반면 TiO_2 성분은 상승하는 특징을 나타내므로, Al_2O_3/TiO_2 비는 멜트가 형성될 당시의 온도를 반영한다고 할 수 있다. 니질암에서 유래한 Manaslu와 Hercynian 복운모 우백질화강암을 비교해 보면, 전자는 후자의 것보다는 더 높은 Al_2O_3/TiO_2의 비를 나타내는데, 이는 전자를 형성했던 멜트는 상대적으로 더 낮은 온도(≤875°C)에서 형성되었음을 지시한다. 한편 석영장석질 암석에서 유래한 화강암들을 비교해보면, 육십령 복운모 화강암은 Lachlan 습곡대의 S-형 화강암보다는 더 높은 Al_2O_3/TiO_2의 비를 가지는데, 이로부터 최대 875°C 아래의 온도에서 형성된 멜트로부터 기원한 것으로 사료된다.

핵심어: 육십령 복운모화강암, 과알루미나질, 우백질화강암, 희토류, 암석성인

Introduction

The strongly peraluminous leucogranitic magmatism is commonly associated with collisions of continental, and constitutes an important group derived by melting of the continental crust. During collision-related event, strong peraluminous granites may have formed as a result of syn- or post-collisional through as diverse tectonic setting processes, and some have occurred along the thrust sheet or shear zone in which the rocks show to be deformed texture (Sylvester, 1998).

The petrogenesis and source rocks for strongly peraluminous granites have been controversial. Their magma can be derived from (a) fractional crystallization of hornblende of parental metaluminous magma (Zen, 1986), (b) reaction between basaltic melts and crustal rocks (Patino Douce and Beard, 1995), (c) partial melts of quartzofeldspathic meta-igneous (orthogneiss) crustal rocks (Miller, 1985), and (d) partial melts of metasedimentary rocks in the crust, such as mature argillaceous-rich pelitic rocks (principally meta-shale) or immature quartzofeldspathic-rich psammitic rocks (principally meta-graywacke) (Chappell and White, 1974).

Particularly, two-mica leucogranites show strongly peraluminous characteristics, and have been recognized as typical products of partial melting of the continental crust. These have supported by recent studies of isotope data, modeling, and experimental results (Harris and Inger, 1992; Gardien *et al.*, 1995; Scaillet *et al.*, 1995; Williamson *et al.*, 1996; Ayres and Harris, 1997; Patino Douce and Harris, 1998; Castro *et al.*, 1999; Harrison *et al.*, 1999).

Although it has been reported that two-mica granites occurred in Yeongnam Massif (Kim *et al.*, 1989a, Kim *et al.*, 1989b, Kim *et al.*, 1991, Kim *et al.*, 1993; Kim and Kim, 1990; Kwon and Hong, 1993), there are two papers for only two-mica granite (Jwa, 1997; Koh and Yun, 1999). Yuksipryeong granite, located in the central part of Yeongnam Massif, shows strongly peraluminous characteristics and contains primary muscovite and Al-rich biotite, corresponding to the typical two-mica granite (Koh and Yun, 1997 and 1999). For few geochemical studies have been done on the Yuksipryeong peraluminous two-mica granite, the geochemical study may provide information about the source rocks and genesis of Yuksipryeong two-mica granite.

According to priority, the aim of present study is to consider the geochemical characteristics of Yuksipryeong two-mica granite, compared with other typical two-mica leucogranites (Manaslu granite in Himalaya, Nepal and Hercynian granites in southwestern Europe) and S-type granites in Lachlan Fold Belt. The final aim focus on identifying the source rocks for Yuksipryeong two-mica leucogranite and temperature when the melt has produced.

Survey of the Two-Mica Leucogranite

S-type granites in Lachlan Fold Belt, Australia

In the strict sense, S-type granites in Lachlan Fold Belt, except some batholiths, are not two-mica granites. However, they might be useful to understand the nature and behavior of strongly peraluminous granite. In addition, S- and I-type granites are closely related with not only spatially but also compositionally like as occurring peraluminous granites distributed in Yeongnam Massif, Korea.

S-type granites in Lachlan Fold Belt characteristically contain biotite $\pm$ muscovite $\pm$ cordierite $\pm$ garnet $\pm$ ilmenite $\pm$ alumino-silicate minerals, whereas I-type granites contain biotite+hornblende $\pm$ sphene $\pm$ magnetite (Chappell and White, 1974; Hine *et al.*, 1978) (Table 1). However, peraluminous I-type granites also consist of biotite+muscovite $\pm$ Mn-garnet $\pm$ andalusite, showing analogy to the mineralogy of S-type granites. In addition, the geochemistry between felsic peraluminous S- and I-type granites shows an overlap; thus it seems to be difficult to distinguish their origin. Muscovite is generally present as secondary, however, some granites such as Granya monzogranite have primary muscovite with 4.0% modal composition, 3.86 wt% normative corundum, and 1.4 of aluminum saturation index, corresponding to two mica granite (Chappell and White, 1992).

According to isotope studies for S-type granites, $^{87}Sr/^{86}Sr$ initial ratios show higher value (>0.708) than those of I-type granites (0.704~0.706), and ε_{Nd} has a range from –9.2 to –5.8. These isotopic heterogeneities suggest that S-type granites in Lachlan Fold Belt have been derived from heterogeneous metasedimentary source including psammopelitic rocks (Chappell and White, 1974 and 1992).

Manaslu two-mica leucogranite in Himalaya, Nepal

Manaslu two-mica leucogranite, located in the Higher Himalaya of central Nepal, is one of 10 leucogranites that formed in the overthrusted Higher Himalaya after the Indo-Eurasian collision. Though the size is relatively small (about 300 km^2) among the other Himalayan leucogranites, it is often taken as a typical example of two-mica leucogranite (Le Fort, 1981; Vidal *et al.*, 1982; Clark, 1992; Scaillet *et al.*, 1995). It mainly consists of quartz, plagioclase, perthitic microcline feldspar, euhedral primary muscovite, and biotite being interstitial and intergrown with muscovite. Tourmaline is not actually part of the mineral assemblage of the granite itself, but mainly restricted to aplite and pegmatite sill crosscutting both granite and surrounding formations (Le Fort, 1981; Scaillet *et al.*, 1995) (Table 1).

