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Water transport to the deep mantle and its effects on the mantle dynamics

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Numerical study for water transport under a volcanic arc revealed dynamics of the water processes inducing melt generation (Iwamori, 1998). Back-arc and intra-plate volcanisms also indicate water migration from a deeper section of the subduction zone. Aiming to understand geodynamical processes of water derived and transported from the subducted slab in the deep subduction zone, we developed a numerical model of water transport coupled dynamically with plate-mantle convection system with a whole mantle scale. We here focus on the mechanism of dehydration from stagnating or penetrating slab and water transport from the mantle transition zone (MTZ). We also consider water transport to deeper mantle and the effects on the global distribution of water-compatible elements that is indicated by the independent component analysis (ICA) of isotope anomaly space (Iwamori and Nakamura, 2012).

We assume that a viscous fluid in a 2-D rectangular box with an extended Boussinesq approximation represents the mantle convection system with integrated lithospheric plates (Tagawa et al, 2007). We incorporate water transport and hydrous mineral phase diagram (Iwamori, 1998; 2007) into the numerical plate-mantle model. We assume that the water dehydrated from water-saturated minerals migrates upward instantaneously with porous flow that is much faster than mantle flow. We introduce reduction of the density and the viscosity due to the hydration into the density and rheology model according to experimental study (Karato and Jung, 2003). We also consider viscous weakening of serpentine or chlorite that is important for water transport in shallow subduction zone.

A serpentine layer generated by dehydration of the oceanic crust plays a key role to control water transport by the subducted slab shallower than about 150 km (Iwamori, 1998; 2007; Horiuchi, 2013). To continuously generate this layer, coupling between the serpentine layer and the plate boundary fault is essential. After dehydration of serpentine, nominally anhydrous minerals (NAMs) (Iwamori, 2007) are a main veneer of the water. In this stage, water capacity of NAMs, which depends on the grain boundary storage as well as that of the hydrous minerals, is the primary factor to control the amount of transported water. This is not so large as about 0.4 wt. % to maintain water-filled region under the arc. The water is carried without dehydration above the 660 km boundary. When the water capacity of the NAMs is about 0.2 wt. %, the amount of the water transported to the mantle transition zone is about 1 % of the basaltic crust mass. When the lower mantle water capacity is lower than the water capacity of the NAMs, the water is expelled at the 660 km phase transition. While the water ascends with the porous flow, the medium rocks descend with asthenospheric flow dragged by the downwelling slab. The repetition of these processes broadens the hydrous layer at the 660 km boundary. A thin water-saturated layer is formed at the 660 km boundary around the penetrating slab. Because of the buoyancy, this becomes unstable so that hydrous plumes are generated. The hydrated layer above the lower mantle slab is thickened by 4 to 5 time more than that in the upper mantle. This result in the increase of the water amount transported into the lower mantle by 4 to 5 times larger than that estimated from the ratio of the water capacity between the upper and lower mantles.

The water reaches the core-mantle boundary region with the subducted slab. The subducted slab sweep out the dense chemical layer above the CMB, so that the dense materials forms a pile-like structure. The distributions of the hydrated materials become exclusive to that of the chemical piles. Iwamori and Nakamura (2012) showed that water-compatible elements (IC2) and OIB components (IC1) have divided distribution. This suggests that the dense chemical pile is not a source for the IC1.

Keywords: water transport, subduction, mantle convection, large-scale heterogeneity