Preliminary Study on the Ultramafic Rocks from the Chungnam Province, Korea

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ABSTRACT: Several ultramafic bodies and ultramafic origin talc deposits are distributed in Chungnam province near the contact zone with Ogchun fold belt. They occur as discontinued belt form with northeast trending, and most of them are more or less sepentinized. Major, trace, and rare earth elements analyses were made of the ultramafics from the study area to constrain their origin and genetic relationships. Compared to the primitive mantle estimates of privious workers, the correlations defined by the studied rock samples indicate similar Ni but very lower Al_2O_3, CaO and TiO_2 contents. It is inferred that source material of the studied rocks might be residual mantle which had undergone a large degree of partial melting event. The REE patterns show relatively flat to enriched in LREE (chondrite normalized La/Yb and Sm/Yb ratios are 1.1−5.2 and 1.2−1.6). Several alternative explaination are possible for LREE enrichment patterns in the studied ultramafic rocks such as 1) enrichment due to late stage alteration, 2) enriched pre-melting composition, and 3) mixing of two components. Based on the result, the LREE enrichment characteristic of the studied rocks might be result from the mixture of two geochemically distinct components; one is depleted residual mantle and the other component which determine the abundances of incompatible elements and responsible for the LREE enrichment.

INTRODUCTION

There are many different rock types in the ultramafic clan and these occur in a varity of field and petrogenetic associations. We expect that there is a variety of processes involved in their origin and emplacement. Accompanying deformation and alteration may partially or completely remove from it the evidence of its original source characteristics and any envelope of contact alteration it might once have possessed.

Several ultramafic bodies and ultramafic origin talc deposits are distributed in Chungnam province near the contact zone with Ogchun fold belt. They occur as discontinued belt form with northeast trending, and most of them are more or less sepentinized. Many studies of geochemistry and mineral chemistry have been done to clarify the genesis of talc ore deposits in the area (Eum and Lee, 1963; Ji and Kim, 1977; Woo et al., 1991). Among them, some studies have contributed to our understand of formation of talc deposits associated with hydrothermal alteration and metamorphic processes. However, previous studies of the ultramafic bodies are few and could not be used to evaluate the origin of ultramafic rocks.

Ultramafic rocks are classified in terms of their field associations and tectonic environment, however, the structure and field associations of the ultramafic bodies of the study area are very complex and do not provide useful information about the origin of ultramafic rocks. For petrogenetic discussion, the ultramafic rocks can be divided into three groups (Wyllie, 1961); 1) layered, stratiform and other intrusions involving gabbro or diabase together with accumulations or concentrations of mafic minerals; 2) alkali rocks of stable continental regions; including kimberlites, mica peridotite, members of ring complexes, and ultrabasic lava flows; 3) the several peridotite-serpentinite associations of the orogenic belts that have been classified together as alpine type intrusions. Based on the mode of occurence, the studied bodies are might be a remanent of either ophiolite complex or alpine type peridotite. In the present paper, we described in detail ultramafic rocks from the study area and attempt to constrain the origin of ultramafic rocks based on trace and rare earth element characteristics.

ANALYTICAL METHOD

Fifty seven samples of the ultramafic rocks were collected from the Chungnam province for petrological and geochemical study (Fig. 1). Sampling bias was avoided by selecting enough number of samples

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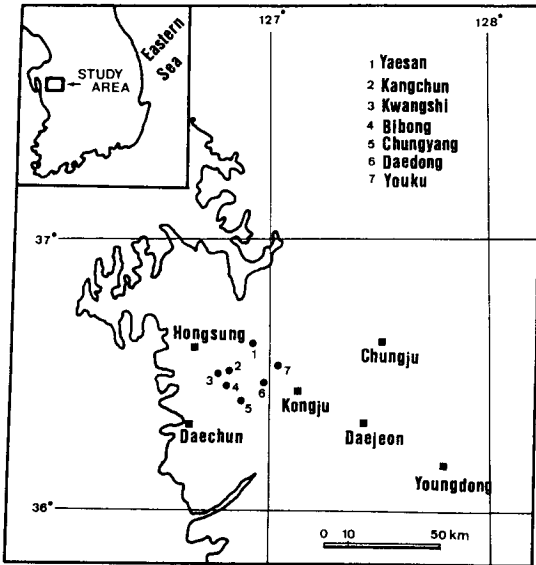** Department of Geology, Korea University, Seoul 136-701, Korea

Fig. 1. Location map of the ultramafic rocks in Chungnam area.

within the same rock units to encompass any small scale heterogenities in rock compositions. Most of the samples were relatively fresh and altered parts were avoided in order to enhance the accuracy of chemical data. The mineralogy of the samples was determined with the aid of the petrographic microscope.

