THE EDGE OF WETNESS: THE CASE FOR DRY MAGMATISM ON MARS. J.H. Jones, SR, NASA/JSC, Houston, TX 77058 (john.h.jones1@jsc.nasa.gov).

Introduction: The issue of whether martian magmas are wet or dry is an important one. The answer to this basic question has profound consequences for how we think about Mars as a planet. Recently, several lines of evidence have been presented that collectively suggest that shergottite parent magmas were once wet. These include: (i) phase equilibria studies that indicate that the Shergotty parent magma required ~2 wt.% water in order to be co-saturated with both pigeonite and augite [1], (ii) reverse zoning of light lithophile elements (Li and B) in shergottite pyroxenes, suggesting the exsolution and removal of an aqueous fluid [1], and (iii) measurement of D/H ratios in SNC minerals that are much lower than atmospheric, suggesting that there may be juvenile (primordial) mantle water [2].

Below I will review the evidence for the diametrically opposite case, that shergottite magmas were effectively dry (<< 1 wt.% H_2O).

The Martian Mantle. Initially, it was believed that the martian mantle was much like that of the Earth, producing basalts that are rather oxidized (~IW+3) compared to those from the Moon or the asteroid belt [3]. Consequently, it has also been assumed that magmas from the martian mantle are similar to those on Earth, which have water as a significant component of their volatile inventory. But this view does not take into account the difference in tectonic styles between the two planets.

Reactions with Fe metal are likely to have dehydrated the early mantles of Earth and Mars. There is general agreement that there is no clear-cut evidence for terrestrial juvenile water and that the water in terrestrial basalts may mostly be from water emplaced in the mantle by subducting slabs [4]. The fact that Mars does not have subduction-driven plate tectonics means that there is no obvious mechanism for hydrating the martian mantle after core formation.

Also, it now appears that the martian mantle is not as oxidized as was originally thought. Those shergottites that appear to be least affected by crustal contamination are also rather reduced (~IW to IW-1 [5]), about the fo_2 expected for basalts with shergottite FeO contents (~18 wt.%) that have come from a source region that once equilibrated with Fe metal [6].

Another consideration is that the shergottites come from depleted source regions [e.g., 5]. QUE94201, for example, has an initial $\varepsilon(^{143}Nd)$ of +50, five times larger than that of the depleted, terrestrial MORB mantle. To the extent that water acts as an incompatible element during basalt petrogenesis, the removal of basalt that depleted the martian mantle in incompatible elements represented a second chance at dehydration if reactions with metal were not sufficient to do the job.

In summary, there is no compelling reason to believe that the martian mantle should contain a significant amount of water or that basalts coming from that mantle should either.

Water Contents of SNC Meteorites. Regardless of these theoretical considerations, it is important to determine how much water is actually in SNC meteorites. For Shergotty and Zagami (meteorite falls whose original water contents have been estimated by phase equilibria [1]) clearly indigenous water (i.e., released above 350°C is 150-200 ppm [7]. This is in contrast to the estimates of ~2 wt.% by [1]. If Shergotty and Zagami originally contained 2 wt.% water, then their dehydration is required to be ≥99% efficient. For Chassigny, another fall, indigenous water is somewhat higher — ~350 ppm [7]. Even so, these water contents are very low.

Mineralogy of SNC Meteorites. The mineralogy of the SNC meteorites is consistent with these low water contents. Phosphates in SNC's are either merrilite [$Ca_3(PO_4)_2$] or chlorapatite [$Ca_5(PO_4)_3Cl$], not hydroxy-apatite. Zagami chlorapatite, for example, only contains about 1000 ppm water [8]. Chlorapatite is the least stable form of apatite. For chlorapatite to form in preference to hydroxy-apatite, the activity of water must be very low.

The water content of SNC amphiboles is also low [8]. The argument has been made that significant water may have been liberated from these amphiboles by the shock events that ejected the SNC's from Mars [1]. However, this seems unlikely. The martian amphiboles discovered thus far are kaersutites with high TiO_2 contents. They are probably best thought of as oxy-amphiboles and necessarily so for Ti charge balance [9]. The SNC amphiboles probably have always had low hydroxyl contents, regardless of how much or how little water was lost due to shock.

