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Water transport coupled dynamically with a plate-mantle convection system involving a shallow to deep subduction zone

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Numerical study for water transport under a volcanic arc revealed dynamics of the water processes inducing melt generation (Iwamori, 1998; 2007). 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 (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 with porous flow that is much faster than mantle flow. In our model, the emitted water is instantaneously transported only to the upward direction. 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 [6]. A numerical method developed by Tagawa et al. (2007) is used to solve momentum and energy conservation equations for the mantle convection. To solve an equation for water transport advected by the mantle flow in which the diffusion term is negligible, a Marker-And-Cell (MAC) method is employed to avoid artificial diffusion.

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, 1998; 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. If the water capacity in the lower mantle is as large as that of NAMs in the mantle shallower than 410 km (~0.2 wt. %), the water is entirely transported to the lower mantle. When the lower mantle water capacity is lower than that, the water is expelled at the post-spinel 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. On the contrary to this, the hydrous plume was not formed from the hydrous NAMs layer over the stagnant slab. At the 410 km boundary, the water is ejected from the hydrous plume as the olivine phase minerals can bear the water much less than MTZ minerals. The ejected water rises with porous flow till the emission is completed. The hydrous plumes fill the water within the mantle wedge from the edge to the 500 to 1000 km distant back-arc area, and those erode to thin the overriding lithosphere.

Keywords: subduction zone, water transport, transition zone, slab, hydrous plume, mantle convection