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

Introduction: A robust feature of the crustal remanent field of Mars is the demagnetization of the large impact basins Hellas, Argyre and Isidis [1,2] and possibly Prometheus [3]. Impacts most likely completely demagnetized the majority of the crust inside the basins and partially demagnetized regions at distances of up to 1.4 basin radii [4], by a shock-induced phase change or magnetic transition of magnetic minerals in the crust. Midsize to large impact basins on Earth often show high-amplitude, short-wavelength magnetic anomalies in their centers (e.g. Sudbury crater, Canada) [5]. The large impact basins on Mars do not show any of these features suggesting that the Martian dynamo must have ceased to operate early in Mars' history, before the end of the late heavy bombardment (4.23-3.9 Ga) [1,6].

The actual processes responsible for the changes in magnetic properties of minerals as a result of shock pressure remain uncertain. Understanding these effects is critical for determining the origin of the demagnetized zones in impact basins, for identifying the major magnetic carrier phases on Mars, and for paleointensity studies of meteorites. Here, the effects of shock on the magnetization and magnetic properties of minerals are studied using shock impact recovery experiments on pyrrhotite and paleomagnetic measurements of naturally shocked basalts from Lonar Crater, India.

Pyrrhotite shock demagnetization experiments: Pyrrhotite ($Fe_{1-x}S$, $x \leq 0.13$) is a common phase in shergottites [7], a widespread accessory phase in ALH84001 [8], and may be an important carrier in the Martian crust. Previous 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 [9]. This pressure range corresponds well to the inferred pressure contour near the edge of the demagnetized zones around Martian impact basins [4,10]. No previous experiments have demonstrated the effects of shock on the magnetization and magnetic properties of pure pyrrhotite.

The new shock experiments show that pyrrhotite significantly demagnetizes (~85-90%) when subject to shock pressures between 1 and 4 GPa (Figure 1). However, the demagnetization does not appear to trend consistently with pressure and a sample shocked to 4 GPa did not completely demagnetize, contrary to what might be expected from hydrostatic experiments [9].

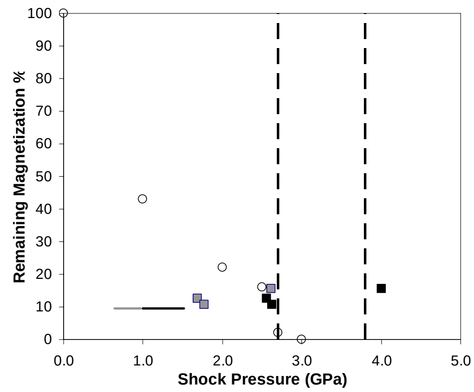

Figure 1: Demagnetization of pyrrhotite: black symbols – principal stress (squares – single shock, line – double shock); grey symbols – pressure assuming elastic shock; open circles – static experiments [9]; dashed lines – phase change region in pyrrhotite from shock data [11].

Shock compression results in permanent changes to the magnetic properties of pyrrhotite. We found that the saturation isothermal remanent magnetization (SIRM) and the mean destructive field (MDF – a measure of the bulk coercivity) of the pyrrhotite samples increased after shock compression, up to ~80% and ~270% respectively. The coercivity (as well as the saturation magnetization) of the pyrrhotite increases with increasing peak shock pressure, known as shock hardening.

Lonar Crater paleomagnetic study: Lonar Crater (15 to 67 kyr [12-14]), located in the southern ~65 Ma Deccan flood basalt province [15] in India (19°58'N, 76°31'E), is the only known terrestrial impact crater formed entirely in basalt. The simple crater is 1830 m across and nearly 150 m deep with a raised rim of about 20-30 m [12,13].

During a field study in January 2005, a total of 98 cores and 45 block samples were collected from a number of sites on the crater rim and wall, in the ejecta blanket and from undisturbed basalt flows outside the ejecta blanket. The sampled basalts and clasts are fine- to coarse-grained, massive, non-vesicular, and relatively unaltered. Preliminary results from paleomagnetic measurements on a subset of the samples indicate that the magnetic vectors of the rocks are characterized by (1) a low-temperature (LT) component that is removed upon heating to 100-200°C and (2) a high-temperature (HT) component that decays with continued heating beyond 450°C (Figure 2a), consistent with previous studies of Deccan basalts [16,17].

