SHOCK DEMAGNETIZATION OF PYRRHOTITE. K. L. Louzada[1], S. T. Stewart[1] and B. P. Weiss[2], [1]Department of Earth and Planetary Sciences, Harvard University, 20 Oxford Street, Cambridge, MA 02138 (louzada@fas.harvard.edu & sstewart@eps.harvard.edu). [2]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, 54-724, 77 Massachusetts Avenue, Cambridge, MA 02139 (bpweiss@mit.edu).

Introduction: Maps of the remanent magnetic field of Mars show demagnetized zones within and around giant impact basins [1]. It is likely that vast regions of the Martian crust were demagnetized due to a shock-induced phase change or magnetic transition of magnetic minerals in the crust. This hypothesis is supported by the fact that around the Hellas and Argyre basins, the edges of the unmagnetized zones roughly correspond with peak shock pressure contour lines of a few GPa [2]. Although pyrrhotite is not a major carrier of magnetization in the Earth's crust, it is a common phase in Martian meteorites [3] and may be an important carrier in the Martian crust.

Understanding the effects of shock waves on magnetic minerals is critical for determining the origin of the demagnetized zones in impact basins and possibly for identifying the major magnetic carrier phases. Here we present the results of the first controlled shock demagnetization measurements on pyrrhotite.

Previous experiments: Shock demagnetization occurs primarily through a shock-induced phase change or magnetic transition, or shock heating above the Curie temperature. Shock demagnetization of predominantly magnetite-bearing basalts has been demonstrated by Pohl *et al.* [4] and Cisowski and Fuller [5]. Magnetite, hematite and titanohematite of varying grain sizes have been shown to significantly demagnetize upon low-pressure shocks (~1 GPa)[6].

Although the phase diagram of pyrrhotite ($Fe_{1-x}S$, $x < 0.13$) is not well known, troilite (FeS) is known to undergo a first order structural phase transition from FeS (I) to FeS (II) near 4 GPa at room temperature [7]. Furthermore, hydrostatic pressure experiments at room temperature have indicated that monoclinic pyrrhotite (Fe_7S_8) undergoes a reversible ferrimagnetic to paramagnetic transition beginning at 1 GPa, with complete demagnetization by 3 GPa [8,9]. This pressure range corresponds well to the inferred pressure contour near the edge of the demagnetized zone around Martian impact basins, which led Hood *et al.* [2] to suggest that pyrrhotite may be a major carrier in the Martian crust. However, no previous experiments have demonstrated the effects of shock on the demagnetization and magnetic properties of pure pyrrhotite.

Experimental method: We performed planar shock recovery experiments on natural, predominantly single domain pyrrhotite samples (saturation remanence to saturation magnetization ratios prior to shock of M_{rs}/M_s~0.7) embedded in aluminum capsules using the 40-mm gas gun in the Harvard Shock Compression Laboratory. The shock experiments were preceded and followed by a suite of material and magnetic characterization measurements conducted at MIT and Caltech (including X-ray diffraction, magnetic hysteresis, low temperature magnetism, isothermal and anhysteretic acquisition, and alternating field demagnetization) in order to asses the changes in crystallographic and magnetic properties of the pyrrhotites.

We analyzed a pyrrhotite nodule from a metamorphosed terrain in Sudbury, Canada (donated by the Harvard Museum of Natural History). The magnetic hysteresis loop of the sample is wasp-waisted, indicating that the sample contains both high and low coercivity fractions (coercivity is the magnetic field required to reduce the external magnetization of a ferromagnetic substance to zero.) Low temperature magnetic studies showed that the sample contains a significant fraction of monoclinic pyrrhotite as indicated by the low temperature transition at 30-34 K, analogous to the Verwey transition in magnetite [10]. The sample consists of a mixture of hexagonal and monoclinic pyrrhotite (Fe/S = 0.893) and a range of grain sizes that are predominantly single domain.

The shock experiments were performed at room temperature and in the Earth's ambient field. One experiment was conducted on a demagnetized sample to verify that no shock remanent magnetization was acquired from the ambient laboratory field.

