INVESTIGATION OF H2O STORAGE AND HYDROUS MELTING OF THE EARLY MARTIAN MANTEL 

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Introduction: Furthering the understanding of the effect of water on the differentiation of early Mars requires the investigation of the phase equilibrium of an undegassed Martian mantle. In particular, water has a significant effect on the solidus temperature, and little is known about the near-solidus behavior in systems chemically equivalent to the Martian mantle at pressures above 4GPa. Early wet melting of Mars during accretion can lead to chemical differentiation and produce mantle heterogeneities that could be reprocessed during late volcanism as the sources for SNC meteorites. Such a chemical differentiation will occur in an H2O-rich melt layer produced when the vapor-saturated solidus is crossed. Hence the need to:
1) define the wet solidus at high pressures,
2) understand how water is stored in hydrous minerals at elevated pressure and temperature conditions and, thus, understand the stability range of hydrous phases in Martian mantle,
3) determine the melt compositions produced in the Martian mantle in the presence of excess H2O.

In this contribution, we present the solidus and near-solidus phase relations experiments performed on a water-saturated Martian model mantle composition using a multi-anvil apparatus over the P range 4.5-7 GPa and ~700-1000°C.

Experimental protocol and analytical techniques: Our starting material is a Martian crust+mantle analog composition [1] with a substantial amount of water (water-saturated experiments) [2].

One experiment was performed in a piston-cylinder Design and protocol are similar to the one in [2] All other experiments were conducted in a multi-anvil apparatus at MIT. Temperature was varied between 700 and 1000°C, and pressure between 4 and 7 GPa. Experimental durations range between 2 and 11 days, depending on the P, T conditions. A homogeneous composition for each phase in the capsule and the absence of zoning indicated a close approach to equilibrium. Pressure was calibrated using the Qz-coesite transition at 3.1GPa and the fayalite-spinel transition in Fe2MgSiO4 at 5.75 GPa at 1200°C. Temperature gradient in the graphite furnace was determined by a two-pyroxene thermometry experiment [3] as well as a two-TC experiment.

After each experiment, the textural relations of minerals and melt in each sample was observed using a reflected-light microscope and electron microprobe imaging. Composition of each phase (minerals + glass) was characterized using electron microprobe analyses. Hydrous phases are identified using both electron microprobe data and Raman spectra (work in progress).

Results and discussion:

Anhydrous phases: Olivine, pyroxene and garnet have been observed in all experiments. Spinel was present in most experiments, in small quantities (~5%). Olivine and pyroxenes are the dominant phases (>70%). Olivine is usually small and round, in small agglomerates or poikilitic, pyroxenes are elongated (needlelike), and garnet size varies from small grains (<5microns) to larger irregular grains (20microns).

Abundance of hydrous minerals and hydrous melt: Different hydrous ferromagnesians phases have been synthesized and tentatively identified using microprobe analyses: some are part of the humite group (composed of olivine-like and brucite-like structure units). Raman spectra are consistent with the presence of these minerals. The following phases are produced by the combining brucite-like + olivine-like structural units to form norbergite and/or Ti-clinohumite.

Other synthesized minerals are close to phase A and phase E. The amount of dissolved water ranges from 1 to 12 wt% (Figure 1).

Small pockets (experiments A20, A33, A34) as well as a significant amount (10 wt% in A25) of hydrous melt have been observed for experiments just above the solidus (~800°C). Each time it was possible to analyze melt, its composition was Si-rich (up to 72 wt% SiO2 in the analysed charges).

The amount of water bound in the Martian mantle is estimated from both phase proportions from mass balance calculations and the water content in hydrous phases. Several wt% of water can be stored in both mineral phases and melt over the investigated T and P ranges (Figure 2). Moreover, it is expected that a significant amount of water can be dissolved in the melt (~30 wt%, [4,5]).

Contrary to what was predicted in [2], the stability field of the hydrous phases for a Martian peridotite composition seems to differ from those determined in the MgO-SiO2-H2O system [6]. The much higher amount of iron as well as the presence of TiO2 and Cr2O3 probably explain (at least partly) the difference.
Water storage during the accretion of the planet: If it is likely that water played a critical role during the formation and differentiation of terrestrial planets, it is still not clear from our current understanding of the early history of the evolution of Mars if water was incorporated during accretion from the solar nebula dust or during a late veneer-type phase. The stability of water-bearing phases at high pressures supports the first hypothesis. Estimates of the amount of water present in bulk Mars are however much lower than what hydrous phases can bear (e.g. only 390ppm water according to [7]). It is possible that the innermost part of the planet did not degas during accretion. As a consequence, heating up this part (by impact or radioactivity) will make the hydrous phases unstable and release water that can become involved in hydrous melt and/or leading to an increase of the hydrogen stored in the nominally anhydrous minerals.

Furthermore, during core formation within the planet, it is probable that hydrous Fe-rich phases have been displaced, due to the segregation of metallic alloys. As suggested by [2], the high solubility of H in iron can lead to the storage of H in the core.

The presence of an abundant quantity of hydrous melt at high pressures provides new scenarios for chemical differentiation in early Mars. Deep hydrous melts could initiate convective upwelling and lead to the transport of water to the surface with resulting chemical differentiation. Actually, it has been shown that only 3 vol% of partial melt is needed to reach a coalescence and a separation from the source [8].