The directions of the LT components of the basalt flows (from the crater wall and beneath the distal edge of the continuous ejecta blanket) and the ejecta along the crater rim lie close to the present-day local field (PLF) (Figure 2b – *blue arrows*) and are therefore likely due to a post-impact viscous remanent magnetization (VRM) overprint. LT components of basaltic ejecta clasts from the distal ejecta blanket show similar thermal demagnetization behavior to the flows, except they show greater scatter and a westward (as opposed to eastward) offset from the PLF. The highly shocked clasts may have higher coercivities (indicating the effects of shock hardening), and acquired a weaker VRM. Since the LT components are not random in the clasts in the ejecta blanket (*purple arrows*), contrary to what would be expected if the clasts acquired a shock remanent magnetization in a rapidly changing plasma field after the impact event [16], the LT component is likely due to VRM acquired in the PLF.

The HT components of the flows are all similar to the directions of the unshocked Deccan flows at Lonar [18] (*green arrows*). We consider them primary in origin and resulting from a reversed Cretaceous magnetic field, in agreement with previous studies [16,17]. The HT components of the ejecta clasts are random (*orange arrows*) as would be expected if they were laid down in random orientations after ejection; they have not been overprinted by the present day field and are therefore also primary.

Discussion: Impact experiments indicate that pyrrhotite demagnetizes significantly due to shock in the pressure range inferred around Martian impact basins. However, pyrrhotite in meteorites shocked to pressures even up to 4 GPa may retain a pre-shock remanence. The increase in SIRM from shock implies that typical normalization paleointensity techniques for meteorites [8] may underestimate true paleointensity.

Similar increases in SIRM and MDF have been observed in magnetite under hydrostatic pressures up to 6 GPa [19]. The mechanisms responsible for these changes in pyrrhotite are not currently understood; defect generation, residual strain in the crystal, domain nucleation, and domain rotation may each contribute to changes in magnetic properties after shock.

The HT components of the magnetic vectors of samples from different locations in and around Lonar crater, shocked to different pressures, were found to be primary and will be studied for changes in magnetic properties as a result of shock. It may be possible to use changes in rock magnetic properties as an indicator of low shock pressures, when petrographic evidence of shock (e.g., shocked minerals) is unavailable.

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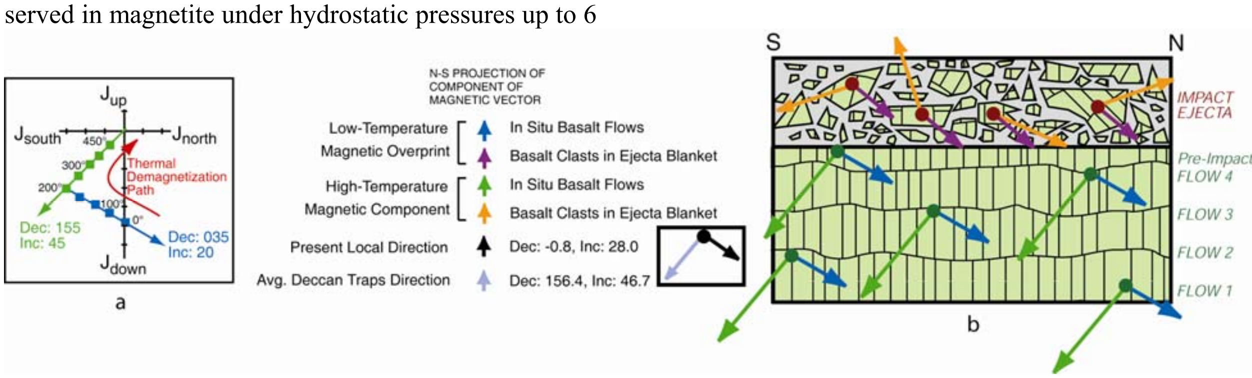

Figure 2: (a) Schematic Zijderveld diagram of the Lonar samples indicating a low temperature component that demagnetizes between 100-200°C and a high temperature component. (b) Schematic of the paleomagnetic results of the ejecta and basalt flows.