

# EARLY IRREVERSIBLE HYDROUS MELTING AND DEGASSING OF THE MARTIAN INTERIOR: AN EXPERIMENTAL STUDY.

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**Introduction:** According to current models of the solar system formation, the concentration of volatile elements in a given planet is expected to increase with distance from the Sun. It is thus probable that the chondritic mix from which Mars accreted is richer in volatiles than that of the Earth. Actually, evidence from Martian meteorites show that Mars is not as depleted in volatile elements as are other terrestrial planets [1]. The most volatile element, H, is of particular importance, because of the tremendous effect  $H_2O$  has on melting temperatures [2]. Carbonaceous chondrites, containing up to 10 wt%  $H_2O$  [3], can bring fairly large amounts of water in an accreting planet. The actual  $H_2O$  content of the Martian mantle may be quite low (down to 36 p.p.m. [1, 4]), and evidence from noble gas isotopes strongly points towards an early degassing process, that has stripped the planet of most volatile gases [5]. Before this degassing event, primordial Mars may have been quite wet.

Radiogenic isotope data for Martian meteorites (e.g., evidence for live  $^{142}Nd$  and  $^{182}Hf$  in their source, [6]) all provide evidence that Mars accreted rapidly and at an early stage differentiated into atmosphere, mantle and core. Furthermore, the preservation of 4.5 Ga old isotopic heterogeneities [7] points toward the absence of subsequent widescale homogenisation processes, as observed on the Earth. It thus appeared that most of Martian characteristics have been acquired during very early differentiation processes.

We investigated the melting behaviour of an undegassed Martian mantle composition, in order to explore the potential influence of water on these early differentiation processes. Experimental studies show that water has a strong effect on melting temperatures [2], and the presence of water may profoundly modify the timing of differentiation in a growing planet. We propose that an early hydrous melting event occurred during the accretion process. This melting event profoundly differentiated the Martian mantle and removed  $H_2O$  from the planet's interior.

**Experimental results:** Experiments have been performed in a piston-cylinder apparatus, at 1.0-2.5 GPa and temperatures between 825 and 1100 °C on a primitive (mantle + crust) Martian composition [8]. They were aimed at locating the water-saturated (~11.8 wt%  $H_2O$  added) solidus and hydrous phase stability fields. The experimental temperatures are low enough, so that Au can be used as a capsule material. Au is very resistant to diffusion of  $H_2$  out of the  $H_2O$ -rich

sample, allowing long run durations, which leads to homogeneous crystalline run products. Identifying very small amounts of melts has proven a difficult task, but we successfully located the wet solidus by monitoring textural changes and identifying small melt pockets on SEM secondary electron images.

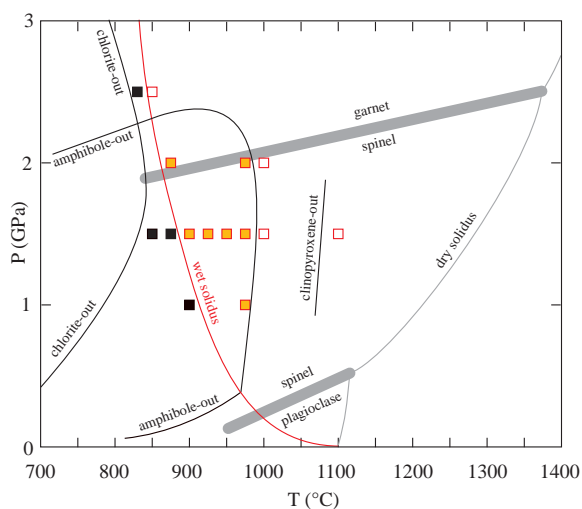


Figure 1. Experimental water-saturated phase diagram of a primitive mantle + crust Martian composition. Chlorite stability field from [10], dry solidus from [9].

Compared to dry experiments [9], the solidus temperature (Figure 1) decreases by as much as 500 °C, down to 850 °C at 2.5 GPa. At pressure below ~2.0 GPa, we observed a ~100 °C wide amphibole-stability field, where melt fractions remain extremely low. However, once the amphibole-out boundary is reached (below 1000 °C), the amount of melt begins to increase very quickly. In a growing Mars, small melt fractions would be generated above ~850-900 °C, and higher melt fraction would be reached once the temperature rises above 1000 °C. Water-rich phases like chlorite have not been observed in our experiments, but experiments in simple systems [10], and wet melting experiments on a more magnesian composition, suggest chlorite may be stable up to near the water-saturated solidus, thus allowing significant amounts of water to be stored until conditions of wet-melting are achieved.

