PROVENANCE AND CONCENTRATION OF WATER IN THE SHERGOTTITE MANTLE.

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Introduction: The water content of the martian mantle is controversial. In particular, the role of water in the petrogenesis of the shergottites has been much debated. Although the shergottites, collectively, contain very little water [e.g., 1,2], some experiments have been interpreted to show that percent levels of water are required for the petrogenesis of shergottites such as Shergotty and Zagami [3]. In this latter interpretation, the general paucity of water in the shergottites and their constituent minerals is attributed to late-stage degassing.

Y980459 (Y98) is a very primitive, perhaps even parental, martian basalt, with a one-bar liquidus temperature of ~1400°C. Olivine is the liquidus phase, and olivine core compositions are in equilibrium with the bulk rock [e.g., 4]. Petrogenetically, therefore, Y98 has had a rather simple history and can potentially help constrain the role of water in martian igneous processes. In particular, once trapped, melt inclusions should not be affected by subsequent degassing.

Methods: We have analyzed olivine-hosted melt inclusions in Y98 for a suite of volatiles using the DTM Cameca 6f ion microprobe: H_2O, CO_2, F, Cl, S, and D/H [5]. More analytical details are given in a companion abstract [5]; but the methodology is nearly identical to that of [6]. Y98 inclusions are glassy, indicating that Y98 cooled quickly upon eruption [7]. Cracks and other possible sources of contamination have been avoided [8]. In addition to standard electron microprobe analysis of potentially viable inclusions, we also obtain ion images of H and C. Only about 50% of the inclusions we investigated were considered acceptable for D/H analysis. The results for these inclusions are presented here and in [5].

Results: Table 1 gives averages and ranges for three melt inclusions from Y98. Water contents range between 150 and 250 ppm, but the H_2O/F ratio of these inclusions remains rather constant. We interpret this constancy as indicating that, once trapped by olivine, the inclusions have acted as closed systems. We also believe that this constant H_2O/F ratio shows that we have indeed successfully avoided contaminated inclusions. Additionally, the D/H ratio of these inclusions is rather constant, ~270‰ [5]. Collectively, these observations give us confidence that the data presented here can place strong constraints on the water content of the shergottite mantle.

The water content of the shergottite mantle: Estimates of the water content of the Martian mantle tend to be bimodal: from a relatively dry (1-36 ppm H_2O [9,10]) to a relatively wet mantle (140 to 250 ppm [11]). As a firm limit, the Y98 melt inclusion data constrain the maximum H_2O content to be <~250 ppm (Table 1), since this is the maximum water concentration we have measured.

We use the Na content of the bulk rock and that of our melt inclusions to estimate how much post-melting concentration of Na and H_2O has occurred, since both Na and H_2O act incompatibly during olivine crystallization. Na_2O in our melt inclusions are three times higher than the bulk Y98 (0.5 wt.% bulk vs. 1.5 wt.% in the inclusions). Therefore, the water content in the Y98 primary melt is estimated to be ~80 ppm.

If we further assume a simple batch melting model with a range of realistic parameters for the water partition coefficient [D(H_2O)] of 0.001-0.01 and melt fraction of 0.2-0.4, the water content of the depleted shergottite mantle (i.e., the Y98 source) is estimated to be 16-33 ppm, which is consistent with the dry mantle hypothesis. And even if the melt fraction that formed Y98 were much higher, the source mantle is still constrained to have < ~80 ppm water.

Of course, this simple calculation assumes that no degassing occurred prior to the entrapment of the melt inclusions. However, our CO_2 data address this issue.

The the maximum CO_2 content of our melt inclusions (Table 1) is ~1600 ppm. Assuming CO_2 saturation as a limiting calcuation, this corresponds to a pressure of ~3 kbar [12]. On Mars this translates into ~30 km depth — consistent with a magma chamber in the lower crust. We therefore infer that degassing prior to melt inclusion entrapment was minimal and perhaps even nonexistent.

For comparison, analysis of a melt inclusion from an enriched shergottite, LAR 06319 (LAR), is of interest. The LAR inclusion has H_2O, F, and Cl concentrations that are much higher than the Y98 inclusions, but CO_2 is not similarly enriched [5]. We interpret this to indicate there had been CO_2 degassing from LAR at a much shallower level in the martian crust [5]. This is because all these elements and compounds are expected to act incompatibly in high degree partial melts at pressure (i.e., both Y98 and LAR have olivine as an early crystallizing phase). For example, the enrichments of F and Cl in LAR inclusions, compared to those in Y98 are factors of ~49 and ~38, respectively.

Provenance of martian water: The origin(s) of water in the terrestrial planets has been debated. Two extreme cases are envisioned: wet accretion of chondrite-like materials *vs.* dry accretion followed by the addition of volatile-rich materials (e.g., comets) [13]. The near-chondritic δD value of 275‰ reported here for the Martian mantle is inconsistent with a cometary origin (δD ≥ ~1000‰, although Earth-like δD values of 33±154‰ were recently reported for a Jupiter-family comet [14]). Instead, our results are much more consistent with a chondritic or "Earth-like" source for martian water.

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