EFFECTS OF VARIABLE DURATION ANNEALING ON THE ROCK MAGNETIC AND REMENANCE PROPERTIES OF SYNTHETIC BASALTS: IMPLICATIONS FOR INTENSITY AND STABILITY OF CRUSTAL MAGNETISM. S. Brachfeld[1], D. Cuomo[1], D. Shah[1], L. T. Petrochilos[2], J. Hammer[2], J. Bowles[3]; [1]Department of Earth and Environmental Studies, Montclair State University, Montclair, NJ 07043, [2]Department of Geology and Geophysics, University of Hawai'i, Honolulu, HI 96822, 3Department of Geosciences, University of Wisconsin–Milwaukee, Milwaukee, WI 53201-0413.

Introduction: This goal of this project is to constrain the magnetic properties and remanence-carrying abilities of materials likely to be present in the Martian crust, with the long-term objective of improving our understanding the Mars magnetic anomalies. The current study builds on previous work in which we use compositional information from SNC meteorites and satellite data to select starting compositions for basalts synthesized over a range of conditions. Previous work focused on bulk composition, fO_2, and cooling rate in controlling oxide mineralogy, magnetic domain state, and intensity and stability of remanence acquired [1-4]. We observed that rapid cooling at QFM conditions of both Fe-rich melts and melts with terrestrial Fe/Al ratios resulted in a magnetic mineral assemblage containing stable single domain titanomagnetite, an assemblage capable of acquiring intense TRMs even in the presence of a relatively weak ambient magnetic field. At slower cooling rates and higher fO_2, oxide grain sizes increased into the multi-domain range, leading to lower TRM intensities.

Here we present results of experiments that were designed to induce exsolution within large multidomain iron oxides and evaluate the effects on remmance acquisition and stability. Exsolution textures were <u>not</u> observed in the sample set described here, for reasons discussed in [4]. However, the experimental conditions are germane to shallow igneous intrusions, which might be a significant volumetric fraction of the Martian crust and potential carriers of crustal magnetic anomalies. This sample set also provides an important contrast to a previous set of fast-cooled (3-230 °C/h) synthetic basalts of the same two compositions [1-3].

Methods: Two starting compositions were used. The first has Fe/Al = 1.5 and is based on the Fe-content of SNC meteorites [5]. This composition is denoted "meteorite-type" (M-type). The second composition has Fe/Al = 0.4, similar to terrestrial basalts [6]. This composition is denoted "terrestrial-type" (T-type). Although the T-type composition is unlikely to represent a majority of the Martian crust [6], we use it here to provide a terrestrial counterpart to the iron-rich basalts.

Samples were prepared at igneous temperatures, then cooled to ~ 1070 ˚C, and then quenched. Samples at this stage of the process are termed "pre-annealed" materials. The pre-annealed materials bearing coarse-grained oxides were next placed in Ag capsules within an evacuated Si tube. Samples were placed in a furnace and held at 650 ˚C for 21 to 257 days under quartz-fayalite-magnetite (QFM) fO_2 buffer conditions, then quenched.

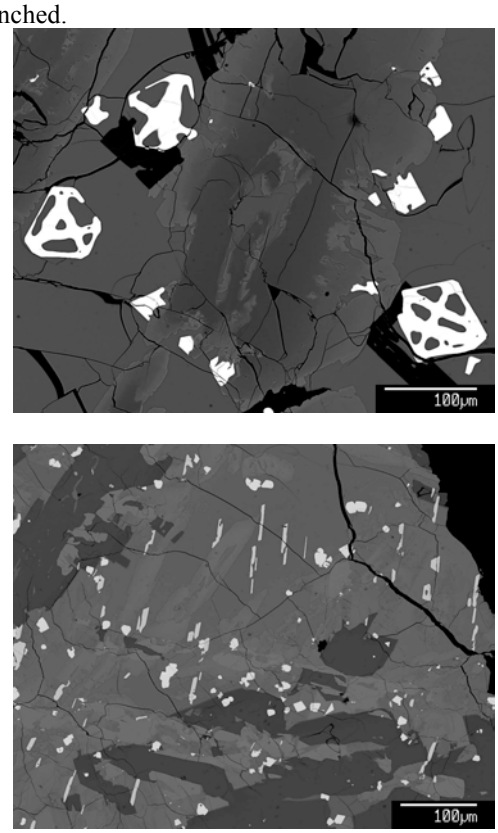

Figure 1. Backscatter electron images of pre-annealed materials for the Fe-rich M-type (top) and Fe-poor T-type (bottom) compositions. M-type starting material contains large titanomagnetites. T-type starting material contains both titanomagnetite and ilmenite.

