I075-025 Room: IC Time: May 28 13:45-14:00

Water transport by slab subduction and generation of wet mantle plume

Eiji Ohtani[1], Konstantin Litasov[2], Asami Sano[3], Motomasa Touma[4]

[1] Institute of Mineralogy, Petrology, and Economic Geology, Tohoku University, [2] CNEAS,Tohoku Univ, [3] Mineralogy, Petrology, and Economic Geology, Faculty of Sci.,Tohoku Univ, [4] Inst. Min. Pet. Econ. Geol., Tohoku Univ.

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Water transport from the surface to the deep earth's interior and its circulation in a global scale are the key issues to understand the effect of water in planetary evolution including origin of ocean. Water is transported into the deep mantle by hydrous minerals in the descending slabs. In cold slabs with local water enrichment, hydrous wadsleyite and hydrous ringwoodite are the main water reservoirs and excess water is stored in superhydrous phase B $Mg_{10}Si_3O_{14}(OH)_4$ in the transition zone. Phase Egg, $AlSiO_3OH$ is also a candidate for water reservoir in the sediment component in cold slabs descending into the transition zone. Water content in mantle olivine is reported to be about 100-200 ppm, whereas the partition coefficient of water between wadsleyite and olivine is $D(H_2O)^{b/a}$=20-40 (Young et al., 1993; Kohlstedt et al. 1995). Therefore, if the water content at the base of the upper mantle is also the same amount of 100-200 ppm, the water content in wadsleyite will be 2000-8000ppm, which is consistent with the maximum solubility of water in wadsleyite at high temperature above 1600C.

The ascending mantle plumes originating in the deep lower mantle can absorb water by interaction with the hydrous transition zone. Absorption of water by mantle plumes can occur effectively, since the diffusion of H^+ is likely to be significantly fast, if we assume that the hydrogen diffusion rate in the transition zone is similar to that in olivine (Mackwell and Kohlstedt, 1990). The chemical equilibrium of hydrogen concentration between the wet transition zone and hot plume can be achieved during the ascent. Temperature dependency of the water concentration in wadslwyite and ringwoodite implies that about 0.2-0.5% of water can be dissolved in ascending mantle plumes at around 1600C. The melting and phase relations of the peridotite composition (Litasov and Ohtani, 2002) reveals that the apparent solidus of the wet mantle peridotite is significantly lower at the base of the upper mantle compared to that of the transition zone. The melting relation of hydrous peridotite implies that dehydration melting could occur at the base of the upper mantle by dehydration of the wet plume due to the transformation from hydrous wadsleyite to olivine

Recent results on determination of the magma density revealed that density-crossover between olivine and magma occurs at the base of the upper mantle (e.g., Agee, 1995; Ohtani and Maeda, 2001). The melt-mantle density crossover is expected to occur also in wet magmas. The density of basaltic magma containing water of 0.5-1wt.% is calculated based on the partial molar volume of water in magma and the bulk modulus of H_2O in the silicate melt and glass (Ochs and Lange, 1997; Burnham and Davis, 1971). The wet basaltic melt containing water around 0.5 wt.% can be denser than the surrounding mantle. This analysis implies that a density crossover between olivine, pyroxene, and wet magmas can occur at the base of the upper mantle. The analysis of the wet partial melt discussed above shows existence of the density crossover even in the hydrous magma at the base of the upper mantle. Thus, the hydrous melt formed by dehydration melting at the base of the upper mantle tends to be stabilized gravitationally.

In spite of high density of the hydrous melt formed at the base of the upper mantle and its gravitational stability, the partial molten zone may not last long in geological time. Hydrogen diffusion in the mantle is significantly fast as discussed above, and hydrogen in the wet magma at the base of the upper mantle tends to release into the relatively dry upper mantle; about 25,000years for reasonable estimation of the size of the molten zone of 10 km; i.e., the hydrous partial molten zone gravitationally stabilized at the base of the upper mantle can be solidified relatively in a short time scale.