Many papers related with Manaslu two-mica leucogranite have been published: for compositions of major and trace elements (Le Fort, 1981; Vidal *et al.*, 1982) for isotope geochemistry (Vidal *et al.*, 1982; Deniel *et al.*, 1987; Ayres and Harris, 1997; Harrison *et al.*, 1999), for crystallization and melting experiment (Gardien *et al.*, 1995; Scaillet *et al.*, 1995; Patino Douce and Harris, 1998), and for trace element modeling (Harris and Inger, 1992). The muscovite-whole rock Rb-Sr age is 21~15 Ma (Vidal *et al.*, 1982), and Th-Pb monazite age is 23~19 Ma (Harrison *et al.*, 1999). The $^{87}Sr/^{86}Sr$ initial ratio shows high value with (0.725 (Vidal *et al.*, 1982; Deniel *et al.*, 1987). The results of previous studies suggest that Manaslu two-mica leucogranites may have been derived from melting of metapelites under vapor-absent condition (Harris and Inger, 1992; Patino Douce and Harris, 1998). As Himalayan leucogranites formed very late in the period of collision-related crustal thickening after the collision began at 54~50 Ma (Scharer *et al.*, 1986; Searle *et al.*, 1997; Walker *et al.*, 1999), it may have crystal-

Table 1. The geochemistry of S-type granites in Lachlan Fold Belt and typical two-mica leucogranites

	S-type granites in Lachlan Fold Belt, Australia	Manaslu two-mica leucogranite in Himalaya, Nepal	Hercynian two-mica leucogranite in Massif Central, France*1
Main references	Chappell & White (1974, 1992) Hine *et al.* (1978)	Le Fort (1981), Vidal *et al.* (1982) Deniel *et al.* (1987)	Turpin *et al.* (1990) Williamson *et al.* (1996)
Source rock	sedimentary rocks	meta-sedimentary (pelite)	meta-sedimentary
Characteristic major minerals	biotite±muscovite±cordierite± garnet±alumino-silicates±ilmenite; no hornblende	biotite±muscovite (tourmaline in only aplite and pegmatite sill)	biotite±muscovite± cordierite±tourmaline
Accessory minerals	monazite, apatite, zircon, magnetite (uncommon); no sphene	monazite, apatite, zircon; no opaque mineral	monazite, ±apatite, zircon, ±garnet, ±sillimanite
CIPW norm	>1wt% corumdum	average 2.2*3 wt% corumdum	>2.1 wt% corumdum
ASI*2	>1.10	average 1.16*3	1.16~1.25
SiO_2	relatively restricted: high, 65-74 wt%	average 74*3 wt%	70~78 wt% (average = 74 wt%, n = 39)
Oxide variations	more irregular than I-type granites: 0.01~0.73 wt% TiO_2, 13.2~15.1 wt% Al_2O_3, <4.0 wt% CaO, low Fe^{3+}/Fe^{2+}	very uniform composition: average 0.07*3 wt% TiO_2, average 14.7*3 wt% Al_2O_3, average 0.5*3 wt% CaO	irregular between individual granites: 0.06~0.38 wt% TiO_2, 13.9~15.5 wt% Al_2O_3, 0.4~1.5 wt% CaO, low Fe^{3+}/Fe^{2+}
Alkali contents	<3.2 wt% Na_2O (in felsic rocks, ≈5 wt% K_2O) but <2.2 wt% ≈2 wt% K_2O), (5.2 wt% K_2O	average 4.1*3 wt% Na_2O, average 4.5*3 wt% K_2O	3.3~4.4 wt% Na_2O, 4.2~5.1 wt% K_2O
Trace elements	high Rb, low Ba and Sr; >142 ppm Rb, <755 ppm Ba, <198 ppm Sr	average 385*3 ppm Rb, average 192*3 ppm Ba, average 76*3 ppm Sr	294~561 ppm Rb, <378 ppm Ba, <133 ppm Sr
Enclaves	pelitic (metasedimentary)		far fewer than I-type granite
$(^{87}Sr/^{86}Sr)i$	0.708~0.720	>0.725, high	variable between individual granites; 0.705~0.722
$(\varepsilon_{Nd})_i$	−9.2~−5.8	−15.9~−13.0	−8.2~−6.1
Age	65 Ma (Rb-Sr whole rock age)	21~15 Ma (muscovite-whole rock age) 23~19 Ma (Th-Pb monazite age)	355~291 Ma (Rb-Sr whole rock age)

*1=Faille de la Marche, Gueret Massif, Millevaches Massif, and Margeride Massif two-mica leucogranites among Hercynian granites, *2=molecular $Al_2O_3/(Na_2O+K_2O+CaO)$, *3=average of 36 samples

lized and emplaced during post-collisional events in this orogen.

Hercynian two-mica leucogranites in southwestern Europe

The Hercynian granites in southwestern Europe lie in a belt with ~3000 km long and 1000 km wide, stretching from Portugal to Carpathians. Hercynian two-mica leucogranites and volcanics equivalent to two-mica granites have been reported to occur in Massif Central (France), Iberian Massif (Spain and Portugal), and Calabrian Arc (southern Italy), which are spatially and temporally associated with calc-alkaline granites (Pichavant *et al.*, 1988; Holtz, 1989; Ortega and Gil Ibarguchi, 1990; Turpin *et al.*, 1990; Rottura *et al.*, 1990; Williamson *et al.*, 1996; Downes *et al.*, 1997; Bea *et al.*, 1999; Castro *et al.*, 1999). Tectonic-timing of two-mica leucogranitic magmatism during tectonic evolution of collision zone has been controversial; for example, one opinion is syn-collisional (Harris *et al.*, 1986; Castro *et al.*, 1999), and the other is late or post-collisional (Williamson *et al.*, 1996; Villaseca *et al.*, 1998). But the ages of leucogranitic magmatism are unique, and these results represent that Hercynian granitic magmatism occurred during 50~60 My (ca. 340~280 Ma) after the beginning of the continental collision (ca. 380~390 Ma) (Ortega and Gil Ibarguchi, 1990; Williamson *et al.*, 1996; Villaseca *et al.*, 1998; Castro *et al.*, 1999). The $^{87}Sr/^{86}Sr$ initial ratios show high value with above 0.71 (Ortega and Gil Ibarguchi, 1990; Williamson *et al.*, 1996; Downes *et al.*, 1997) (Table 1).

According to geochemical and experimental studies on two-mica leucogranites, the probable source rocks are meta-pelitic sedimentary (Turpin *et al.*, 1990; Williamson *et al.*, 1996; Castro *et al.*, 1999) and quatzofeldspatic rocks (graywacke or orthogneiss) (Holtz, 1989; Ortega and Gil Ibarguchi, 1990; Turpin *et al.*, 1990). For example, among the Hercynian two-mica leucogranites in N. W. French Massif Central, Gueret Massif, Millevaches Massif, and Margeride Massif two-mica leucogranites were derived from melting of meta-sediments, but the Saint Sylvestre two-mica leucogranite was derived from melting of Precambrian granites (Turpin *et al.*, 1990).

Petrography of Yuksipryeong Two-mica Leucogranite

Yuksipryeong two-mica granite is distributed widely around Sosang-myon of Hamyang-gun, the central part of the study area, intruded into all neighboring granites and gneisses (Fig. 1) (Koh and Yun, 1999). It contains few xenoliths, but rare biotite-rich schlierens are present. Grain size is medium to coarse, and texture is mainly equigranular with some plagioclase or K-feldspar megacryst in southern and northeastern margin. Pegmatitic and aplitic dikes locally intruded two-mica granite, especially in the southern part. The Yuksipryeong two-mica granite mainly consists of 21~45% quartz, 9~27% perthite, 4~15% microcline, 21~41% plagioclase, 1~7% muscovite, and 3~7% biotite (Koh and Yun, 1999). Accessory minerals are zircon, apatite, epidote, and opaque minerals. Subhedral quartz commonly shows undulatory extinction, and has incipient subgrains. Plagioclase is oligoclase (An_{22-13}) and is euhedral to subhedral. It shows albite and Carlsbad-albite twins with remarkable zonation. Alkali feldspar generally occurs anhedral microcline and microperthite, and alkali feldspar phenocryst is mainly perthitic microcline showing poikilitic texture, and its X_{or} is 0.90 ~0.94.