Shergotty Phase Equilibria. Experimental studies on a reconstructed Shergotty inter-cumulus liquid (SIL) indicate that this composition has only pigeonite on its liquidus at one bar [10]. Therefore, the SIL is not multiply saturated with pigeonite and augite at low pressure [10], even though petrographic observation of Shergotty requires it to be [3]. Addition of an augite component to the SIL composition produces multiple saturation at one bar and ~1150°C. Alternatively, addition of ~2 wt.% water to the SIL composition produces multiple pyroxene saturation at ~500 bar and ~1120°C [1]. McSween et al. [1] concluded, therefore, that significant water was necessary to produce the observed phase assemblages of Shergotty and Zagami.

This conclusion seems unlikely. First, both Shergotty and Zagami are exceedingly dry. Secondly, the one-bar anhydrous experiments that were fortified with augite reproduce the core pyroxene compositions of Shergotty and Zagami better than the hydrous experiments do. Third, the anhydrous experiments of [3] closely bracket the natural pyroxene compositions. Fourth, the anhydrous experiments of [3] and the anhydrous augite-fortified experiment (Sy-24) of [10] give nearly identical results. For major elements, the Sy-24 glass [10] and the average of Sh-7 and Sh-18 of [3] agree to within 10%. The temperature of the Sy-24 experiment was 1150°C and the average of the Sh-7 and Sh-18 run temperatures is 1148°C. This agreement between two very different experimental regimes is impressive. I conclude that the derivation of the SIL composition by Hale et al. [11] either systematically excluded an augite component or overestimated a pigeonite component. Therefore, the experiments on natural materials, where no compositional reconstruction is necessary [3], are to be preferred.

Exsolution of Aqueous Phase: Li and B. Of the various evidences for wet shergottites, the reverse zoning of the light-lithophile-elements (LLE) is the most interesting and compelling [1]. However, at least one experimental study failed to demonstrate that B prefers aqueous fluid over basaltic liquid [12]. This is an area where more data and experiments would be welcome.

Exsolution of Aqueous Phase: Halogens. The Cl/Br ratios of SNC meteorites are remarkably close to that of CI chondrites [13,14]. The Cl/Br ratio of Nakhla is quite a bit lower than CI but this rock has experienced hydrothermal alteration, a process that could fractionate halogens. In fact, the experimental data of [15] suggest that the exsolution and loss of an aqueous fluid will fractionate Cl and Br. In their experiments at 900°C and 2 kbar, K_D(Cl/Br) for aqueous fluid/silicate melt is ~0.5. Therefore, the observation that Shergotty has a Cl/Br ratio that is both ~chondritic and similar to other shergottites suggests that halogen fractionation did not occur. This may further suggest that no fluid phase was lost from the Shergotty parent magma or that the amount of fluid lost was insufficient to fractionate Cl and Br.

Recapitulation. Taken as a whole, the evidence that SNC meteorites in general, and the shergottites in particular, were ever wet is not compelling. Certainly the water is not there today. If it was lost as a condensed aqueous fluid, it did not fractionate halogens. If it was lost as steam from a magma chamber, then the loss process is required to be highly efficient. [Actually, both loss mechanisms are required to be efficient.] A more plausible explanation is that the water was never there.

Juvenile Water on Mars? In light of the foregoing discussion, is there juvenile water on Mars? Yes, there probably is such water, but not much of it. Combined H and C isotopic data can be used to identify martian volatile element reservoirs [16]. The only SNC to have both isotopically light H and C is Chassigny [7], and these are properties attributed to the martian mantle [17]. As discussed above indigenous water in Chassigny is about 350 ppm and has a ∂D of ~-50 ‰. Because of the complex petrogenesis of Chassigny, translating this amount of magmatic water into source region concentrations is difficult. If Chassigny is 90% anhydrous cumulate of a 5% partial melt, then the martian mantle contained about 175 ppm water. To better constrain this concentration, better models both for the petrogenesis of Chassigny and the siting of Chassigny water would be required.

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