**Implications:** Our experiments provide new constraints on the role of H<sub>2</sub>O in the early history of Mars. During accretion H<sub>2</sub>O would be preserved in the hydrous minerals of chondrites which would remain stable until about 30 % of the mass of the planet had accreted in a rapid accretion process [11, 12]. The maximum amount of H<sub>2</sub>O that could be sequestered in the planet would be 3.0 wt. % of the total mass.

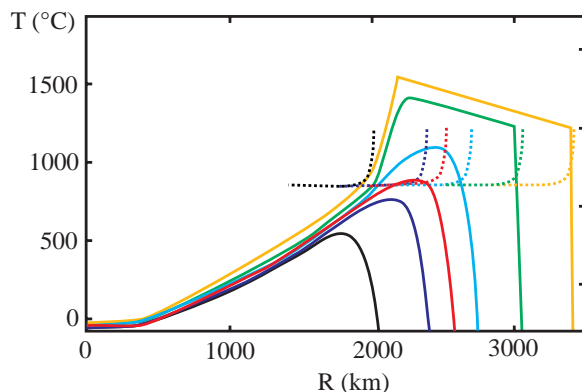


Figure 2. Thermal evolution of a growing Mars. Solid curves are thermal profiles calculated at different stages of accretion (redrawn from [11]). Dotted curves are the wet solidi at each stage. Melting would begin when the planet reached ~ 75% of its final radius (i.e., 40 % of its mass, red curves).

As accretion continued, the material added to the surface of the growing planetesimal would be anhydrous, and the interior temperature would continue to increase (Figure 2) until it passed through the H<sub>2</sub>O-saturated solidus. H<sub>2</sub>O-saturated melts would be produced in the outer 400 km of the growing planet, and would rise buoyantly into the shallower, hotter anhydrous exterior. As they ascended into the overlying hotter mantle, they would be out of thermal and chemical equilibrium with the surrounding silicate material. To re-equilibrate, the melts would be heated by the surroundings and would dissolve solids, decreasing the H<sub>2</sub>O content of the melt as it ascended and reacted with the hotter overlying material. This would continue to near the surface of the growing planet, until the depth of vapor-saturation was reached, when degassing and crystallization would occur. This process is identical to the flux melting process that occurs in modern terrestrial subduction zones [13]. A second melting event might follow this initial wet-accretion-melting. This melting would occur at greater depths and would be initiated by radioactive heating of the deep interior. As the interior becomes hotter, the hydrous minerals would become unstable and release H<sub>2</sub>O, which would ascend into the overlying mantle

and initiate H<sub>2</sub>O-saturated melting. These melts would also evolve in response to an inverted temperature gradient that develops as the planet continues to evolve. These two processes will strip the outer Martian mantle of water in an early catastrophic accretion-driven melting event. They would be expected to lead to a proto-crust of basaltic andesite similar to that found in terrestrial subduction zone settings. Small amounts of H<sub>2</sub>O might be preserved in the proto-crust or some deeply buried H<sub>2</sub>O that survived the first melting event might be sequestered in the core [14].

**References:** [1] Dreibus G. and Wänke H. (1985) *Meteoritics*, 20, 367-381. [2] Mysen B.O. and Boettcher A.L. (1974) *J Pet*, 16, 520-548 [3] Wasson J.T. and Kallemeyn G.W. (1988) *Phil. Trans. Royal Soc. London*, 325, 535-544 [4] McSween H.Y.Jr et al. (2001) *Nature*, 409, 487-490 [5] Ott U. (1988) *GCA*, 52, 1937-1948 [6] Halliday A.N. et al. (2001) *Space Sci Rev*, 96, 197-230 [7] Borg L.E. et al. (1997) *GCA*, 61, 4915-4931 [8] Dreibus G. and Wänke H. (1984) *27<sup>th</sup> Int. Geol. Congress*, 11, 1-20 [9] Bertka C.M. and Holloway J.R. (1994) *CMP*, 115, 313-322 [10] Jenkins D.M. and Chernovsky J.V. (1986) *Am. Min.*, 71, 924-936 [11] Senshu H. et al. (2002) *J. Geophys. Res. E*, 107, 5118. [12] Abe Y. and Matsui T. (1986) *Proc. 17<sup>th</sup> Lunar Planet. Sci. Conf.*, E291-E302. [13] Gaetani G.A. and Grove T.L. (2003) *AGU Monograph* 138, 107-134. [14] Jana D. and Walker D. (1999) *GCA*, 63, 2299-2310