Mineral compositions were determined on the JEOL-733 electron microprobe at Yon Sei university using a 15 kV accelerating voltage, a 20 nA beam current and 10 micron beam diameter. Selected 10 rock samples were analyzed for major and trace elements. Phillips (PW 1480) X-ray fluorencense spectrometer was used to determine major element compositions of the whole rock. REE and selected trace elements were analyzed by Inductively Coupled Plasma mass spectrometer (VG Elemental-PQII Plus) at Korea Basic Science Center. Sample powders for analysis were prepared by grinding in a tungsten carbide shatter box.

PETROGRAPHY AND MINERAL CHEMISTRY

Concerning the ultramafics, rare outcrops show small cores of very fresh part; as a rule, they are almost hydrated to associations of serpentine minerals, chlorites and opeque minerals. Briefly, some of the rocks are altered and are composed mainly of secondary minerals typical of greenschist facies (i.e., albite, tremolite, chlorite, serpentine, and calcite). However, relict magmatic minerals and textures are preserved in places and can be used along with the pseudomorphs to characterize the original petrography of the rocks.

The ultramafic rocks collected in the Chungnam area can be divided into two groups; serpentinized dunite and serpentinzed peridotite.

Serpentinized Dunite

The serpentinized dunite contains more than 90% cumulus olivine and minor orthopyroxene (enstatite), spinel, opeque minerals (chromite and magnetite), and garnet. The rocks are affected by serpentinization with variable amount. Olivine is medium grained and Mg rich (Fo: 91.2-91.6). The large olivine crystals are locally decomposed into serpentine and iron ores along conspicuous fractures.

Serpentinized Peridotite

Thin section analyses of serpentinized peridotite indicate that the primary phases of the specimens consist mainly of olivine and orthopyroxene with small amounts of brown spinel. The secondary minerals observed include serpentine, chlorite, talc, tremolite, and calcite. As a result of extensive serpentinization, the original textures in most of the specimens are badly obscured. In those with lesser degrees of serpentinization, however, a number of relict olivine grains seperated by mesh serpentines still preserve optical continuity, making it possible to define the original grain boundaries and grain sizes. Orthopyroxenes are compositionally enstatite with low Al_2O_3 (0.88~1.14 wt.%).

The primary mantle mineralogy consisted of varying amounts of olivine, orthopyroxene, spinel, and plagioclase. All the samples in this study area have been partially to completly serpentinized. Olivine appears to have been the most susceptible to serpentinization, followed by orthopyroxene. Olivine, from Bibong area, typically appears fresh, but samples to other area are altered to serpentine. Plagioclase was not observed in most of the samples from this investigation, however, some chlorite may represent pseudomorphs after plagioclase.

Olivine

The ultramafics in the study area show a narrow range in olivine compositions from $Fo_{91.2}$ to $Fo_{91.6}$, CaO (>0.02 wt.%) and NiO (0.18~0.28 wt.%). Slightly serpentinized in olivine grains often show magnetite

Table 1. Electron microprobe analyses for representative minerals.

	OLIVINE				SERPENTINE				HORNBLENDE		
	BB-1	BB-1	BB-2	KC-1	KC-1	KC-1	BB-3	BB-4	YK-4	BB-2	BB-2
SiO_2	41.21	41.88	41.13	40.39	40.24	41.38	40.57	40.55	55.54	53.12	54.12
TiO_2	0.00	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.75	0.27
Al_2O_3	0.00	0.04	0.00	0.00	0.00	0.00	0.07	0.34	1.30	4.02	2.39
FeO	8.49	8.51	8.57	8.32	4.42	4.48	4.06	3.26	8.08	8.33	9.70
MnO	0.16	0.07	0.00	0.00	0.00	0.00	0.13	0.14	0.24	0.18	0.08
MgO	49.50	49.59	50.48	50.92	37.39	37.96	38.14	37.64	18.17	18.03	17.68
CaO	0.01	0.00	0.00	0.05	0.00	0.03	0.01	0.11	12.71	11.74	11.67
Na_2O	0.02	0.04	0.01	0.07	0.02	0.04	0.06	0.18	0.18	0.74	0.33
K_2O	0.04	0.00	0.00	0.00	0.02	0.02	0.03	0.01	0.03	0.30	0.09
Cr_2O_3	0.04	0.00	0.00	0.00	0.03	0.00	0.06	0.00	0.04	0.11	0.24
NiO	0.22	0.15	0.28	0.19	0.12	0.26	0.29	0.06	0.00	0.04	0.04
Total	99.66	100.33	100.51	99.92	82.26	84.16	83.42	82.31	96.32	97.36	96.61

