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Subduction water recycling

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Hydrated ultramafic rocks play a key role in the transport of water from the surface to the mantle along subduction zones. Many key geochemical and geophysical features of Earth depend on this deep water cycle. Previous studies have demonstrated that antigorite and chlorite are the dominant water carriers in subducted slabs up to pressures corresponding to 100-150 km depth. Beyond 200 km depth hydrous Mg-silicates (“alphabet phases” A, E, D) as well as wadsleyite and ringwoodite potentially can host weight per cent of H_2O. The phase relations of hydrous ultramafic rocks and the geotherms in the critical depth range of 120-200 km will determine how much water is cycled through arc magmatism back to the Earth surface and how much water is subducted to the deeper mantle. To date, very limited information is available to constrain this crucial aspect of the deep water cycle.

We have conducted piston cylinder experiments in the range of 4-6.2 GPa and 600-850°C to address subduction water recycling in chlorite-rich ultramafic rocks using natural starting materials. Chlorite is stable up to 800°C at 4 GPa and then there is a moderate backbend of chlorite stability to 5.6 GPa, 740°C. Above 5.6 GPa, chlorite reacts to a hydrous Mg-Al-silicate, the 11.5 Å phase (12 wt% H_2O) + garnet + olivine. Above 6.2 GPa, 600-700°C chlorite breaks down to Mg-sursassite (7.2 wt% H_2O) + 11.5 Å phase + olivine. The transition of chlorite to these other hydrous Mg-Al-silicates occurs at significantly higher temperature and lower pressure conditions than previously reported, with important consequences for the deep water cycle.

The new results show that along warm and intermediate slab geotherms, all hydrous phases in subducted ultramafic rocks will break down. Also in the warmer mantle wedge, no hydrous phases are stable. Thus, for these conditions, a few 100 ppm of water will be stored solely in the nominally anhydrous minerals garnet, pyroxenes and olivine. However in cold subduction zones and even more so in the cold interior of subducted slabs, water can be transferred from the hydrous phase chlorite via the hydrous 11.5 Å phase and Mg-sursassite to the hydrous “alphabet phases”, providing an efficient mechanism to transport significant amounts of water to the deeper mantle along subduction zones. Thus, water incorporated in hydrous ultramafic rocks in the uppermost part of the subducted slab and in the hydrated forearc will not be able to be transported beyond 150 km depth and will be mostly recycled through arc magamatism at timescales of a few million years. In contrast, water incorporated in the slab lithospheric mantle due to hydration at bending faults will likely be transported to the deeper mantle and might return to the surface only after residence times of several 100 million years.