Biotite shows yellowish brown to dark brown in color, and usually contains inclusions of apatite, zircon, and opaque minerals. It occurs as a euhedral to subhedral grain, intergrown with or parallel to muscovite, or as inclusions within muscovite, or as an interstitial phase with muscovite. Its compositions are approximately 2.4~2.5 atoms per formular unit (a.p.f.u.) of tetrahedral Al (Al^{IV}) and 0.5~0.6 a.p.f.u. octahedral Al (Al^{VI}). The Fe/(Fe+Mg) ratios in biotite are 0.62~0.69 with an average of 0.63. The size of euhedral muscovite is comparable to the other magmatic minerals and has a narrow reaction rim. Primary muscovite forms 70~80% of the total muscovite and has higher TiO_2 contents (0.751~0.996 wt%) than late-post magmatic muscovite. Its composition is not pure muscovite but shows celadonite or tschermark substitutions.

Pegmatitic dike is mainly composed of 45% quartz, 3% perthite, 3% microcline, 29% plagioclase, and 11 % muscovite. Accessory minerals are biotite, apatite, and opaque minerals. The texture is porphyritic, and phenocrysts are quartz, muscovite, plagioclase, and microperthitc microcline. Muscovite occurring as subhedral phenocryst is late to post-magmatic muscovite with low TiO_2 contents (0.248~0.254 wt%) (Koh and Yun, 1999).

Geochemistry of Yuksipryeong Two-mica Leucogranite

Major and trace elements analyses were carried out on the X-ray fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometer (ICP-MS) in Korea Basic Science Institute, Seoul Branch.

Major elements

The major element compositions and contents of normative corundum of the Yuksipryeong two-mica granite and pegmatitic dike are listed in Table 2.

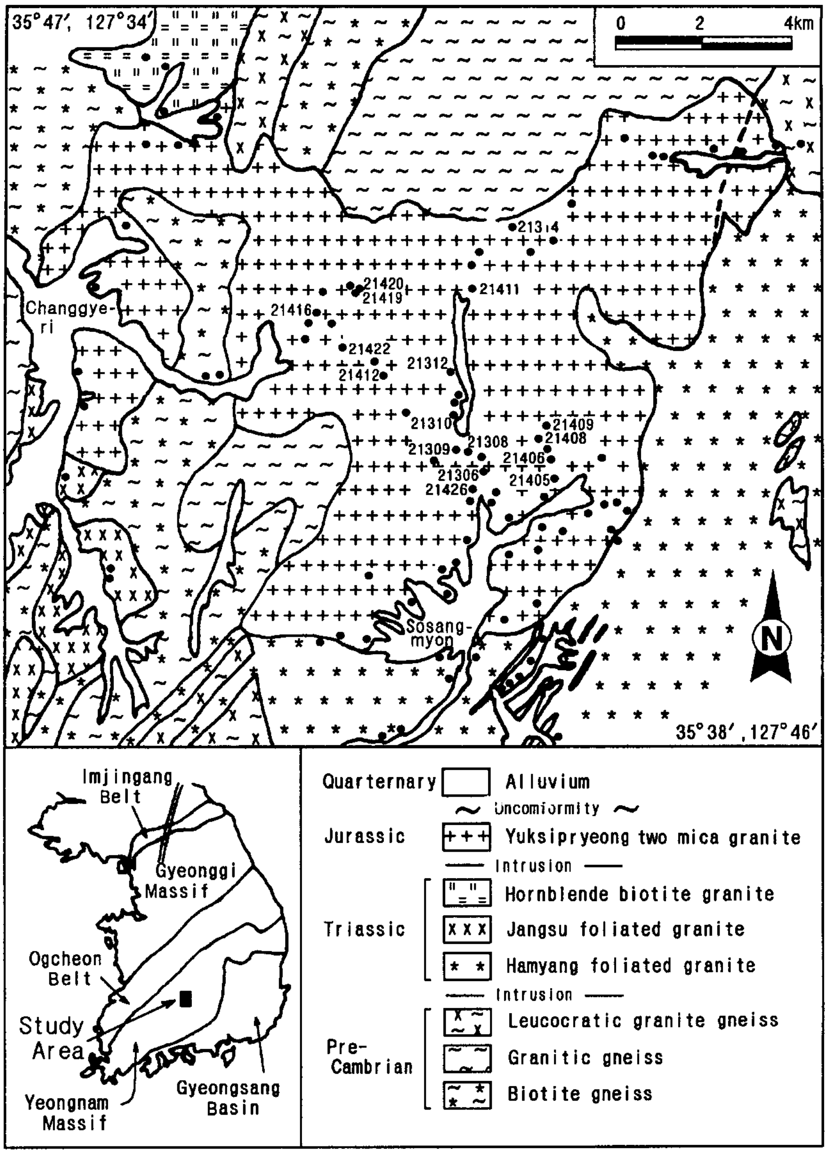

Fig. 1. Geological map of the study area.

Yuksipryeong two-mica granite has restricted high SiO_2 compositions with 69.9~73.2 wt% (average = 71.4 wt%, n = 13) (Fig. 2), being slightly lower than Manaslu two-mica leucogranite (average = 74.0 ± 0.6 wt%, n = 36) in Himalaya. Hercynian two-mica leucogranites in Massif Central, France have 70~78 wt%, and S-type granites in Lachlan Fold Belt show broad spectrum of SiO_2 composition from 65 to 74 wt%. The pegmatitic dike in the study area has high SiO_2 composition of 80.3 wt%.

The TiO_2 concentrations decrease from 0.25 to 0.16 wt% as increasing SiO_2, and TiO_2 contents is 0.03 wt% in pegmatitic dike (Fig. 2a). They are average 0.07 ± 0.07 wt% in Manaslu two-mica leucogranite, 0.06~0.38 wt% in Hercynian two-mica leucogranites, and 0.01~0.73 wt% in S-type granites in Lachlan Fold Belt. Yuksipryeong two-mica granite shows a decreasing trend of Al_2O_3 from 16.7 to

Table 2. Representative chemical compositions of Yuksipryeong two-mica leucogranite and pegmatitic dike