	PYROXENE				PHLOGOPITE		CHLORITE
	BB-5	BB-5	BB-5	BB-4	KC-1	KC-1	BB-3
SiO_2	58.40	57.76	58.36	57.86	38.94	38.18	28.24
TiO_2	0.02	0.04	0.09	0.13	0.25	0.46	0.00
Al_2O_3	0.97	1.03	0.88	1.14	14.64	15.05	20.75
FeO	5.13	5.40	5.40	5.60	2.40	2.70	10.96
MnO	0.14	0.22	0.16	0.17	0.06	0.15	0.26
MgO	35.90	35.91	35.67	34.83	27.12	27.71	25.35
CaO	0.19	0.15	0.14	0.25	0.04	0.05	0.00
Na_2O	0.04	0.03	0.05	0.02	0.01	0.00	0.01
K_2O	0.02	0.01	0.01	0.00	8.52	8.10	0.00
Cr_2O_3	0.13	0.15	0.08	0.10	1.11	1.03	0.01
NiO	0.07	0.00	0.02	0.07	0.09	0.11	0.00
Total	101.01	100.70	100.85	100.16	93.19	92.53	85.59

bands that form along fractures in the olivines.

Pyroxene

In the majority of the samples, orthopyroxene cover a ristricted range in enstatite. TiO_2 is relatively low (<0.13 wt.%) and have ristricted range of Cr_2O_3 (0.08~0.16 wt.%), CaO (0.13~0.25 wt.%) and Si makes up 1.97~1.99 of the 2.0 cations in tetrahedral positions. The alumina contents of the orthopyroxene phenocrysts are relatively low (<1.14 wt.%) suggesting a low-pressure origin (Cameron et al., 1980).

Serpentine

The serpentine "polymorph(s)" present in each samples were roughly determined followed by Peacock (1987) based on electron microprobe analysis data. Lizardite is true polymorphs with the ideal serpentine formula, $Mg_6Si_4O_{10}(OH)_8$, whereas antigorite are sli-

ghtly SiO_2-rich and MgO, OH- poor, owing to the alternating wave structure of antigorite (Whittaker and Wicks, 1970). The chemical differences between antigorite and lizardite are small, but can be discerned with the electron microprobe data (Table 1). Based on Peacock's (1987) work (antigorites; Si: 4.037-4.15, Mg: 5.157-5.649; lizardite; Si: 3.937-4.026, Mg: 5.522-5.776, cations based on 14 anhydrous 6 oxygen atoms), and Woo et al. (1991), serpentine occurs in the study area is antigorite which characterized by magnetite bands that form along fractures in the olivine.

Tremolite

Tremolite occured as minor phase in some ultramafic rock samples. It occurs as colorless prisms and show a good cleavage. Individual tremolite prisms vary from fresh, to partially serpentinized along cleavages and fractures.

Table 2. Chemical compositions of the analyzed samples in the study area.

