Cr and Al diffusion in chromite-spinel-olivine tri-crystal phase boundary

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Interface and grain boundaries between minerals are important paths for transport of materials through rocks. The width of interface (or grain boundary) between crystals can act as fast diffusion paths along, which play an important role in transportation of chemical species and in diffusion creep.

The diffusivity of atoms along interface boundaries is controlled by three parameters: the width of interface (d), the diffusion coefficient along interface (D_g) and the ratio of concentration between the interface region and host crystals (b). In most experimental studies, only the product of d and D_g was determined with the assumption of b=1. In this study, the sensitivities of the d and bD_g parameters in diffusion experiments are examined by numerical calculations and diffusion experiments using interfaces along tri-crystals of chromite, spinel and olivine.

Two dimensional diffusion equation (e.g., Fisher, 1951) was solved numerically by an explicit method assuming that boundary conditions remain unchanged. The concentration of elements within crystals and along the interface boundary can be determined by three parameters: a dimensionless parameter b_d ($b_d = dbD_g/(2D_vL)$), a ratio between a characteristic distance L ($L^2 = D_vt$) and d (k = L/d), and time (t). The b_d constrains a diffusion type: body diffusion dominant, boundary diffusion dominant, and both body and boundary diffusion effective (Joesten, 1991). The k can constrain the concentration profile if k is remarkably small. We also found that d and bD_g can be obtained separately if k is one to several, for which nm-scale precise analyses of elemental concentrations are required. If the profile is measured in micron-scale, d and bD_g cannot be separated and only dbD_g is obtained.

We applied this result to interface boundary diffusion experiments between chromite spinel and olivine, which is required to determine the flow law of diffusion creep.

Experiments were carried out with a multi-anvil type (MA-8 type) high-pressure apparatus at the Earthquake Research Institute, University of Tokyo. Starting materials are single crystals of spinel from Myanmar ($MgAl_2O_4$, Cr/(Cr+Al)=Cr#=0.006-0.02), chromite spinel from the Esashi, Hokkaido ($(Mg,Fe)(Cr,Al)_2O_4$, Cr#=0.87-0.93) and synthetic forsterite. Chromite spinel and forsterite were fabricated as semicircular columns with 1.5mm in diameter and about 1mm in height, and their flat column faces were joined together to be a cylinder. spinel was cored to a cylinder as the same size with the coupled cylinder. The two cylinders were set tightly into a cylindrical graphite capsule keeping their polished surfaces in direct contact. In order to fulfill the condition of the semi-infinite diffusion along interface, the same amount of powdered chromite and forsterite were mixed and put beneath the combined cylinder of forsterite and chromite spinel. The furnace assembly is the same as that used in Yasuda et al. (1990). The run product was cut perpendicular to the two contact planes and analyzed with EPMA for the area and line analyses. dbD_g at 1600 degree C was estimated to be almost four order of magnitude lager than D_v.

The flow law of diffusion creep of chromite spinel can be constrained from the diffusivity of Cr and Al in chromite spinel (Suzuki et al., 2005 AGU Fall Meeting) and their diffusivity in interface boundaries between chromite and olivine estimated in this study. Diffusion data shows that the interface boundary diffusion can be effective in diffusion creep below 1600 degree C. We discuss the plastic deformation mechanisms of chromite spinel in peridotite under upper mantle conditions.