	Yuksipryeong two-mica leucogranite													Dike[#1]
Sample	21306	21309	21310	21312	21314	21405	21406	21408	21409	21411	21412	21422	21426	21419
SiO_2	72.52	73.19	71.50	71.24	69.93	71.32	70.72	72.22	70.75	72.19	71.10	71.44	70.08	80.25
TiO_2	0.16	0.16	0.17	0.16	0.25	0.20	0.22	0.21	0.22	0.19	0.19	0.19	0.22	0.03
Al_2O_3	15.66	15.32	16.06	16.29	16.67	16.07	16.31	15.63	16.35	15.60	16.04	16.26	16.53	12.25
FeO	0.51	0.55	0.58	0.62	0.72	0.54	0.74	0.68	0.57	0.71	0.79	0.60	0.65	0.28
Fe_2O_3	0.61	0.66	0.63	0.48	0.88	0.73	0.65	0.68	0.98	0.64	0.57	0.58	0.91	0.28
MnO	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.03
MgO	0.31	0.29	0.30	0.33	0.49	0.32	0.39	0.34	0.44	0.30	0.36	0.31	0.36	0.12
CaO	1.79	1.74	1.81	1.85	2.09	1.77	2.20	1.93	1.99	1.78	1.81	2.05	1.83	0.24
Na_2O	3.79	3.49	3.72	3.51	3.79	3.52	3.92	3.64	3.59	3.90	3.46	4.12	3.71	2.65
K_2O	3.64	3.75	4.06	4.31	3.79	4.43	3.53	3.20	3.75	3.26	4.41	3.17	4.26	2.53
P_2O_5	0.05	0.05	0.06	0.08	0.07	0.07	0.07	0.08	0.09	0.06	0.07	0.06	0.09	0.09
LOI	0.66	0.55	0.68	0.60	0.84	0.70	0.72	0.85	0.85	0.84	0.82	0.70	0.81	1.16
Total	99.79	99.84	99.69	99.59	99.64	99.76	99.59	99.56	99.68	99.59	99.75	99.59	99.57	99.93
Norm C	2.34	2.47	2.39	2.67	2.70	2.42	2.20	2.86	2.98	2.57	2.44	2.47	2.70	4.96
ASI	1.16	1.17	1.16	1.17	1.17	1.16	1.14	1.20	1.20	1.18	1.16	1.16	1.17	1.61
CaO/Na_2O	0.47	0.50	0.49	0.53	0.55	0.50	0.56	0.53	0.55	0.46	0.52	0.50	0.49	0.09
Al_2O_3/TiO_2	97.88	95.75	94.47	101.81	66.68	80.35	74.14	74.43	74.32	82.11	84.42	85.58	75.14	408.33
Trace elements														
Rb	142	147	156	166	144	161	75	131	159	140	180	140	178	214
Ba	706	819	941	1050	862	1350	429	595	1100	692	1140	651	985	20
Sr	367	339	421	423	431	467	258	426	427	367	427	500	391	14
Nb	4.7	4.6	4.9	1.8	1.9	3.4	0.1	2.2	2.4	3.2	1.9	4.6	4.3	6.7
Y	8.2	6.7	6.9	10.4	9.7	5.8	3.7	6.8	6.0	8.4	7.1	15.6	7.9	2.6
Pb	26.5	25.4	27.3	27.9	23.5	29.9	17.8	24.8	26.7	24.1	28.7	27.3	28.4	8.0
Zr	46.7	34.5	39.5	48.7	31.7	26.4	13.3	26.9	32.9	37.7	21.5	32.9	45.7	5.3
Th	7.5	7.4	7.6	7.8	7.4	6.6	4.1	7.1	6.7	7.4	7.2	7.4	8.7	0.9
Rb/Sr	0.39	0.43	0.37	0.39	0.33	0.34	0.29	0.31	0.37	0.38	0.42	0.28	0.46	15.40
Rb/Ba	0.20	0.18	0.17	0.16	0.17	0.12	0.18	0.22	0.14	0.20	0.16	0.22	0.18	10.70
Rare earth elements														
La	24.7	26.8	28.8	32.0	32.6	26.1	16.8	26.6	26.1	24.8	26.0	24.4	28.4	1.2
Ce	42.2	45.2	49.6	53.8	54.6	43.7	29.1	49.8	45.6	44.3	44.1	42.8	49.1	2.3
Pr	4.52	4.82	5.22	5.66	5.79	4.48	3.07	5.25	4.86	4.73	4.73	4.68	5.24	0.31
Nd	14.8	15.6	16.9	18.7	19.1	15.2	10.1	17.4	16.4	15.7	15.9	15.7	17.6	1.1
Sm	2.72	2.67	2.97	3.28	3.39	2.53	1.73	3.01	2.72	2.84	2.84	2.74	2.95	0.44
Eu	0.62	0.65	0.71	0.74	0.77	0.81	0.43	0.75	0.79	0.62	0.70	0.67	0.72	0.03
Gd	2.37	2.46	2.49	2.83	2.85	2.07	1.46	2.57	2.42	2.47	2.44	2.37	2.69	0.44
Tb	0.30	0.27	0.28	0.37	0.34	0.25	0.17	0.32	0.28	0.33	0.30	0.32	0.32	0.09
Dy	1.52	1.34	1.31	1.85	1.71	1.15	0.75	1.47	1.27	1.61	1.48	1.95	1.57	0.51
Ho	0.27	0.23	0.21	0.34	0.30	0.21	0.12	0.26	0.22	0.30	0.24	0.45	0.29	0.08
Er	0.73	0.63	0.60	0.93	0.85	0.53	0.34	0.66	0.60	0.80	0.65	1.48	0.78	0.21
Tm	0.12	0.08	0.08	0.13	0.12	0.08	0.05	0.09	0.09	0.12	0.08	0.25	0.12	0.04
Yb	0.69	0.57	0.57	0.85	0.76	0.48	0.30	0.57	0.55	0.77	0.57	1.61	0.73	0.28
Lu	0.11	0.07	0.07	0.11	0.09	0.07	0.04	0.08	0.08	0.10	0.07	0.21	0.11	0.04
ΣREE	95.67	101.39	109.82	121.59	123.27	97.65	64.46	108.82	101.97	99.49	100.10	99.62	110.62	6.95
$(La/Yb)_N$	15.94	20.55	22.63	16.48	18.62	23.40	24.81	22.52	21.68	14.97	20.05	6.89	17.34	2.14
Eu/Eu*	0.73	0.76	0.77	0.72	0.73	1.05	0.81	0.80	0.93	0.70	0.80	0.78	0.77	0.19

#1 = pegmatitic dike

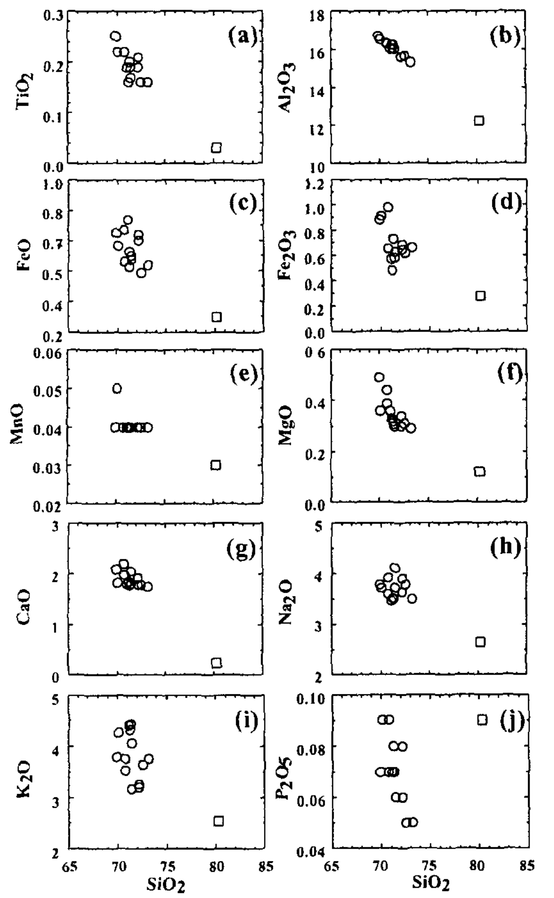

Fig. 2. Major element variation diagrams. [○=Yuksipryeong two-mica granite, □=pegmatitic dike]