	KC-A	KC-B	DD-1	DD-2	CY-6	YS-1	BB-1	BB-2	KS-3	KS-5
SiO_2	40.24	40.01	39.55	38.64	40.33	38.93	38.96	39.15	39.08	39.78
TiO_2	0.01	0.01	0.02	0.04	0.02	0.02	0.01	0.01	0.02	0.02
Al_2O_3	0.01	0.01	1.20	0.98	0.58	0.70	0.29	0.71	1.10	1.29
FeO*	9.42	10.51	8.34	8.59	7.75	8.77	8.83	9.05	8.50	8.74
MnO	0.09	0.08	0.10	0.15	0.07	0.11	0.13	0.12	0.14	0.13
MgO	36.60	36.55	38.16	37.85	38.82	37.85	40.14	39.12	37.73	38.02
CaO	0.92	0.16	0.08	0.46	0.03	0.08	0.37	0.37	0.18	0.71
Na_2O	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	1 0.01
K_2O	0.01	0.01	0.04	0.08	0.01	0.01	0.01	0.01	0.01	0.01
P_2O_5	0.03	0.04	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02
Total	87.34	87.39	87.52	86.82	87.64	86.51	88.77	88.57	86.79	88.73
Cr	741.3	305.1	2069.1	1174.3	2291.9	2772.8	962.8	1702.7	2479.0	1994.2
Co	111.9	116.2	100.2	79.8	80.7	109.4	109.0	108.0	106.6	105.4
Ni	1861.8	2094.1	2234.6	1808.8	1678.7	2299.7	2280.2	2223.0	2210.3	2151.8
Cu	2.8	1.2	1.0	0.9	0.7	14.4	1.6	2.2	1.9	4.5
Zn	40.9	26.3	36.5	29.1	34.6	45.8	25.9	34.6	42.2	34.4
Rb	0.40	0.40	6.18	7.41	0.40	0.40	0.40	0.45	0.39	0.37
Sr	23.35	5.71	2.40	9.93	0.25	2.39	1.91	2.89	1.61	4.15
Y	0.53	0.84	0.93	0.53	0.54	0.77	0.12	0.31	0.63	0.91
Zr	0.17	0.16	0.83	0.86	0.34	0.86	0.44	0.62	0.61	0.74
Nb	0.14	0.17	0.87	0.52	0.45	0.15	0.11	0.10	0.14	0.36
Ba	13.54	9.75	6.00	8.87	2.10	2.10	1.90	1.98	2.10	2.54
La	0.22	1.58	1.71	0.91	0.74	1.46	0.21	0.50	0.45	0.43
Ce	0.27	1.10	1.62	0.85	0.74	1.47	0.24	0.49	0.66	0.90
Nd	0.16	0.56	0.49	0.29	0.40	0.52	0.15	0.23	0.42	0.63
Sm	0.11	0.37	0.28	0.17	0.22	0.37	0.11	0.17	0.22	0.25
Eu	0.01	0.05	0.02	0.02	0.02	0.05	0.02	0.01	0.03	0.06
Gd	0.04	0.10	0.08	0.05	0.08	0.13	0.05	0.04	0.08	0.15
Yb	0.27	0.35	0.55	0.30	0.30	0.55	0.15	0.25	0.55	0.13
Ta	0.56	0.27	0.24	0.27	0.66	0.25	0.22	0.15	0.08	0.22
Pb	1.29	2.19	0.22	0.33	0.53	1.11	0.49	0.45	0.86	0.99

FeO* represents total iron.

ANALYTICAL RESULTS

Major Elements

Major, trace and rare earth elements (REE) analyses of the ultramafic rocks of the study area are given in Table 2. Variation between two oxides due to an igneous or an alteration process can be best observed where the oxides are normalized by an oxide that is constant during that process. This technique has been used to examine fractionation trends in igneous suites (Pearce, 1969; Irvine, 1979) and to deal with alteration problems (McQueen, 1981; Beswick, 1982). Relationships between MgO and FeO with respect to other oxides are shown in Fig. 2. Relatively well defined trend indicate that the element in the denominator was immobile during alteration. However, caution is required since not all denominators used

in the diagram are constant during igneous processes (e.g., SiO_2, CaO). In plots dealing with these elements, some scatter from trends may vary well be due to igneous processes. Some samples show scatter on plots where K_2O, MnO, Na_2O are denominators can be attributable to alteration. Thus, the chemical composition of the majority of the rocks does not seem to have been affected by the complex post-igneous events.

Fig. 3 shows Al_2O_3, CaO, TiO_2 and Ni versus MgO diagram with primitive mantle compositions from the literatures (Jatoutz et al., 1978; Palmo and Nickel, 1985; Hofmann, 1988) for comparison. Compared to the primitive mantle estimates of previous workers, the studied rock samples show very low Al_2O_3, CaO, TiO_2 and similar Ni contents.
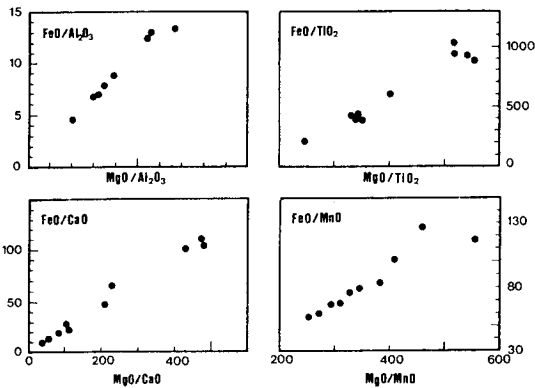
Trace and REE

