THE ROLE OF H₂O ON MANTLE MELTING IN THE TERRESTRIAL PLANETS. T. L. Grove, E. Médard and C. B. Till, Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge MA 02139, USA (tlgrove@mit.edu; emedard@mit.edu; ctill@mit.edu).

Introduction: Recent laboratory studies of the melting behavior of Martian and Earth mantle peridotite compositions have redefined our understanding of hydrous melting. Studies by Grove et al. [1] and Médard and Grove [2] have revisited the melting equilibria and the stability of hydrous phases on the solidus of mantle materials.

The phase relations for the Earth and Martian mantle compositions are compared in Figure 1. In both cases the peridotite solidus at 3 GPa is ~ 800 °C, which is 200 °C lower than previously accepted values. At 3.0 GPa, the dry solidus for Earth or Martian mantle compositions is ~1400 °C [3, 4]. Addition of H₂O to planetary mantles can thus decrease melting temperatures by as much as 600 °C relative to dry melting. This will have important consequences for planetary differentiation. At pressures above 0.5 GPa, amphibole is present on the vapor-saturated solidus and remains stable to ~ 2 GPa. At pressures greater than 2.4 GPa chlorite becomes a stable phase on the solidus and it remains stable until ~ 3.6 GPa. Therefore, melting at 2.4 to 3.6 GPa occurs in the presence of chlorite, which contains ~ 12 wt. % H₂O. On the Earth, chlorite could transport large amounts of H₂O into the descending mantle wedge in subduction zones. On Mars, chlorite may be stored in the martian lithosphere. Chlorite may be the ultimate source of H₂O for terrestrial subduction zone magmatism. The stability of chlorite on the peridotite solidus may resolve the long-standing puzzle of how H₂O can be transported to a sufficient depth in the mantle wedge so that it can participate in melting to generate hydrous arc magmas.

Melting Earth’s Mantle: In light of these new insights into the chemical processes that lead to melt generation in subduction zones, we can focus on the influence of mantle dynamics and physical processes on melting. Variations in mantle permeability near the base of the wedge, above the subducted slab may exercise important controls on the access of fluids and/or melts to the overlying wedge. The presence of chlorite in the wedge may also influence rheological properties and seismicity in the vicinity of the slab - wedge interface. Advancing our understanding of the thermal structure in the convecting mantle is crucial because it influences melting in the wedge. Improved knowledge of rheology and permeability will help us to develop more robust models of mantle flow and temperature distribution in the mantle wedge. By combining evidence from petrology, geochemistry and geophysics the mysteries that attend the generation of melt in the mantle wedge can be resolved.

Water incorporation during accretion: Recent evidence from Ceres, a small proto-planet orbiting in the asteroid belt, indicates that large water-rich planetary bodies were in existence during the early evolution of the Solar System [5]. The formation of water-rich versus dry bodies is likely a complex function of initial amount of water in the planetesimals, timing of accretion, and concentration of short-lived radioactive isotopes [6]. The existence of water-rich planetesimals and small-protoplanets in the inner Solar System allows reexamination of the hypotheses for the incorporation of H₂O into planets.

Water and early melting on Mars: By combining hydrous phase relations and thermal models of planetary evolution we can gain some insight into the role played by H₂O during accretion. There are two main reason to focus on Mars: (1) Mars accreted from a chondritic mix richer in volatile elements than for other terrestrial planets [7]. (2) The size of Mars is almost identical to the typical size of a proto-planet just before the giant impact stage [8], suggesting that Mars may have escaped the formation of a planet-scale magma ocean that obliterated most of the signature of early accretion and differentiation processes on Earth.

We propose that an early hydrous melting event occurred during the accretion process. This melting...
event profoundly differentiated the Martian mantle and removed \( \text{H}_2\text{O} \) from the planet's interior. Water has a strong effect on melting temperatures and mantle viscosity, and the presence of water will accelerate the differentiation process, in agreement with the evidence that Mars differentiated into atmosphere, mantle and core at a very early stage [9].

![Figure 2. Water-saturated phase relations of a primitive mantle + crust Martian composition, after [2]. Circled numbers are estimated total water contents bound in hydrous phases, calculated from phase proportions and water content in hydrous phases.](image)

**Fate of \( \text{H}_2\text{O} \) during accretion:** During accretion, \( \text{H}_2\text{O} \) would be preserved in the hydrous minerals of incorporated chondritic materials which would remain stable until about 30% of the mass of the planet had accreted in a rapid accretion process (Fig. 3). As accretion continued, interior temperature would increase until it passes a series of dehydration and melting reactions. Dehydration in the deeper parts of the planet would lead to flux melting in the shallower parts.

![Figure 3. Thermal model of planetary accretion [10] compared to experimentally derived phase diagram for a wet Martian composition (Fig. 2). Different shades of gray represent the amount of water that can be bound in hydrous silicates: dark gray, \( \geq 4 \) wt%, light gray 0.4-1.3 wt%, white, no stable hydrous phase. The dashed line is the water-saturated solidus, i.e., the low-temperature boundary of the melting region. Thin black lines are thermal profiles at different stages of planetary growth, when the planetary radius \( R \) was 0.6, 0.7, 0.75, and 0.8 times its final radius \( R_f \). Major dehydration and degassing occur when the planet reached about 70% of its final radius (30% of its final mass). Figure from [2].](image)

The innermost part of the planet would remain undegassed during accretion, and contains \( \text{H}_2\text{O} \) stored in buried hydrous silicates. A feature of all thermal models of planetary evolution is that the inside of the planet heats up only after or during the latest stages of accretion, as a result of core formation and heating by long-lived radioactive isotopes [11]. Large amounts of \( \text{H}_2\text{O} \) could thus be transferred into “nominally anhydrous silicates” in the deep mantle, and might even be incorporated into the core [12].