15.3 wt% as SiO_2 increases (Fig. 2b), and these Al_2O_3 contents are higher than Manaslu two-mica leucogranite (average = 14.7±0.4 wt%), Hercynian two-mica leucogranites (13.9~15.5 wt%), and S-type granites in Lachlan Fold Belt (13.2~15.1 wt%). Pegmatitic dike has 12.3 wt% Al_2O_3.

Comparing S-type granites in Lachlan Fold Belt with usually lower Fe_2O_3/FeO, the FeO and Fe_2O_3 concentrations in Yuksipryeong two-mica granite show a similar range of 0.51~0.79 and 0.48~0.98 wt%, respectively, and those in pegmatitic dike have contents of 0.28 wt% (Fig. 2c and 2d). The MgO concentrations decrease from 0.49 to 0.29 wt% in Yuksipryeong two-mica granite, and it is 0.12 wt% in pegmatitic dike (Fig. 2f).

The CaO concentrations slightly decrease from 2.20 to 1.74 wt% as increasing SiO_2 in Yuksipryeong two-mica granite (Fig. 2g), which are higher than Manaslu two-mica leucogranite (average = 0.50±0.16 wt%) and Hercynian two-mica leucogranites (0.37~1.45 wt%). The S-type granites in Lachlan Fold Belt show relatively high concentrations of CaO (0.29~3.98 wt%), but have lower CaO contents than I-type granites (0.45~8.10 wt%). The Na_2O contents are 3.51~4.12 wt% in Yuksipryeong two-mica granite (Fig. 2h), average 4.06±0.27 wt% in Manaslu two-mica leucogranite, and 3.25~4.41 wt% in Hercynian two-mica leucogranites, which are higher than those of S-type granites in Lachlan Fold Belt with <3.2 wt%. Yuksipryeong two-mica granite has slightly lower concentrations of K_2O with 3.17~4.43 wt% (Fig. 2i) than Manaslu two-mica leucogranite with average 4.50±0.26 wt% and Hercynian two-mica leucogranites with 4.16~5.11 wt%. S-type granites in Lachlan Fold Belt show wide range of K_2O with < 5.20 wt%. The P_2O_5 concentrations in Yuksipryeong two-mica granite decrease from 0.09 to 0.05 as SiO_2 increases (Fig. 2j). In pegmatitic dike, the concentrations of CaO, Na_2O, K_2O, and P_2O_5 are 0.24, 2.65, 2.53, and 0.09 wt%, respectively, being lower than Yuksipryeong two-mica granite (Fig. 2).

Samples from Yuksipryeong two-mica granite show poorly negative linear trend for TiO_2, FeO, Fe_2O_3, MgO, CaO, K_2O, and P_2O_5, and do strongly for Al_2O_3 in Harker diagram, which represents feldspar, biotite, and apatite fractionations. Pegmatitic dike has higher SiO_2, but lower the other major element compositions than Yuksipryeong two-mica granite (Fig. 2).

Yuksipryeong two-mica granite has characteristically high normative corundum contents (2.20~2.98 wt%) (Table 2), and other two-mica leucogranites and S-type granites in Lachlan Fold Belt listed in Table 1 also have high corundum contents with >1.

Yuksipryeong two-mica granite has low color index (<16%) and FeO^T+MgO+TiO_2 contents (1.6~2.3 wt%, average = 1.9 wt%) (Fig. 3a), corresponding to the nature of leucogranite. The high aluminum saturation index [ASI: molecular Al_2O_3/(Na_2O+K_2O+CaO)] (1.14~1.20, average = 1.17) represents strong peralumi-

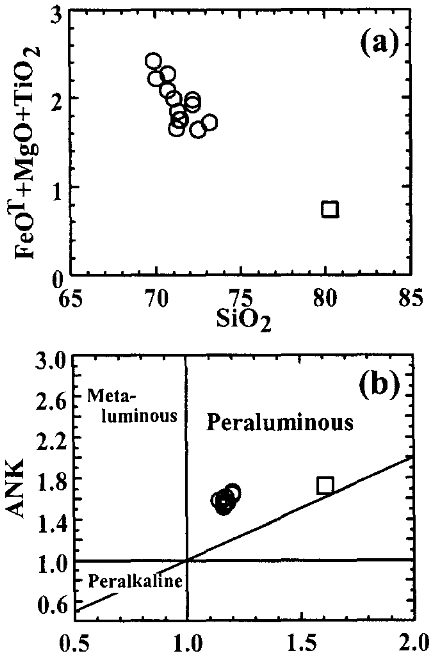

Fig. 3. (a) SiO_2 vs. $FeO^T+MgO+TiO_2$ diagram. (b) molecular $Al_2O_3/(CaO+Na_2O+K_2O)$ vs. $Al_2O_3/(Na_2O+K_2O)$ diagram. Symbols are same as Fig. 2.

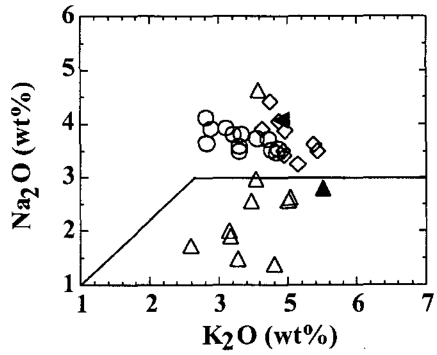

Fig. 4. K_2O vs. Na_2O diagram for S-type granites in Lachlan Fold Belt and two-mica leucogranites. Data source: Chappell and White (1992) for S-type granites in Lachlan Fold Belt; Le fort (1981) for Manaslu two-mica leucogranite (average compositions of 36 samples); Williamson *et al.* (1996) for Hercynian two-mica leucogranites. The line represents the compositional boundary between S-type and I-type granites in the Lachlan Fold Belt (Chappell and White, 1974). [○=Yuksipryeong two-mica granite, △=S-type granites in Lachlan Fold Belt, ▲=S-type two-mica monzogranite in Lachlan Fold Belt, ◀=Manaslu two-mica leucogranite, ◇=Hercynian two-mica leucogranites]

nous characteristics (Table 2 and Fig. 3b) belonging to Chappell and White' basis value (ASI≥1.1). In the K_2O-Na_2O diagram (Fig. 4), Yuksipryeong, Manaslu, and Hercynian two-mica leucogranites have higher Na_2O contents than S-type granites in Lachlan Fold Belt. These strongly suggest that basis content of <3.2 wt% Na_2O in peraluminous rocks is not prerequisite for identifying S-type granite presented by Miller (1985).