Fig. 2. Ratio plots of the ultramafic rocks. Figure represent the relationships between MgO and FeO with respect to other oxides.
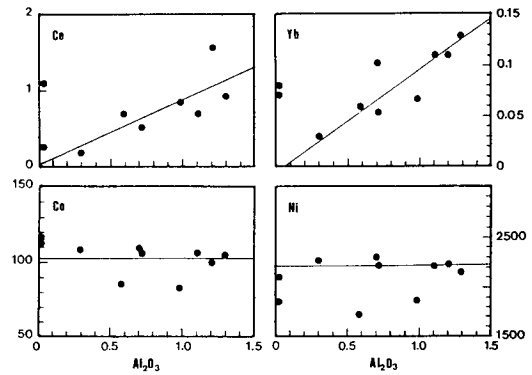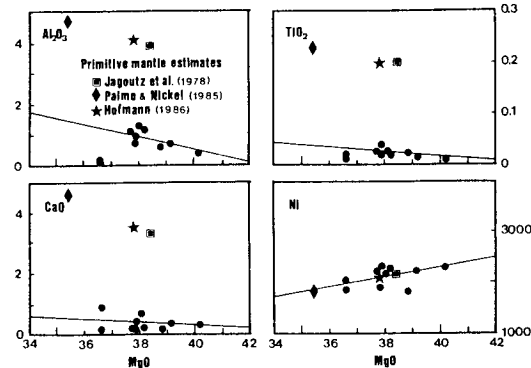

Fig. 3. MgO variation diagrams for several elements in the ultramafic rocks in Chungnam area. Primitive mantle estimates from the literature are given for comparison.

In the past, the more highly altered nature of massive peridotites (e.g., the ubiquitous presence of serpentine) led many geochemists to concentrate their efforts on the less altered mantle xenoliths found in volcanic rocks. However, the problems created by alteration have become less important because several studies have shown that major element and REE abundance trends are not obviously affected by serpentinization (Frey et al., 1985; Bodinier et al., 1988). Also, it has been suggested that the elements such as Ti, P, Zr, Hf, Th, Cr, Ni, Sc, Nb, Y, and HREE are resistant to alteration and metamorphism (Pearce and Cann, 1973; Floyd and Winchester, 1975; Wood et al., 1976; Condie et al., 1977; Ludden and Thompson, 1978; Ludden et al., 1982), while other elements such as Sr, Ca, Ba, K, and Na can be shown to be mobile even during low grade alteration (Humphris and Thompson, 1978).

Fig. 4. Variation of the trace elements versus Al_2O_3 content. Regression lines of the ultramafic rocks are drawn on plots.

Variation of trace elements with increasing Al_2O_3 content are shown in Fig. 4. Incompatible elements increase with increasing Al_2O_3 contents. Because Al_2O_3 and incompatible elements are preferentially enriched in partial melts of peridotites, such correlations are expected in residual mantle from large degree of melting of a common source. REE analyses for the studied rocks are given in Table 2. The REE abundances, conventionally normalized to chondrite values (Thompson, 1982) are plotted in Fig. 5. All samples are characterized by relatively flat to enriched in LREE (chondrite normalized La/Yb and Sm/Yb ratios are 1.1~5.2 and 1.2~1.6). "V" shaped patterns are observed in the olivine-rich samples of the studied rocks. This type of pattern was generated by the accmulation of olivine which characteristically has this type of REE distribution (Masuda, 1968; Frey et al., 1971; Frey, 1984). The positive Eu anomalies occuring in the studied rocks, which lack of plagioclase, might be caused by preferential mobility of Eu^{+2} during serpentinization (Frey, 1984).

