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Deep mantle slabs and the deep Earth's water cycle

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Water enters the Earth‘s mantle at trenches by subduction of oceanic lithosphere. Most of water immediately returns to the atmosphere through island arc volcanism, but part of it, which could be retained in Dense Hydrous Magnesium Silicates (DHMSs) and Nominally Anhydrous Minerals (NAMs) like olivine, is expected as deep as the Earth‘s mantle transition zone (410-660km depth). Water carried by subducted slabs is the only source of water of the deep mantle. It makes the understanding of the processes of water transfer from a deep slab to the mantle a key element to estimate the water content and distribution in the Earth‘s mantle, especially in the transition zone.

Here we present results from numerical modeling of two possible processes for slab dehydration and discuss them in regard to the Transition Zone water content: i) Within the Earth‘s mantle transition zone by diffusion of water out of the slab, and ii) at the base of the upper mantle (660km depth) by percolation of hydrous fluids formed by water exsolution from the slab.

Regarding stagnant slab dehydration by diffusion, we consider temperature dependent water solubility in transition zone olivine polymorphs (Wadsleyite, Ringwoodite). We show that if water solubility is decreasing with increasing temperature, the expected water flux reduction is mitigated by a self adjustment of the water concentration gradient. This feed-back effect is induced by the coupling of heat diffusion (cooling of a stagnant slab) and water diffusion (dehydration of a wet stagnant slab into a dry mantle above it). The water concentration is displaying a local maxima just below the slab-mantle interface that could reach the solubility limit of the mineral and trigger melting.

When slab eventually reaches the lower mantle (660km depth), due to its low solubility in lower mantle minerals, the remaining water is likely to be released as anhydrous fluid, during the spinel-postspinel phase change. The dynamics of this fluid phase is investigated through a 1-D model using two-phases flow theory, in which a source term has been introduced to take the fluid precipitation into account. The competition between the advective transport by the descending slab and the buoyant rise has been explored for the all range of possible properties of solid and of fluid phases. The most likely behavior is an effective compaction resulting in an accumulation of fluid at and below the phase change. The pressure difference between the fluid and the matrix increases continuously, exceeding the yield strength of rocks. As a result, cracks would initiate and evolve toward the formation of dykes. Thus, it is expected that water comes back to the upper mantle by the way of dykes propagating along the direction of the maximum compressive stress.

Those two processes are likely to make the transition zone rather wet in the vicinity of a subducting slab.