Sylvester (1998) suggested Al_2O_3/TiO_2-CaO/Na_2O diagram for identifying the source compositions of peraluminous granites (Fig. 5a). The ratios of CaO/Na_2O and Al_2O_3/TiO_2 depend on the source composition, temperature, pressure, and effect of added H_2O. Particularly, the dominant control of CaO/Na_2O ratio in the strongly peraluminous granites is plagioclase/clay ratio of the source rocks, which means that melts derived from clay-poor, plagioclase-rich sources (quartzofeldspathic psammite or orthogneiss) tend to have higher ratio than melts derived from clay-rich, plagioclase-poor sources (pelite). According to the melting experiments on clay-rich natural metapelite (Patino Douce and Johnston, 1991), the Na_2O composition dissolves in the melt, but CaO is stabilized in garnet until garnet is consumed at very high temperature, thus the melt has low CaO/Na_2O ratio. In the case of melting experiments on plagioclase-rich rocks such as psammite (Skjerlie and Johnston, 1996), plagioclase is not commonly consumed completely during partial melting, and the concentrations of CaO and Na_2O in the melt will increase with further melting. The melt has lower CaO and Na_2O contents than source rocks, but the CaO/Na_2O ratio remains broadly constant.

Yuksipryeong two-mica leucogranite has higher the CaO/Na_2O ratios (0.5~0.6) than Manaslu two-mica leucogranite (average 0.12) and Hercynian two-mica leucogranites (0.1~0.4). This suggests that Yuksipryeong two-mica leucogranite was derived from clay-poor, plagioclase-rich quartzofeldspathic source (psammite or orthogneiss) rather than clay-rich, plagioclase-poor pelite (Fig. 5a).

The concentrations of Al_2O_3 in the strongly pera-

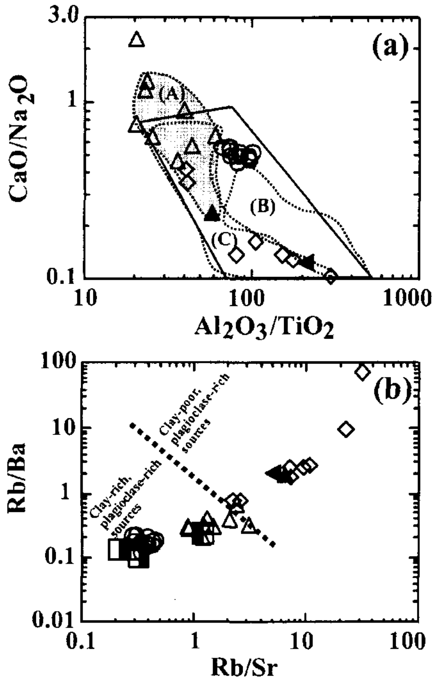

Fig. 5. (a) Al_2O_3/TiO_2 vs. CaO/Na_2O and (b) Rb/Sr vs. Rb/Ba diagrams (Sylvester, 1998). The regions represent (A) strongly peraluminous S-type granites in Lachlan Fold Belt, (B) strongly peraluminous Himalayan granites, and (C) strongly peraluminous Hercynian granites. The dashed line divides granites derived from clay-poor, plagioclase-rich source rocks into those derived from clay-rich, plagioclase-poor source rocks. Data sources are those as in Fig. 4, Na (1994) for quartzites, and Condie (1993) for meta-graywacke and meta-pelite. Symbols are same as Fig. 4.

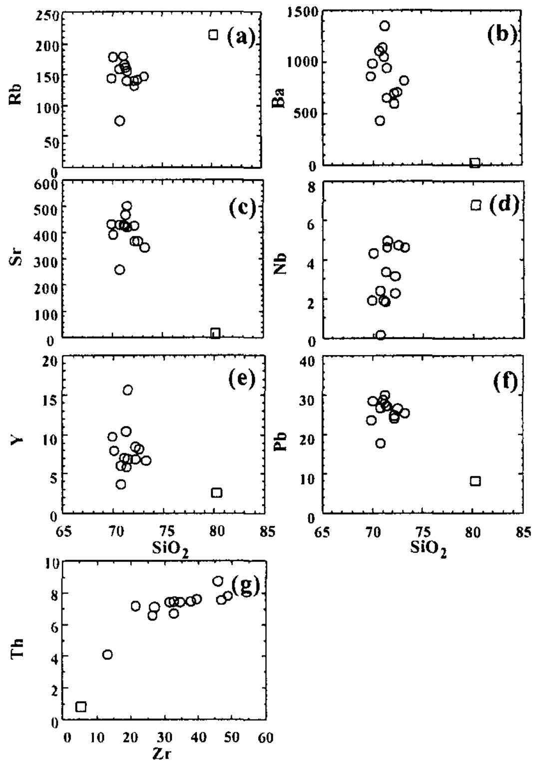

Fig. 6. Trace element variation diagrams. Symbols are same as Fig. 2.

luminous melts remain nearly constant, but those of TiO_2 increase with increasing temperature (Patino Douce and Johnston. 1991; Skjerlie and Johnston, 1996). Thus the Al_2O_3/TiO_2 ratio may reflect relative temperature at which melt is formed. Manaslu two-mica leucogranite has high Al_2O_3/TiO_2 ratios with average 210, representing that the melt was formed at relatively low temperature (≤875°C suggested by Sylvester (1998)). This corresponds well to the results of the anatexis experiments (Scaillet *et al.*, 1995; Patino Douce and Harris, 1998) which were carried out for Himalayan strongly peraluminous rocks and Manaslu two-mica leucogranite, formed at 750~770°C and 803°C, respectively.

Yuksipryeong two-mica leucogranite has higher Al_2O_3/TiO_2 ratios (74~102) than S-type granites in Lachlan Fold Belt (20~61), suggesting that the melt of Yuksipryeong two-mica leucogranite was produced at lower temperature than that of S-type granites in Lachlan Fold Belt, which was produced at ≥875°C (Sylvester, 1998). Considering that the crystallization temperature of biotite included in muscovite ranges from 675 to 750°C and may represent early stage crystallization in the melt (Koh and Yun, 1999), the melt of Yuksipryeong two-mica leucogranite may have produced below 875°C.

Trace and rare earth elements

Trace elements: The trace and rare earth element compositions of the Yuksipryeong granite and pegmatitic dike are listed in Table 2.

