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The origin of dunite: constraints from major exchange component, and incompatible and compatible trace elements

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Dunites occurring within the mantle section of ophiolites are the most refractory rock in that it is strongly depleted in melt components. They consist of almost two minerals with highest liquidus temperature, olivine and spinel, of which chemical characteristics are represented by Mg-Fe ratio of olivine and Cr-Al ratio of spinel: the major two exchange components in peridotite system. Olivine also contains NiO as the third abundant cation, which is more compatible than MgO. Because residue of extensive melting of a fertile peridotite in closed system is unlikely for the origin of dunite bodies, two mechanisms involving open processes have been invoked (Kelemen, 1990; Kelemen et al., 1995). One is porous channel formed by reaction between the host peridotites and olivine-saturated melt and the other is sealed open conduit, which might be developed by combination of fracture formation and reactive melt transport (Suhr et al., 2003). In spite of its minor abundance, the dunite has profound importance in that it could have played an important role in transportation of melt from the mantle to the crustal magma chamber (Kelemen et al., 2000). In order to evaluate its importance, extensive petrologic and geochemical investigations have been made on dunite bodies (e.g., Kelemen et al., 1995; Suhr et al., 2001), but such data sets have not been quantitatively examined by taking all elements into consideration. Particularly, modeling behavior of Cr-Al exchange component, which is recorded in spinel as its Cr-Al ratio, has difficulty because of the lack of thermodynamic model for Cr component in pyroxenes.

The purpose of this study is quantification of the behavior of the major two exchange components in peridotite system, Mg-Fe and Al-Cr, and that of both incompatible and compatible trace elements in magmatic reactions related to the formation of dunite. Suhr et al., (2003) modeled open system reaction involving Mg-Fe exchange component and Ni, but this study treats Cr-Al component as well as incompatible elements as additional critical constraints. We utilize general equations describing mass balance in a general open magma system according to Ozawa (2001) by fixing our coordinate to solid. Equilibrium relationships for Cr and Al partitioning between minerals and melt are expressed by appropriate parameterization of melting experiments (e.g., Baker and Stolper, 1994). The equations are further adopted to derive equation for the reaction front to constraint its velocity in reactive transportation forming dunite. This approach was applied to compositional variation of olivine and spinel in dunite relative to the host harzburgite in ophiolite complexes to quantitatively specify the relevant reaction processes.

Because an open reaction system involves many physical and chemical parameters, we need constraints from the energy conservation in general. However, peculiar and unusual covariations between components in a specific phase or in two phases require a stricter parameter range. Two such cases are negative correlation between Fo mol% in olivine and C/(Cr+Al) of spinel and negative correlation between Fo mol% and NiO wt% in olivine. Usual explanation for such trends call for unusual melt composition as reactant, but the modeling shows that a common differentiated melt can explain such trends by coupling of melt influx and melting reaction with appropriate parameters for the open reaction.