We performed petrographic and magnetic analysis on pre- and post-annealed samples of both M-type and T-type compositions. Compositional analysis was performed using a JEOL JXA-8500F Field Emission Hyperprobe at the University of Hawai'i at Mānoa. Magnetic susceptibility, hysteresis parameters, and the intensity and stepwise alternating field demagnetization of natural remanent magnetization (NRM), anhysteretic remanent magnetization, and isothermal remanent magnetization was performed at Montclair State University.

Results and Discussion: Titanomagnetite crystals in M-type samples are skeletal, euhedral, equant, and ~30-80 µm in diameter (Fig. 1). We also observed rounded and equant titanomagnetite grains ~5-15 µm in diameter that occur in clusters [7]. Titanomagnetite crystals in the T-type material are euhedral, equant, and ~5-10-µm in diameter. The T-type titanomagnetites have more Ti, Mg, and Cr than their M-type counterparts. Ilmenite crystals are euhedral and elongated, ~5-30 µm in length (Fig. 1).

Both M-type and T-type samples possess a strong NRM. The NRM is inferred to be a thermoremanent magnetization (TRM) acquired during quenching and air-cooling after the 650 °C anneal in the ambient laboratory field. NRM values range up to 170 mAm^2/kg and 47 mAm^2/kg in M-type and T-type samples, respectively. ARM values range up to 68 and 11 mAm^2/kg in M-type and T-type samples, respectively. However, both compositions display very soft coercivity spectra [8]. In the M-type samples 90% of the ARM is removed at the first demagnetization step at 10 mT. Samples annealed for 110-257 days had slightly harder AF demagnetization spectra, with 40-70 % of remanence remaining after the 10-mT demagnetization step. Similarly, T-type samples annealed for 110-257 days had approximately 35-75 % of the remanence remaining after the 10-mT demagnetization step. Hysteresis measurements are consistent with the ARM AF demagnetization data. Hysteresis parameters for M-type compositions plot within the multidomain region of a Day Plot. T-type samples plot in the lower-right corner of the pseudo-single domain (PSD) region. Samples annealed at 110-257 days move slightly up and the to left for both M-type and T-type samples, which we speculate may be due to the growth of single domain magnetite within glassy regions of the sample as they undergo devitrification.

The oxides generated in the annealed samples are larger than those produced in the rapidly-cooled samples of the same composition. While grains up to 40 µm in diameter were observed in the slowest (6 ˚C/h) of the rapidly-cooled samples, the rapidly-cooled samples also contained sub-micron oxide grains within the groundmass or as decorations on the edges of pyroxene crystals [2-3]. In contrast, there no oxides smaller than ~ 5 µm visible in the electron microscopy images of the annealed samples and no indication of stable single domain grains in the magnetic properties of samples annealed for less than 110 days. Therefore, although the M-type annealed samples carry an intense NRM, the soft coercivity spectra of these samples make it unlikely that the NRM would remain stable over geologic time. The slight hardening of the AF demangetization spectrum for samples annealed at 110-257 days suggests that the magnetic properties of the annealed basalts may shift towards those of their rapidly-cooled counterparts at sufficiently long anneal times.

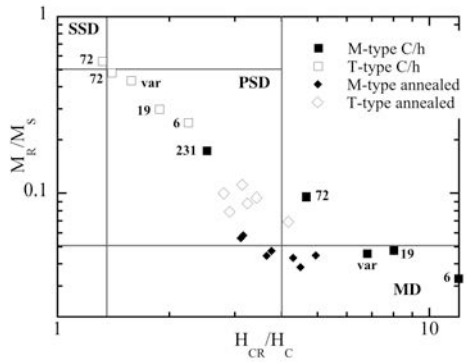

Figure 2. Comparison of magnetic hysteresis parameters for QFM M-type and T-type samples cooled at rates of 6-72 ˚C/hr [2-3] and samples annealed at 21 to 257 days (this study).

Conclusions: Two basalt compositions were synthesized and held at conditions designed to encourage exsolution within iron oxides. Although exsolution did not occur, the experimental conditions are germane to shallow igneous intrusions and provide a slow-cooled counterpart to previous experiments with rapidly-cooled basalts of the same composition. Both M-type and T-type samples display magnetic susceptibility, NRM, and ARM intensities comparable to or those of their rapidly-cooled counterparts. However, ARM in the annealed samples is very easily demagnetized, with > 90 % of the ARM removed at the 10 mT demagnetization level. Samples annealed for 110-257 days had slightly harder coercivity spectra, presumably due to sub-micron iron oxides forming in glass during devitrification. Even though the magnetic properties of these long-duration anneal samples are moving towards those of their rapidly-cooled counterparts, the rapidly cooled samples retain much higher magnetization at high AF treatments. An M-type intrusion containing exclusively multidomain grains and residing near the Martian surface would likely be shock-demagnetized, given its very soft coercivity spectra.

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