Yuksipryeong two-mica leucogranite has 75~180 ppm Rb (average = 148 ppm) (Fig. 6a), which is lower than Manaslu two-mica leucogranite with average 385 ppm Rb and Hercynian two-mica leucogranite with 294~561 ppm Rb. The Rb concentrations of Yuksipryeong two-mica leucogranite are similar to Namwon two-mica granite showing evolved characteristics (Kwon and Hong, 1993). S-type granites in Lachlan Fold Belt have 142~1400 ppm Rb, and can be divided into unfractionated and fractionated S-type granite by 250 ppm Rb concentration (Chappell and White, 1992). Unfractionated S-type granites in Lachlan Fold Belt have average 221 ppm (n = 160), and fractionated ones do average 475 ppm (n = 119). Pegmatitic dike in the study area has higher Rb content (214 ppm) than Yuksipryeong two-mica leucogranite. During the cooling and crystallization of granitic melts in the late-stage, a volatile-rich phase such as aplite or pegmatite may be formed and some trace elements remove or mobilize (Hanson, 1978). The Rb seems to have moved from the granitic melt to the fluid resemble for forming pegmatitic dike. Rb-ion mainly substitutes K-ion, and this net result is reflected by the composition of muscovite, biotite, and K-feldspar. As the mineral/melt partition coefficients (Kd) of Rb in high silica melt are 3.2 for biotite and 1.8 for K-feldspar (Nash and Crecraft, 1985), the high Rb content in pegmatitic dike may result in an abundance of modal muscovite than Yuksipryeong two-mica leucogranite.

Yuksipryeong two-mica leucogranite has Ba concentrations of wide range from 429 to 1140 ppm (average = 943 ppm) (Fig. 2b), which is higher than unfractionated S-type granites in Lachlan Fold Belt with average 512 ppm, Manaslu two-mica leucogranite with average 192 ppm, and Hercynian two-mica leucogranites showing very wide range (1~378 ppm) (Williamson *et al.*, 1996). Pegmatitic dike has the lowest Ba content (20 ppm). As the Ba has mainly substitution relation with K-ion and are mostly contained in the biotite (Kd = 23.5) and K-feldspar (Kd = 11.5), the Ba removing from the two-mica granitic melt into pegmatitic fluid is very low, corresponding to the very low contents of modal biotite and K-feldspar in pegmatite dike.

The concentrations of Sr are 258~500 ppm (average = 403 ppm) in Yuksipryeong two-mica leucogranite (Fig. 6c), and are higher than those of unfractionated S-type granites in Lachlan Fold Belt (average = 114 ppm), Manaslu two-mica leucogranite (average = 76 ppm), and Hercynian two-mica leucogranites (7~133 ppm). The Sr content in pegmatitic dike is 14 ppm. The Sr has mainly substitution relation with Ca-ion, and thus is mostly in plagioclase composition (Kd = 15.6 for 71~76 wt% SiO_2) (Nash and Crecraft, 1985). The Sr removing from the two-mica granitic melt into pegmatitic dike is very low, coinciding with the low concentration of plagioclase in pegmatite dike.

Yuksipryeong two-mica leucogranite has lower Rb, and higher Ba and Sr than unfractionated S-type granites in Lachlan Fold Belt, Manaslu two-mica leucogranite, and Hercynian two-mica leucogranite. Pegmatitic dike has higher Rb content, and lower Ba and Sr contents than two-mica leucogranite (Fig 6).

Yuksipryeong two-mica leucogranite has lower contents of Nb (0.15~4.94 ppm) than pegmatitic dike (6.73 ppm) (Fig. 6d). The Y contents range from 3.7~15.6 ppm (average = 7.9 ppm) (Fig. 6e) in Yuksipryeong two-mica leucogranite and in pegmatitic dike it is 2.61 ppm. Pegmatitic dike has lower 8.0 ppm Pb than two-mica leucogranite with 17.8~29.9 ppm (average = 26.0 ppm) (Fig. 6f), corresponding to low modal composition of feldspar and biotite (Kd = 2.5 for K-feldspar, 1.0 for plagioclase, and 0.8 for biotite) (Nash and Crecraft, 1985). The concentrations of Zr and Th in Yuksipryeong two-mica leucogranite are 13.3~48.7 and 4.12~8.72 ppm, respectively, and those in pegmatitic dike are 5.3 and 0.85 ppm, respectively (Fig. 6g). As Zr and Th are mainly distributed into zircon, Zr-Th diagram shows positive relation, indicating zircon-fractional crystallization is strong in melt of two-mica leucogranite. Yuksipryeong two-mica leucogranite shows slightly decreasing trends of Rb, Ba and Sr, but increasing trend of Y as SiO_2 increases, which results from micas, feldspar, and apatite crystallization (Fig. 6).

In strongly peraluminous granitic melt, Rb, Sr and Ba provide information of source rocks and critical constraints on the conditions prevailed during melting, whereas REEs are primarily controlled by accessory phase behavior (Miller, 1985; Harris and Inger, 1992). The strongly peraluminous granites show linear array of increasing Rb/Sr ratio as Rb/Ba ratio increases in the Rb/Sr-Rb/Ba diagram (Fig. 5b). While Manaslu and Hercynian two-mica leucogranites derived from pelitic source have higher Rb/Sr and Rb/Ba ratios than Yuksipryeong two-mica leucogranite. This means that strongly peraluminous granites with high CaO/Na_2O ratio tend to have lower Rb/Sr and Rb/Ba ratios than those with low CaO/Na_2O ratios (Sylvester, 1998).

The pelite-derived melts will not be particularly higher in Rb and Ba than pelite, because mica and K-feldspar are abundant in the residue, but Sr is similar to contents of pelite because of a low bulk solid/liquid partition coefficient (Miller, 1985). Thus Rb/Ba ratio in pelite-derived melt will be more than about 0.25 (Miller, 1985), and this result coincides with Sylvester's study (Fig. 5b). In the case of psammite-derived melt, the Rb/Sr and Rb/Ba ratios tend to be higher than source, because large amounts of plagioclase for which Sr and Ba are compatible but Rb is incompatible elements will be left behind after melting. However, the Rb/Sr and Rb/Ba ratios in the strongly peraluminous melts are a function not only of source composition but also the amounts of plagioclase and K-feldspar left behind in the source rocks (Miller, 1985; Harris and Inger, 1992; Sylvester, 1998). In Fig. 5b, Manaslu and Hercynian two-mica leucogranites derived from clay-rich, plagioclase-poor meta-sedimentary rocks (Turpin *et al.*, 1990; Patino Douce and Harris, 1998) show considerable difference in the Rb/Sr and Rb/Ba ratios. These can be explained by amount of residual mineral, that is, degrees of partial melting (Harris and Inger, 1992; Williamson *et al.*, 1996).

Yuksipryeong two-mica leucogranite has higher Sr and Ba, but lower Rb contents, thus the Rb/Sr and Rb/Ba ratios is lower than Manaslu and Hercynian two-mica leucogranites. This suggests that Yuksipryeong two-mica leucogranite was derived from clay-poor, plagioclase-rich quartzofeldspathic rock (psammitic rock or orthogneiss).

Rare earth elements (REEs): Yuksipryeong two-mica leucogranite has total REEs of 95.7~123.3 ppm (Table 2). Two-mica leucogranite and pegmatitic dike have distinctive chondrite-normalized REE patterns.

