PROVENANCE AND CONCENTRATION OF WATER IN THE SHERGOTTITE MANTLE. J. H. Jones[1], T. Usui[2], C. M. O'D. Alexander[3], J. I. Simon[1], and J. Wang[3], [1]KR, NASA/JSC, Houston, TX, 77058 (john.h.jones@nasa.gov); [2]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX, 77058; CIW-DTM, 5241 Broad Branch Road, NW, Washington, DC 20015-1305.

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 from a depleted mantle, with a one-bar liquidus temperature of ~1400°C. Olivine and chromite are the liquidus phases, 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, melt inclusions should not be affected by subsequent degassing once they have been trapped.

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 by ion imaging [e.g., 8]. In addition to standard electron microprobe analysis of potentially viable inclusions, we also obtain ion images of H and C. Only a small percentage of the inclusions we investigated were considered acceptable for both D/H analysis and determination of volatile element concentrations. The results for these inclusions are presented here (Table 1) and in [5].

In addition to Y98, we have also measured volatiles and D/H in a single melt inclusion from an enriched shergottite, LAR 06319 (LAR).

Results: Table 1 gives concentration 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 [5]. 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 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 Y98 data presented here can place strong constraints on the water content of the shergottite mantle.

Conversely, the LAR inclusion has a D/H ratio of ~+5000‰ and extremely high concentrations of H_2O, Cl and F relative to Y98. We take these results to indicate that LAR water is mainly crustal in origin and gives little insight into the water content of the martian mantle.

Water in 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 upper 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 a 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.

Degassing: 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 maximum CO_2 content of our Y98 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 the enriched LAR shergottite is of interest. The LAR inclusion has H_2O, F, and Cl concentrations that are much higher than the Y98 inclusions, but CO_2 and S are not similarly enriched (Table 1). We interpret this to indicate there had been CO_2 degassing from LAR at a much shallower level in the martian crust. The S content of the LAR inclusion is so far from sulfide liquid saturation levels, that SO_x or H_2S degassing may also have occurred [13]. This is because all these elements and compounds we have analyzed 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 ~36 and ~27, respectively. So F/Cl ratios are rather constant, and we infer from this that F and Cl are difficult to fractionate from one another, and that neither F nor Cl in Y98 and LAR have experienced significant degassing.

Is the D/H ratio of the shergottite mantle even lower? The D/H ratio that we have measured for Y98 is very low compared to the martian atmosphere. However, even lower D/H ratios have been measured in martian meteorites [e.g., 1,14]. For example, a bulk-rock, stepped-temperature-release study of one Chassigny sample yielded a rather narrow range of D/H ratios from -25 to -100‰ between 200 and 1000°C [1]. Further, the noble gas measurements of [15] on Y98 were interpreted by these authors to represent a mixture of shergottite mantle and martian air. Therefore, it is possible that our Y98 D/H measurements are upper limits to the true D/H ratio for the shergottite source region.

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) [16]. The near-chondritic δD value of ~270‰ 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 [17]). Instead, our results are much more consistent with a chondritic or "Earth-like" source for martian water.

It is also true, though, that our inferred water contents for the shergottite mantle could hardly be described as "wet." But this seeming inconsistency must be viewed light of the fact that the Y98 mantle had been depleted in incompatibles (such as water) at least twice before the melting event that led to the formation of Y98 [2]. Therefore, we favor a "wet" accretion of chondritic materials to explain water in the shergottite mantle.

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Table 1
Summary of Melt Inclusion Analyses*‡

Meteorite	D/H (‰)	H2O	CO2	F	Cl	S
Y980459	+271	193	816	13.5	38	822
	(267-275)	(146-251)	(265-1601)	(9.9-17.1)	(27-48)	(634-930)
LAR 06319	+5079	1872	240	490	1018	82

*Concentrations in ppm. ‡Averages and ranges (in parentheses).