SHOCK REMAGNETIZATION OF MARTIAN METEORITE SULFIDES: INSIGHTS FROM IN-SITU HIGH-PRESSURE MAGNETIC EXPERIMENTS. S. C. Steele1, R. R. Fu1 M. W. R. Volk1, A. Jones1,2, P. Thaler1, S. Hsieh3, R. A. Fischer1, 1Harvard University Department of Earth and Planetary Sciences, 2 University of Chicago Department of Physics, 3University of California Berkeley, Department of Physics.

Introduction: Almost all martian meteorites show petrographic evidence of exposure to shock pressures between 1 and ~50 GPa [1]. Because phase transitions experienced by some ferromagnetic minerals between 1 and 30 GPa can produce extensive demagnetization [2], understanding the magnetic responses of minerals to pressure is key to interpreting the paleomagnetic records of martian meteorites.

Of particular concern is whether a pyrrhotite phase transition at 1-5 GPa can irreversibly reset remanence. Pyrrhotite is the main magnetization carrier in many martian samples [3] and is the dominant ferromagnetic mineral in the martian meteorite ALH 84001, the paleomagnetic study of which has yielded some of the strongest constraints to-date on the strength and longevity of Mars’s extinct dynamo [4,5]. Complete remagnetization of pyrrhotite at just 1-5 GPa would challenge interpretations of the magnetic record in ALH 84001, with important implications for the dynamo’s inferred strength and cessation age.

In previous shock gun experiments, surviving remanence steadily decreased for peak pressures up to 3-5 GPa [6, 7] while 6-12 GPa peak pressures appeared less efficient at resetting remanence [7]. However, like real impact shocks, shock gun experiments may produce heterogeneous pressure fields that can complicate the determination of peak pressures experienced by individual grains [8].

As a complement to these previous experiments, we used a hybrid quantum diamond microscope-diamond anvil cell (QDM-DAC; [9, 10]) to make in-situ magnetic measurements of meteoritic pyrrhotite samples under pressure. The QDM-DAC uses fluorescence from nitrogen vacancy (NV) centers implanted into the culet of a DAC diamond to map magnetic fields at micrometer-scale resolution (Fig. 1). This instrument allows us to take advantage of well-calibrated techniques for estimating pressure in DACs to quantify the magnetic response of martian pyrrhotites over a large range of peak pressures.

In this work, we measured the magnetic fields produced by a pyrrhotite grain from the martian meteorite EET A79001 under pressures up to 4.8 GPa. Although we observed a sharp transition in the grain’s magnetic moment around 0.8 GPa, we found that the original magnetization direction was retained through compression and decompression and the moment partially recovered after decompression. This suggests pressures between 1-5 GPa may not completely reset remanence, consistent with the results of previous shock gun experiments [7].

Methods: A ~50 micrometer pyrrhotite grain was extracted from a sample of EET A79001 (lithology A), given a 2 T isothermal remanent magnetization, and loaded into the sample chamber of a QDM-DAC (Fig. 2A). Visible light images and magnetic maps were produced immediately after closing the cell (Fig. 2A,B) and then after each stepwise change in pressure. We estimated the pressure in the cell using calibrated NV fluorescence methods [11].

In this experiment, after loading the cell we increased the pressure in the cell to 4.8 GPa in 0.05-1.5 GPa steps, then brought the cell back to atmospheric pressure in several 1-2 GPa steps, imaging at each pressure step. We then used the visible light images and magnetic maps produced at each pressure step to identify the magnetic anomaly associated with the pyrrhotite grain in the cell. We then fitted this magnetic anomaly to a dipole to determine the grain’s magnetic moment and orientation at each step (Fig. 3).

Results & Discussion: During compression, the moment of the EET A79001 pyrrhotite grain decreased slowly until ~0.8 GPa, at which point it decreased sharply to ~5% of its original value. The moment...
remained stable thereafter while the pressure increased to 4.8 GPa, then recovered to 10-20% of its initial value during decompression (Fig. 4).

The rapid decrease in moment at ~0.8 GPa may have corresponded to demagnetization from the 1-5 GPa pressure phase transition of pyrrhotite, although it is typically documented at ~3 GPa [6, 7]. However, companion experiments on terrestrial pyrrhotite did not experience a similar sudden loss in magnetization until ~5 GPa, showing that the pressure response is complex and possibly dependent on polymorphs.

Although the moment changed significantly over the course of the experiment, the magnetization direction remained stable throughout: the average of the directions at 3.05 and 0.11 GPa during the decompression cycle was just 16° from the averaged direction of the <0.8 GPa steps. Preservation of the original magnetization direction, including at steps where the moment magnitude is small, suggests demagnetization from these high pressures was not complete.

These results suggest shock pressures up to 5 GPa may not completely reset remanence in pyrrhotite and imply that magnetization directions may be well preserved through impact events. However, the incomplete recovery of the original magnetic moment may have important implications for the paleointensities estimated from shocked grains.

Further experiments with additional pyrrhotite samples from EET A79001 and other martian meteorites will be required to determine the range of the expected magnetic response to pressure. In particular, additional experiments to quantify the effect of pressure on paleointensities recovered for martian meteorite pyrrhotites, specifically, would be valuable for interpreting the paleomagnetic record in ALH 84001.

Conclusions: We performed in-situ magnetic measurements of a pyrrhotite grain from the martian meteorite EET A79001 under pressures up to 4.8 GPa using a QDM-DAC. This imaging revealed a sharp decline in magnetization at ~0.8 GPa, consistent with a known low-pressure phase transition in pyrrhotite. Magnetization was partially recovered upon decompression and the original magnetization direction was preserved, suggesting passage through this phase transition did not permanently destroy the grain’s magnetization. If this behavior is typical, it would suggest that remanences in some martian meteorites may reliably record ancient, pre-shock magnetization directions. In future work, we will repeat these experiments for additional pyrrhotite grains from EET A79001 and other martian meteorites over a broader range of peak pressures to better characterize the response of martian meteorite pyrrhotite to high pressures.