**Iron redox systematics of martian magmas.** K. Righter¹, L. Danielson¹, A. Martin¹, K. Pando², S. Sutton², M. Newville³, ¹NASA/JSC, ²Univ. Chicago, GSECARS.

**Introduction:**
Martian magmas are known to be FeO-rich and the dominant FeO-bearing mineral at many sites visited by the Mars Exploration rovers (MER) is magnetite [1]. Morris et al. [1] propose that the magnetite appears to be igneous in origin, rather than of secondary origin. However, magnetite is not typically found in experimental studies of martian magmatic rocks [2,3]. Magnetite stability in terrestrial magmas is well understood, as are the stability of FeO and Fe₂O₃ in terrestrial magmas [4,5]. In order to better understand the variation of FeO and Fe₂O₃, and the stability of magnetite (and other FeO-bearing phases) in martian magmas we have undertaken an experimental study with two emphases. First we document the stability of magnetite with temperature and fO₂ in a shergottite bulk composition. Second, we determine the FeO and Fe₂O₃ contents of the same shergottite bulk composition at 1 bar and variable fO₂ at 1250 °C, and at variable pressure. These two goals will help define not only magnetite stability, but pyroxene-melt equilibria that are also dependent upon fO₂.

**Experimental and analytical techniques:**
A synthetic basaltic shergottite composition, similar to the bulk composition of Zagami, was prepared from high purity oxides, and homogenized by repeated fusion and grinding. Some experiments (series A and C) were carried out at 1 bar in gas mixing furnaces controlled by CO-CO₂ mixtures and equilibrated at 1300 °C. High pressure experiments (Series B) were carried out in piston cylinder and multi-anvil apparatus at NASA-JSC [6,7].

**Series A:** was carried out on the shergottite composition between FMQ – 3 and FMQ + 3, at 1300 °C. This series is meant to constrain the variation of Fe³⁺/Fe(tot) for a martian composition over a large fO₂ range, and will serve as a baseline for understanding any variation we find in iron redox ratio for samples equilibrated at higher pressure and volatile contents.

**Series B:** Several kinds of experiments were carried out at higher pressures in a piston cylinder and multi-anvil apparatus. Some experiments were completed in molybdenum capsules, which buffer fO₂ at the Mo-MoO₂ buffer, near IW [8]. Other experiments were carried out in graphite capsules with fO₂ monitored by Co-(CoMg)O sliding sensor [9]; these equilibrated at FMQ-2 [6]. These experiments were designed to define the effect of pressure on the Fe³⁺/Fe(tot) in the shergottite.

**Series C:** The last series of experiments was carried out at 1 bar, at subliquidus conditions to help define magnetite stability. Several experiments were carried out at FMQ -1 and variable temperature. Others were carried out at fixed temperature (1050 °C) and variable fO₂ from FMQ+0.5, FMQ, FMQ-0.5, FMQ-1. These experiments were carried out to supplement previous work [4,5] at these relatively low temperatures where magnetite may or may not be stable.

Run products were analyzed by electron microprobe for major and minor elements using standard approaches (e.g., [6]). Measurements of Fe³⁺ and Fe⁵⁺ in the experimental glasses were made using micro-XANES (X-ray absorption near edge structure) at the Advanced Photon Source (Argonne National Lab). A monochromatic X-ray beam from a Si(111) double crystal monochromator was focused onto the sample and the fluorescent X-ray yield was plotted as a function of incident X-ray energy (more detail can be found in [10]). Fe-bearing glasses are used to calibrate valence vs. centroid energy (area-weighted average energy of the pre-edge peaks). XANES has the advantage of good spatial resolution – an important capability when analyzing high pressure glasses, and also samples with mineral – melt mixtures.

**Terrestrial magmatic constraints**
The variation of Fe³⁺/Fe(tot) in silicate melts has been well studied for terrestrial magmatic rocks, which typically have Al₂O₃ between 10 and 20 wt% and FeO up to 15 wt% [5, 11-13]. However, shergottites contain lower Al₂O₃ contents and higher FeO contents [14], suggesting that any calibrations for terrestrial magmas must be extrapolated to compositions well outside the calibration database (Fig. 1). The only experiments done at very high FeO contents are those from simple systems and carried out in air (Fig. 1). Indeed, when such

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*Figure 1: FeO (total) vs. Al₂O₃ for experimental data used to predict the Fe³⁺/Fe(tot) in terrestrial basalt. Data (from [5, 11-13]; shergottite data from Lodders 1998 compilation, [14]) do not overlap with shergottite compositions.*
Our new results: Our new results for shergottite glasses indicate that the Fe$^{3+}$/Fe(tot) remains as low as 0.05 even at FMQ+2. The effect of pressure does not change this significantly, although we have only 1 GPa data so far and will expand to higher pressures near 4 GPa, as might be possible in the martian crust and mantle.

The role of phosphorus (P) in FeO-bearing silicate melts is important to define [19]. In terrestrial systems, there can be Fe$^{3+}$-$P^{5+}$ complexing that can affect the overall Fe$^{3+}$/Fe(tot) ratios independently of fO$_2$ [19]. Therefore, we carried out a series of experiments with variable P$_2$O$_5$ contents. For this shergottite composition, the effect of P$_2$O$_5$ is very small, causing a change in Fe$^{3+}$/Fe(tot) of only 0.01 across 3 wt% P$_2$O$_5$.

In the subliquidus series experiments, we found that magnetite is only stable at 1000 °C and FMQ-1. This is a significantly lower temperature than many 1 bar terrestrial samples, where magnetite stability is between 1050 and 1100 °C. Future analyses will measure the Fe$^{3+}$/Fe(tot) in glasses co-existing with magnetite in these experiments and others at higher fO$_2$.

Implications:
Low ferric/ferrous ratios in shergottites are consistent with the smaller stability field for magnetite. In future experiments, the effect of dissolved water will be explored -- hydrous conditions could increase ferric/ferrous and thus expand the magnetite stability field. If the commonly observed surficial magnetite (e.g., at MER sites) is igneous in origin, it likely originates from more evolved (fractionated) or more oxidized magmas which are not necessarily represented in the meteorite collections.

References: