AN IGNEOUS ORIGIN FOR MARTIAN MAGNETIC ANOMALIES? J. E. Hammer[1] , S Brachfeld[2], M. J. Rutherford[3]. [1]Department of Geology and Geophysics, University of Hawaii, 1680 East-West Road Honolulu, HI 96822, jhammer@soest.hawaii.edu, [2]Byrd Polar Research Center, Ohio State University 1090 Carmack Rd Columbus, OH 43210-1002, [3]Department of Geological Sciences, Brown University Box 1846 Providence, RI 02912.

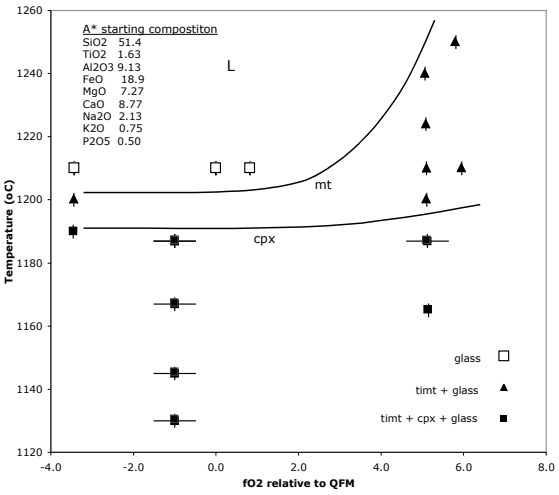
Introduction: The presence of alternately magnetized sources on Mars indicates that at one time Mars had a magnetic field, presumably generated by an internal dynamo, and that its polarity reversed at least once before shutting off[1]. Mars does not currently possess a magnetic field, so the anomalies are attributed to remanent magnetization (RM) of minerals in the crust. The initiation and cessation of the inducing field, its timing, and the implications for Mars thermal evolution, compositional differentiation, and volatile budget are critical components of understanding the planetary dynamics of Mars. Isobaric (1 bar) constant-rate cooling experiments were run using Fe-rich (i.e., Martian) basalt to ascertain whether conditions necessary for crystallization of minerals retaining intense RM are consistent with any of the models proposed for generation of the Martian magnetic anomaly.

Cooling experiments: The material investigated is synthetic A*, a liquid composition in equilibrium with olivine and pyroxene during crystallization of the Shergottites, Chassigny, and other cumulate SNC meteorites[2]. The compositional and rheological characteristics of A* are shared by other proposed SNC parent melts (low in Al_2O_3 and FeO-rich)[3,4].

The first series of experiments determined the near-liquidus phase relations for the A* composition over a range of fO_2 values corresponding to the Fe-wüstite (IW) to MnO-Mn_3O_4 (MNO) solid buffer assemblages (Figure 1). Care was taken to minimize Fe loss during the experiments: runs at the most reducing conditions were executed in Mo foil, and the intermediate to oxidizing fO_2 experiments were run in Pt capsules presaturated with Fe by running A* at the experimental temperature for 12-24 h. Sample capsules and solid buffer assemblages were loaded into fused quartz tubes, evacuated to a moderate vacuum (≤10 Pa), then sealed shut. The solid buffer assemblage was inspected at the termination of each run to confirm or bracket the experimental fO_2.

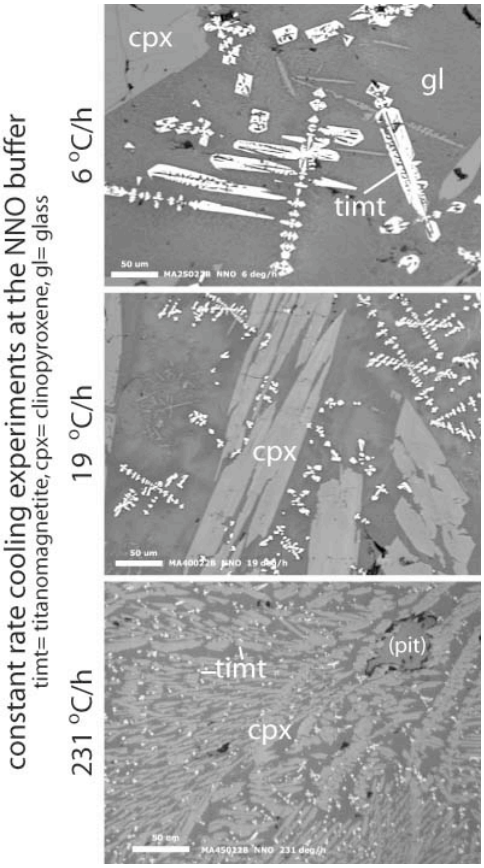
A second matrix of 24 experiments were run to examine the kinetics of low-pressure oxide crystallization as a function of fO_2 and cooling rate. Evacuated fused quartz capsules containing sample + buffer (IW, QFM, NNO, MNO) were bundled together, brought to 1210 ^oC, then cooled to ~300 ^oC. Five sets of constant-rate cooling experiments (230, 72, 19, 6, and 3 $^oC\ h^{-1}$) were run using a programmable temperature controller. Rapid (highly nonlinear, ~1.5E5 $^oC\ h^{-1}$) cooling was imposed by immersion of the capsules in water.

Figure1: PRELIMINARY LIQUIDUS PHASE DIAGRAM FOR A*



Textural characterization: A dazzling variety of titanomagnetite (TiMt) and clinopyroxene (Cpx) morphologies were produced that broadly correlate with cooling rate (Figure 2). Texturally, there was no discernible effect of experiment fO_2, except on the abundance of titanomagnetite in the charge. For both TiMt and Cpx, increasing experiment duration (lower cooling rate) correlates with increasing crystal content, grain size coarsening, and morphological transition from highly skeletal, cruciform (TiMt), and dendritic (Cpx) forms toward euhedral forms. Except for the MNO charge, which started below the TiMt liquidus at 1210 ^oC, no crystallization was observed in the most rapidly cooled (10 E5 $^oC\ h^{-1}$) series. Long strands of collinear TiMt crystals evident in 2D images appear to represent single crystals linked outside the plane of the cut surface. These morphologies complicate the determination of crystal nucleation rate by standard image processing techniques[5]. Instead, the ratio of the mineral surface area to mineral volume is considered a measure of the surface free energy controlling nucleation kinetics in these experiments. We calculated a nondimensional index of surface energy by finding the ratio of the glass-TiMt interfacial boundary length, including internal holes, to the circumference of a single circle having the equivalent area. Preliminary measurements indicate that the index ranges over sev-

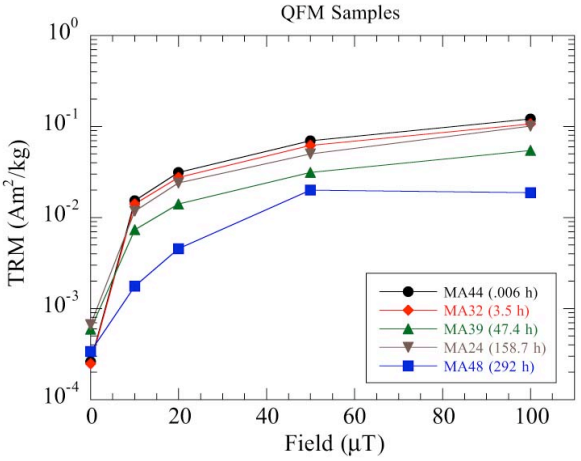
eral orders of magnitude, consistently increasing in proportion to cooling rate.



Magnetic characterization: Samples from the cooling experiments were characterized for concentration of ferromagnetic material, magnetic domain state, magnetic mineralogy, ability to carry anhysteretic remanent magnetization and thermoremanent magnetization (ARM and TRM, respectively) using a suite of applied field- and temperature-dependent methods. The range of laboratory cooling rates used was sufficient to generate magnetic mineral assemblages with variable composition and magnetic domain states.

Several broad trends are evident. The samples prepared at the MNO buffer have the highest saturation magnetization and the highest magnetic susceptibility of any given cooling rate applied. The samples prepared at the IW buffer have the lowest saturation magnetization and the lowest magnetic susceptibility for any given cooling rate. The QFM and NNO sample sets are very similar with respect to the abundance of magnetic material. Consistent with the petrographic observations, we observe a magnetic grain size coarsening with slower cooling rates for the QFM, NNO, and MNO samples. Using in-field measurements and high-temperature methods, the IW sample set appears dominantly paramagnetic with the exception of the sample synthesized at the slowest cooling rate. However, low temperature methods and induced remanences (ARM and TRM) indicate the presence of a remanence-bearing phase in the IW samples. We did not observe pure end-member magnetite or hematite. Curie temperatures range from ~300-510 ^{o}C, consistent with Ti-rich titanomagnetite or Ti-rich titanohematite. Samples prepared at the MNO buffer had the highest Curie temperatures (475-495 ^{o}C), with no apparent relationship to cooling rate. Samples prepared under the QFM and NNO buffers had lower Curie temperatures, although there appears to be a significant shift in mineralogy at the slowest cooling rates. Nearly all samples in the QFM, NNO, and MNO sets displayed a magnetic order/disorder transition in the 30-65K range, with no apparent relationship to cooling rate.

We imparted TRM at 550^{o}C in ambient fields of 10, 20, 50 and 100 μT (Figure 3). At the 50 μT step, we observe TRM intensities of 0.1-70 x10^{-3} Am^{2}kg^{-1}.



Summary: Magnetic characteristics of rapidly cooled A* basalt crystallized under moderate to highly oxidizing conditions are comparable to those described for rapidly cooled terrestrial basalts[6] and modeled as potential source materials for the Martian anomalies[7].

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