WATER PLANETS AND HYDROGEN IN NOMINALLY ANHYDROUS MINERALS. J. R. Smyth1,
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Introduction: Although liquid water controls many of the surface processes including carbon-based life, Earth’s oceans constitute only about 0.025% of the planetary mass. Water solubility in the nominally anhydrous silicates of the upper mantle can exceed one weight percent. It is likely then that many times the amount of water in the oceans is tied up as trace hydrogen in nominally anhydrous minerals of the mantle. Searches for water-bearing planets may be facilitated by an understanding of the potential for water storage in the solid phases of planetary interiors.

Water solubility in pyroxene, olivine, wadsleyite and perovskite can control many of the processes of the interior. Water solubility affects density and elastic properties and hence seismic velocities. Water solubility can control melting. Trace H in these minerals has a dramatic effect on deformation and rheology as well as electrical conductivity.

Deep Water Cycles: In the Earth’s crust water can enter mineral structures as hydroxyl or as molecular water. Oceanic crust can hydrate by deep circulation and hydrothermal alteration at divergent plate boundaries. Most of this water is, however, returned to the hydrosphere with the breakdown of nominally hydrous minerals on subduction. Most of the nominally hydrous minerals will breakdown at depths less than about 300 km. However, at this depth the nominally anhydrous minerals of the subducting crust and lithosphere can incorporate sufficient H to cycle the water of the oceans through the deep mantle several times at current subduction rates. It is likely then that Earth’s oceans are sustained by a deep water cycle to depths of at least 660km [1].

Interior Reservoirs: The water storage capacity of the nominally anhydrous mineral in the upper mantle and transition zone has been estimated at up to ten times the amount of water in the oceans [1,2]. The water storage capacity of the lower mantle is more difficult to constrain as there are conflicting estimates of the H solubility in the Mg and Ca silicate perovskites [3]. H is also highly soluble in liquid iron metal and there are currently no firm constraints on the amount of H that may be incorporated into the core.

Substitution Mechanisms and Isotope Effects: The predominant substitution mechanism appears to be two protons for one Mg, as octahedral vacancies are observed in hydrous olivine, wadsleyite, and ringwoodite [3]. This means that there are hydroxyls in the structure, and hydroxyls preferentially exclude deuterium. Further the IR absorption feature shifts to lower energies with the higher pressure phases. This means that H included in this interior reservoir will be light relative to SMOW. Given the potential size of the reservoir, it further implies that the bulk D/H ratio of the planet is poorly constrained.

How Much Is There: H contents of melt inclusions in MORB indicate that these magmas are relatively dry 0.1 to 1.0 weight percent H2O. This implies that the source rocks are less than about 200 ppm H2O by weight. However, H is extremely mobile and measured H contents of melt inclusions may not be representative of MORB magmas. Further, crystal/melt H distribution coefficients as large as 0.1 have been observed for some nominally anhydrous minerals.

It is unlikely that the nominally anhydrous minerals of the transition zone are saturated as this would result in significant melting on upward convection across the 410 km discontinuity. Hydrogen incorporation into nominally anhydrous minerals has a large effect on elastic properties and seismic velocities. Comparing the model P and S velocities of PREM with the nominally anhydrous phases we observe that an anhydrous transition zone would be too fast so that observed velocities in this region are consistent with significant hydration at 0.3 to 0.6 percent H2O by weight. Upper mantle velocities are consistent with hydration at 0.2 to 0.4 percent. Lower mantle velocities, however are consistent with an anhydrous perovskite plus periclase assemblage. However data on the effects of hydration on elastic properties of these phases are preliminary and the pressure and temperature derivatives are poorly constrained.