DISCUSSION

Fig. 3 shows good correlations for Al, Ca, Ti and Ni each with MgO. The primitive mantle composition was originally inferred by Jagoutz et al. (1979) and more recently refined by Palmo and Nickel (1985) and Hofmann (1986). Relative to the primitive mantle estimates of privious workers, the correlations defined by the studied rock samples indicate similar Ni but very lower Al_2O_3, CaO and TiO_2 contents. From this diagram, it is inferred that source material of the studied rocks might be residual mantle which had undergone a large degree of partial melting
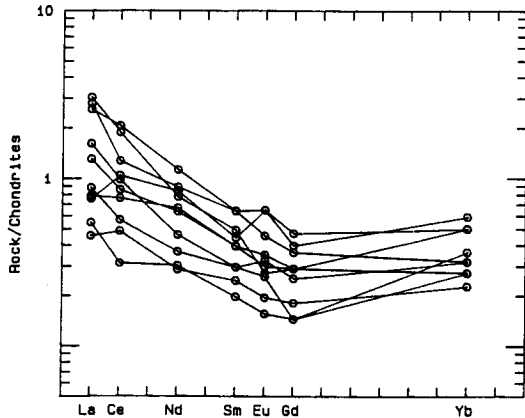
Fig. 5. Chondrite-normalized rare earth element abundances of the ultramafic rocks in Chungnam area. Normalized chondrites values were taken from Thompson's (19 82).
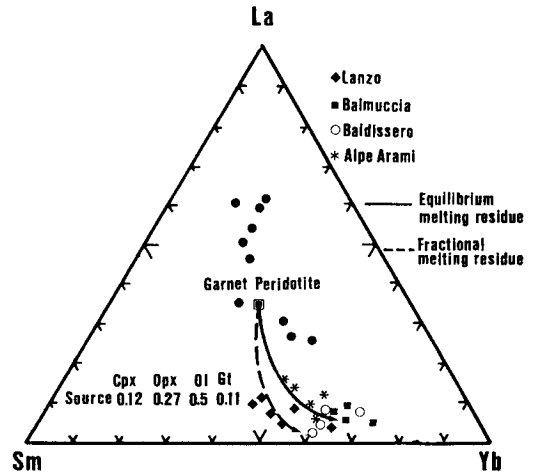

Fig. 6. La-Sm-Yb plots of rocks from the study area and other localities compared with computed distributions in equilibrium melting residua (solid line) and fractional melting residua (dashed line). Melting episodes operating on garnet peridotite.

event. Other evidence to support this is the compatible and incompatible element trends with Al_2O_3 content (Fig. 4). Based on mineral/melt distribution coefficients for olivine, pyroxene, spinel and garnet, it is expected that (La/Yb)c in residual peridotites should decrease with decreasing Al_2O_3 content and no variation of compatible elements such as Ni and Cr during partial melting.

The most striking feature of REE characteristics of the studied rock is their overall LREE enrichment pattern with respect to ultramafics from other localities (Table 3). Fig. 6 shows that trends of the computed residual mantle compositions resulting from melting models for garnet peridotite assemblage. The La-Sm-Yb in this plots are normalized to the chondrite abundances (La : Sm : Yb=0.34 : 0.195 : 0.22, Wakita et al., 1971). These diagram offer some advantages with respect to binary plots (Ottonello et al., 1983); 1) the plot of a certain composition is independent of the source/chondrite enrichment factor, 2) compositions of produced liquid and crystalline residues under equilibrium conditions are diametrically opposite with respect to the center of the ternary diagram, although not related by the lever rule. The same is true for fractional melting residue and fractionally accmulated liquids; and 3) effects of variability in the clinopyroxene, garnet/liquid partion values due to Henry's law problem are very much reduced. In Fig. 6, the studied rocks and rocks of other alpine peridotites such as Lanzo (Bodinier, 1988), Balmuccia, Baldissero (Ottonelli et al., 1984), and Alpe Arami (Ernst, 1978) were plotted in La-Sm-Yb ternary diagrams. The mantle residue compositional va-

riation trends were calculated with the melting proportion of cpx : opx : ol : gt (12 : 27 : 50 : 11, Fig. 6). As shown by the melting residue trends in figure, the rocks from other localities can be regarded as residue of a partial melting event which operated on the garnet bearing peridotites before their emplacement. However, melting of the primitive mantle seems to have difficulty explaining the LREE enrichment of the studied rocks. Several alternative explaination are possible for LREE enrichment patterns in the studied ultramafic rocks such as 1) enrichment due to late stage alteration, 2) enriched pre-melting composition, and 3) mixing of two components.