Results and Discussion: Figure 1 shows results from four shock experiments with peak pressures between 1 and 4 GPa (blue diamonds) indicating that pyrrhotite indeed significantly demagnetizes when subject to modest shock pressures. Samples shocked to pressures of ~2.5 GPa show good agreement with the previously published hydrostatic data (open squares) [9]. However, a sample shocked to 4 GPa did not completely demagnetize, contrary to what might be expected from hydrostatic experiments. Even though the known phase boundary for troilite is near 4 GPa, we do not believe that a structural transition occurred in pyrrhotite at this pressure because the sample was not fully demagnetized.

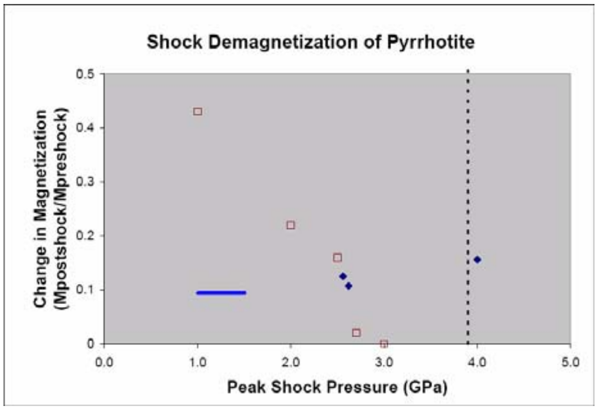

Figure 1: Demagnetization of pyrrhotite: blue diamonds – this work single shock; blue line – this work double shock; open squares – static experiments [9]; dashed line – FeS (I)-(II) phase boundary in troilite [7].

One sample was shocked twice at pressures between 1 and 1.5 GPa. This double-shocked sample was significantly more demagnetized than what would be expected from the hydrostatic experiments, indicating the efficiency of shock demagnetization from multiple impact events. We are in the progress of conduction more single-shock experiments at low and high pressures and will determine the shock pressure required to fully demagnetize pyrrhotite.

Shock compression results in permanent changes to the magnetic properties of pyrrhotite. We found that the saturation remanence and coercivity of the pyrrhotite samples increased after shock compression. The change in the mean destructive field (MDF, the field that is required to reduce the remanence to one-half its initial value - a measure of the bulk coercivity) is shown in Figure 2. The MDF (or coercivity) of the pyrrhotite increases with increasing peak shock pressure, indicating that shocks harden the coercivity of pyrrhotite.

Similar behaviour has been observed in magnetite under hydrostatic pressures up to 6 GPa [11]. Suggested mechanisms for the stress hardening in magnetite are changes in the magnetostriction and magnetoelastic constants, which would increase the single domain-multidomain threshold radius. The creation of metastable hexagonal ferrimagnetic pyrrhotite [3] could also explain the increase in saturation remanence, although this is unlikely as shock heating during the experiments was negligible. We calculate a maximum of about 10 ºC temperature increase at 4 GPa.

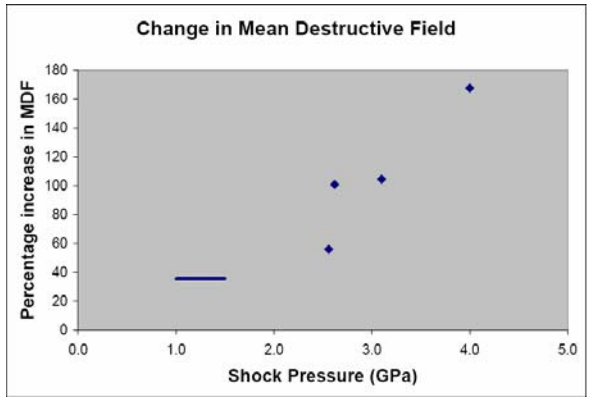

Figure 2: Increasing coercivity with increasing pressure in pyrrhotite: blue diamonds – this work single shock; blue line – this work double shock.

Conclusions: Impact experiments indicate that pyrrhotite indeed demagnetizes due to shock in the pressure range inferred around Martian impact basins. On the other hand, pyrrhotite may be less susceptible to shock demagnetization than has been previously inferred from hydrostatic experiments. Furthermore, pyrrhotite in meteorites shocked to pressures even up to 4 GPa may retain a pre-shock remanence, although this remanence is likely to have been hardened in coercivity and weakened in intensity by the shock.

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