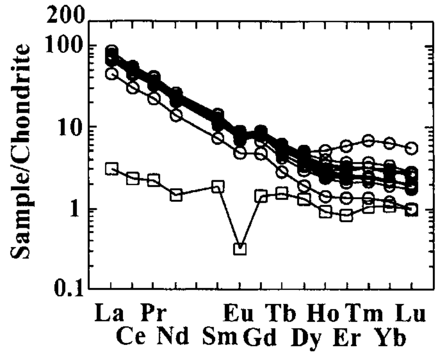

Fig. 7. Chondrite (Taylor and McLennan, 1985)-normalized REE diagram. Symbols are same as Fig. 2.

Two-mica leucogranite shows very steep ($(La/Yb)_N$ = 6.9~24.8), light REEs (LREEs)-enriched and heavy REEs (HREEs)-depleted pattern with low to moderate Eu anomalies (Eu/Eu* = 0.7~0.9). The one sample with 1.0 Eu anomalies may result from including of plagioclase phenocryst (Table 2). The fractionation of REE during melting is function of abundance of phases, that is, the initial liquids may show positive or negative Eu anomalies and light REE enrichment or depletion, which depend upon residue mineralogy (Miller, 1985). The initial melt having formed Yuksipryeong two-mica leucogranite represents weakly depleted content on feldspar after melting source, as mentioned above, and this result agrees with the melt behavior derived from clay-poor, plagioclase-rich quartzofeldspathic source. And the low to moderate Eu anomalies represent that the melt has relatively high degree of partial melting from the source. While LREEs has narrow compositional gab among each sample in Yuksipryeong two-mica leucogranite, HREEs show more wide compositional variations which result from zircon fractionation within melt.

Pegmatitic dike has low total REEs of about 7.0 ppm and is depleted in all REEs. It shows flat-pattern ($(La/Yb)_N$ = 2.1) with strong negative Eu anomalies (Eu/Eu* = 0.2) (Table 2 and Fig. 7). The strong Eu negative anomaly corresponds well to low Sr content, representing that plagioclase composition is relatively depleted.

Discussion

According to previous studies on the granitic rocks distributed in the Yeongnam Massif, the strongly peraluminous are closely related to the granitic rocks with calc-alkaline, metaluminous nature both in time and in space. Besides, the geochemistry of strongly peraluminous granites shows both I- and S-type granite characteristics in various classification schemes (Kwon and Hong, 1993; Na, 1994). Thus, in many studies, the geneses on strong peraluminous granites including two-mica leucogranites have been explained by fractionation from less peraluminous granitic melts. Like example of S-type and I-type granites from Lachlan Fold Belt, because both type granites show similar chemical compositions, excepting the fact that felsic S-type granites has more higher normative corundum than I-type granites, it might be difficult to make two type discrimination, especially, in felsic rocks.

Although two-mica leucogranites are generally considered as the typical products derived from partial melting of crustal material, the genesis on the Yuksipryeong two-mica leucogranite is needed to study more on the surrounding granitic rocks. Because we could not except the consideration that S-type granites in Lachlan Fold Belt show the geochemical variation the from unfractionated to fractionated granite, and the Yuksipryeong two-mica leucogranite show geochemistry analogy to the Namwon two-mica granite showing to be highly fractionated than the surrounding granitic rocks.

As mentioned above, the source rocks for the two-mica leucogranite are various and have been controversial. In addition, it is very difficult to distinguish the source rocks for Yuksipryeong two-mica leucogranite between quartzofeldspathic meta-igneous (orthogneiss) crustal rocks and quartzofeldspathic-rich psammitic rocks (meta-graywacke) in CaO/Na_2O and Rb/Sr-Rb/Ba ratios. In the isotopic study for granitic rocks, Na (1994) suggested that the most probable candidates for source rocks of the peraluminous granites distributed in the Yeongnam Massif, are the Precambrian basement gneiss and, to a lesser degree, the metasedimentary rock including psammitic rock. However, it is necessary to study isotope geochemistry for better understanding of source materials of Yuksipryeong two-mica granite.

Conclusions

The geochemistry of Yuksipryeong two-mica leucogranite and pegmatitic dike compared with S-type granites in Lachlan Fold Belt and typical two-mica leucogranites (Manaslu and Hercynian two-mica leucogranites) has following characteristics and may lead to the following conclusions.

(1) Yuksipryeong two-mica granite has the color index (<16%) and low FeO^T+MgO+TiO_2 (2.2~2.5 wt%; average = 1.9 wt%), which corresponds to leucogranite. It represents strongly peraluminous characteristics with high aluminum saturation index (1.15 ~1.20), and high normative corundum content (2.20~ 2.98 wt%).

(2) Yuksipryeong two-mica leucogranite shows negative linear trend for TiO_2, Al_2O_3, FeO, Fe_2O_3, MgO, CaO, K_2O, P_2O_5, Rb, Ba, and Sr as SiO_2 increases, and the positive relation of Zr and Th, which result from feldspar, biotite, apatite and zircon fractionation. Pegmatitic dike has higher SiO_2, Rb, and Nb, but lower other major, Ba, Sr, Y, Zr, Th, Pb, Zr and Th contents than Yuksipryeong two-mica leucogranite, which result from removing or mobilizing for some elements from the granitic melt.

(3) Yuksipryeong two-mica leucogranite has higher Sr and Ba, but lower Rb contents, thus the Rb/Sr and Rb/Ba ratios is lower than Manaslu and Hercynian two-mica leucogranites.

(4) Yuksipryeong two-mica leucogranite has total REEs with 95.7~123.3 ppm, and chondrite-normalized REE pattern is very steep ($(La/Yb)_N$ = 6.9~24.8), light REEs (LREEs)-enriched and heavy REEs (HREEs)-depleted pattern with low to moderate Eu anomalies (Eu/Eu* = 0.7~0.9). While pegmatitic dike has low total REEs contents with 7.0 ppm, and chondrite-normalized REE pattern is flat ($(La/Yb)_N$ = 2.1) with strong negative Eu anomalies (Eu/Eu* = 0.2).

(5) Na_2O contents show difference between strongly peraluminous granites: ≥3.2 wt% in Yuksipryeong, Manaslu, and Hercynian two-mica leucogranites; and <3.2 wt% in S-type granites from the Lachlan Fold Belt. Thus, this suggests that the below 3.2 wt% Na_2O content in strongly peraluminous granites is not the requisite for identifying S-type granite.

(6) The CaO/Na_2O and Rb/Sr-Rb/Ba ratios mainly depend on plagioclase/clay ratio of the source rocks in the peraluminous melts. Yuksipryeong two-mica leucogranite has higher CaO/Na_2O and low Rb/Sr-Rb/Ba ratios than Manaslu and Hercynian two-mica leucogranite derived from pelite source, which represent that it was derived from clay-poor, plagioclase-rich source such as quartzofeldspathic (psammitic or orthogneiss) source rocks.

(7) In the strongly peraluminous melt, Al_2O_3/TiO_2 ratio may reflect relative temperature at which melt have been formed. Yuksipryeong two-mica leucogranite having lower Al_2O_3/TiO_2 ratio than S-type granites in Lachlan Fold Belt, are considered to have been produced at relatively lower temperature than latter, that is, at below the maximum 875°C.

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