LREE enrichment resulting from alteration and metamorphism, and it may be an important process in determining the REE content of serpentinized and metamorphosed ultramafics from alpine peridotites and ophiolites. The possibility of REE mobility during late stage alteration process has been recognized by many researchers (Frey, 1969; Frey, 1970; Ottonello et al., 1984, etc.) but no one has dealt with the problem in a rigorous and meaningful manner. Recently, Frey and Suen (1983) studied Ronda peridotites ranging from 5 to 30% serpentine and found no correlation of REE abundances with degree of serpentinization. Moreover, when several samples from an individual massif are studied the same coherent major and trace element abundance trends are defined by samples with widely different amounts of serpentine (e.g., Frey et al., 1985; Bodinier et al., 1988)

Table 3. REE characteristics of the different types of ultramafic rocks.

Alpine Peridotite	Ophiolite	Inclusions in Alkali Basalt	Ultramafics from the study area
Lherzolite (D)	*Herzburgite (D)*	*Spinel lherzolite Harzburgite (D)*	*Harzburgite (D)*
LREE: 0.01~0.6 chon.	very low REE	variety of REE abundances	(La/Yb)c>1
HREE: 1~2 chon.	0.001~0.5 chon.	(mostly enriched in LREE)	
CaO: 1.14~3.37%		CaO: <1.8%(Herzburgite)	CaO<1%
Al₂O₃: 1.9~3.72%			Al₂O₃<1.5%
Herzburgite & Dunite (R)	*Lherzolite (R)*	*Lherzolite (R)*	
LREE: 0.03~0.1 chon.	similar to lherzolite	(La/Yb)c>1	
HREE: 0.3~0.6 chon.	in Alpine peridotite		

Data sources: 1) alpine peridotite: Dickey et al., 1977; Frey et al., 1985; Loubet et al., 1975; Menzies et al., 1977; Ottonello et al., 1979. 2) ophiolite: Kay and Senechal, 1976; Menzies, 1976; Pallister and Knight, 1981; Suen et al., 1979. 3) inclusion: Chen and Frey, 1980; Frey and Green, 1974; Frey et al., 1971; Ottonello, 1980; Philpotts et al., 1972; Stosch and Seck, 1980 (D: dominant, R: rare).
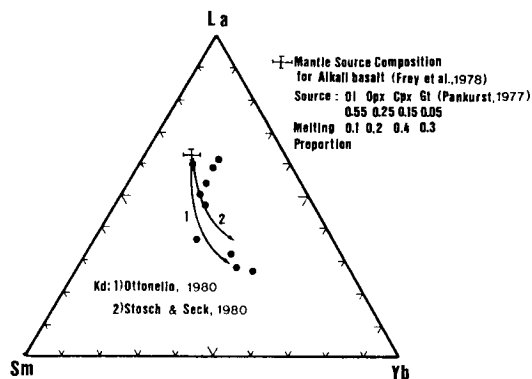

Fig. 7. Computed La, Sm, and Yb distribution trends for melting episodes operating on the calculated source for alkali basalt. The rocks from the study area were plotted for comparison with respect to calculated melting residua.

which supports the assumption by Loubet et al. (1975) that serpentinization has no significant effects on REE abundances. 2) LREE enrichment resulting from the partial melting of LREE enriched mantle such as mantle source for alkali basalts. Fig. 7 shows that compositional variation trends of the mantle residues which generated by partial melting of enriched mantle source (data from Frey et al., 1978). As can be deduced from Fig. 7, these trends may represent that the studied rocks were generated from the enriched mantle rather than chondritic primitive mantle source. However, it seems difficult that we regarded these rocks as residual mantle after generation of alkali basalt with respect to their size, occurance mode, and their emplacement mechanism. Thus, the most favorable explaination for the LREE enrichment is

mixing model which suggested by Frey and Green (1974). They interpreted the LREE enrichment as resulting from mixture of two geochemically distinct components; one is depleted residual mantle which determines the major mineralogy, major element composition and abundances of compatible trace elements such as Ni, Co and HREE, and the other component which determine the abundance of minor and incompatible elements and responsible for the LREE enrichment. Recent experiments of REE partitioning between minerals and H_2O and CO_2 rich fluids at high pressure show that these fluids preferentially enrich LREE (Mysen, 1979; Wendlandt and Harrison, 1979); thus, the latter component may have been a H_2O or CO_2 rich fluid. Therefore, the relative LREE enrichment of the ultramafic rocks from Chungnam area might be resulted from upward migration of a hydrous liquid which forming a LREE enriched region of the upper mantle.

