Pressure Control on D/H Fractionation of Mineral-Fluid Systems with Implications for Subduction Zone Dehydration and the Deep-Earth Water Cycle

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Water in oceanic crusts that is carried into Earth's mantle at subduction zones is continuously released during subduction-induced dehydration, resulting in the generation of arc volcanism. The extent of lithosphere dehydration and associated hydrogen isotope (D/H) fractionation during subduction are critical to understanding the global water cycle. δD values of magmatic melt inclusions from subduction-related arcs (δD: ca. -50 to -10‰) are found greater than those of MORB (δD: -80±10‰) and subduction slabs (δD: ca. -50‰) [1]. These data have been interpreted that complementary hydrous mantle components were produced during subduction: D-enriched mantle wedge and D-depleted slab, assuming large negative D/H fractionation between hydrous minerals and water during dehydration.

Several experimental and theoretical studies have clearly demonstrated that in addition to temperature, pressure and dissolved NaCl affects significantly D/H fractionations of hydrous mineral – fluid systems [2, 3, 4]. Pressure increases the reduced D/H partition function ratio (β-factor) of hydrous minerals, while the D/H β-factor of aqueous fluids decreases with pressure. A combination of these two contrasting isotope effects on the two phases is that the value of $10^3 \ln\alpha_{D/H}$ ($= \delta D_{mineal} - \delta D_{fluid}$) increases from negative values to less negative values with pressure, resulting in magnitudes of D/H fractionations between hydrous minerals and aqueous fluids that are smaller than previously assumed [1]. These new data and our improved understanding of the D/H fractionation suggest that hydrated subduction slabs release water relatively D-enriched fluids in shallow depths, but they release relatively D-depleted fluids with increasing depths below arcs. These results have important implications for the hydrogen isotope evolution of terrestrial water reservoirs and the water cycle.

REFERENCE:
[1] Shaw, Hauri, Fischer, Hilton & Kelley (2008), EPSL 275, 138-145; [2] Horita, Cole, Polyakov & Driesner (2002), GCA 66, 3769-3788; [3] Withers & Zhang (2003) AGU abstract; [4] Horita, Driesner & Cole (2018), GCA 235, 140-152.