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ペロフスカイトとペリクレースからのリングウッダイトの反応縁の成長速度とマントルプリュームのダイナミクスへの応用
Growth rate of ringwoodite reaction rim between perovskite and periclase with implications for dynamics of mantle plumes

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Seismological studies have shown that some upwelling mantle plumes are originated from the lower mantle (e.g., Montelli et al. 2004). The 660-km seismic discontinuity is thought to be responsible for the phase boundary from ringwoodite to perovskite and periclase (post-spinel transformation) (e.g., Ito and Takahashi, 1989). Hence, when the plumes pass across the 660-km seismic discontinuity, ringwoodite will be formed via a reaction of perovskite and periclase. The reaction rate on the ringwoodite formation from perovskite and periclase has an effect on dynamics of the plumes. If the reaction rate is slow, perovskite and periclase should be survived as a metastable phase after the plumes pass across the 660-km discontinuity. Therefore, negative buoyancy operating inside the plumes increases, which leads to generate a resisting force for the mantle convection. Thus, dynamics of the plumes could be controlled by the reaction rate of ringwoodite formation from perovskite and periclase. In this study, we examine the reaction rates of ringwoodite formation from perovskite and periclase by utilizing reaction rim method. Based on the results, we discuss the dynamics of the plumes taking the growth kinetics into account, and the rate-limiting step in the ringwoodite formation from perovskite and periclase.

High-pressure and high-temperature experiments were carried out using a Kawai-type multi-anvil high-pressure apparatus. The starting materials were single crystals of $MgSiO_3$ perovskite and periclase. They were polished, and contacted with each other. The experiments were conducted at 22.5 GPa, and 2073K for 1-12 hours. After the experiments, the ringwoodite reactions rims produced between perovskite and periclase was observed by using Field-emission scanning electron microscope. From the back-scattered electron (BSE) images, the thickness (L) of the ringwoodite rims in each sample was measured.

The ringwoodite was produced at the interface between perovskite and periclase. L increases with proportion to square root of time (t), indicating that the reaction proceeds by a diffusion-controlled mechanism (e.g., Schmalzried, 1978). The reaction constant, k ($k = L^2/t$), is determined to be $4.2 * 10^{-15}$ m^2/s. The microstructural observation showed that the ringwoodite formation was restricted to the perovskite-ringwoodite interface, which suggested that the reaction rate was controlled by diffusion of MgO in ringwoodite. In addition, previous diffusion studies have shown that Mg diffusion rates are much faster than O diffusion in ringwoodite (Farber et al. 2000; Shimojuku et al. 2009). Thus, the O diffusion is likely to be rate-controlling step of ringwoodite formation. By using the determined reaction constant, the difference of depth (h) at which transformations from perovskite plus periclase to ringwoodite occur in mantle plumes and surrounding mantle was calculated. The calculation shows h takes at most 0.1 m under the feasible conditions of the mantle plumes. This value is much smaller than depth variation expected from Clapeyron slope for the post-spinel transformation (e.g., Litasov et al. 2005). Thus, growth kinetics of the ringwoodite reaction from perovskite and periclase could have a minimal effect on the topography of the 660-km seismic discontinuity and negative buoyancy in the mantle plumes.

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