CONCLUSIONS

Geochemical data, field and petrographic study for the ultramafic rocks in Chungman area have been integrated to conclude the followings.

1. Compared to the primitive mantle estimates of previous worker's, the studied rocks show very low Al_2O_3, CaO, TiO_2 and similar Ni contents. It may represent that the studied rocks might be residual mantle which had undergone a large degree of melting.

2. The LREE enrichment characteristic of the studied rocks might be result from the mixture of two geochemically distinct components; one is depleted

residual mantle and the other component which determine the abundances of incompatible elements and responsible for the LREE enrichment.

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충남지역에 분포하는 초염기성암의 기원규명을 위한 기초연구

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요   약 : 충남 예산군 및 청양군 일대에 분포하는 시대미상의 초염기성암의 기원을 규명하기 위하여 주성분, 미량성분 및 희토류원소(REE)의 전암분석의 결과를 이용하여 연구하였다. 전암분석결과에 의하면 주성분원소 중 K_2O와 Na_2O를 제외한 대부분의 원소들은 후기변질작용에 관계없이 일정한 상관관계를 보여주며, primitive 맨틀의 화학조성과 비교할 때 매우 낮은 Al_2O_3 (<1.5%), CaO (<1%), TiO_2의 값을 나타내며, 비슷한 Ni의 함량을 가진다. 이점으로 미루어 본역의 암석은 상당한 양의 부분용융 (large degree of partial melting)을 받은 맨틀의 잔여물(residues)로 사료된다. REE의 chondrite normalize value는 (La/Yb)c=1.1−5.2, (Sm/Eu)c=0.6−1.5 및 (Sm/Yb)c=1.2−1.6 (dunites=0.53−0.77)의 값을 나타낸다. 대부분의 초염기성암이 LREE가 빈화(depleted)된 ((LREE/HREE)$_c$<1) 특징을 보이는데 반해 이 지역의 초염기성암들은 LREE가 약간 부화(enriched)된 ((LREE/HREE)$_c$<1) REE pattern을 나타낸다. 또한, La-Sm-Yb의 ternary diagram을 살펴보면 이들은 chondrite의 값과 유사한 primitive한 맨틀의 부분용융 후의 잔여물보다 상당히 La가 부화된 양상을 보이며, alkali basalt의 source가 되는 부화된 맨틀의 부분용융 후의 잔여물과 비슷한 화학조성을 나타내고 있다. 이와같은 현상은 사문암화와 같은 후기변질작용 (late stage alteration), pre-melting composition 이 LREE가 부화된 경우, 혹은 빈화된 mantle의 잔여물과 LREE가 부화되어 있는 어떤 component의 mixing에 의한 부화의 가능성 등을 생각해 보았다. 그 결과, 1) 본역의 암석들은 가장 덜 변질받은 암석들만 분석하였고, MgO와 FeO를 다른 oxides로 나눈값을 도시해본 결과 대부분의 oxide들이 매우 좋은 trend를 보여주므로 후기 변질작용에 의한 LREE의 부화가능성은 희박하다고 생각되며, 2) 본역의 암석을 alkali basalt의 source와 같은 LREE가 부화된 deep mantle source에서 부분용융 후의 잔여맨틀로 생각하기에는 이들이 지표 위로 나타날 수 있는 emplacement mechamism을 설명하기가 불가능하다. 따라서 이러한 점으로 미루어볼 때, 이 지역의 초염기성암의 LREE 부화는 두 가지 component의 mixing에 의한 가능성이 가장 높은것으로 사료된다. 상당한량의 부분용융을 받은, 즉 빈화된 맨틀과 LREE가 부화된 component의 mixing에 의하여 이와같이 LREE가 부화된 특성을 보여주고 있다고 사료된다. Component의 성분으로서는 고압에서 LREE를 많이 함유하는 H_2O나 CO_2-rich fluid, 혹은 부화된 맨틀의 low degree of partial melting에 의하여 LREE가 부화된 partial melt일 가능성이 높으며 이들이 올라오면서 빈화된 잔여맨틀과 mixing되면서 본역의 암석과 같이 LREE를 부화시켰다고 사료된다.