INTERPRETING LUNAR IMPACT DEMAGNETIZATION SIGNATURES USING LUNAR PROSPECTOR MAGNETOMETER/ELECTRON REFLECTOMETER DATA. J. S. Halekas[1], R. J. Lillis[1], M. E. Purucker[2], K. L. Louzada[3], S. T. Stewart[3], M. Manga[4], [1]Space Sciences Laboratory, U. C. Berkeley, [2]Raytheon at Planetary Geodynamics Lab, GSFC, [3]Dept. of Earth and Planetary Sciences, Harvard. [4]Dept. of Earth and Planetary Sciences, U.C. Berkeley. Corresponding author's e-mail: jazzman@ssl.berkeley.edu.

Introduction: Lunar crustal magnetization has proven enigmatic and difficult to interpret ever since the Apollo subsatellites first discovered its existence nearly forty years ago. Today, we still do not completely understand its properties or origin, though we know that impacts can modify its distribution, with large impacts capable of both creating and destroying crustal magnetization. In particular, many lunar craters have clear demagnetization signatures. If we can understand the physics of impact demagnetization, we can use these signatures as a way to probe the properties of pre-impact crustal magnetization. In this work, we construct crater demagnetization models and compare to observations in order to constrain the strength and coherence scale of lunar crustal magnetization.

Lunar crustal magnetic fields: Lunar Prospector (LP) measured the distribution of crustal fields over the entire lunar surface from orbit, using both electron reflectometer (ER) and magnetometer (MAG) data. Both maps [1,2] show crustal fields over much of the surface, with variable magnitude and polarity and non-uniform spatial distribution. Apollo surface magnetometers also measured fields which vary in polarity and magnitude over length scales of only a few km [3].

The largest regions of strong lunar crustal fields correlate with the antipodes of young large impact basins [4], suggesting an impact-related magnetization process. On the other hand, lunar impact craters of all sizes tend to show demagnetization relative to their surroundings [5,6], with some large basins displaying a secondary central magnetization signature [6]. The thermal and shock effects associated with hypervelocity impacts should both efficiently demagnetize target rocks in the absence of a strong global field. Observed demagnetization signatures, which often extend well beyond the crater rim (outside of regions which experience significant heating), suggest that shock plays a greater role than thermal effects at the Moon [6].

Impact demagnetization signatures: Impact demagnetization signatures depend both on the physics of the demagnetization process(es) and on the characteristics of pre-impact magnetization. If pre-impact magnetization has a coherence scale comparable to or larger than the crater, we should observe large fringing fields near the demagnetization boundary, due to the magnetization contrast. On the other hand, for coherence scales smaller than the crater, we expect to observe fewer edge effects. Fig. 1 shows two sample model runs where we created a randomly jumbled magnetization distribution with a given coherence scale J, completely demagnetized test craters, and calculated the average magnetic field radial profiles that a magnetometer would measure near the surface. Since even small lunar craters show few large edge effect fields (like pink line in Fig. 1), simulations like this one allow us to conclude that lunar crustal magnetization must have a relatively small coherence scale [5].

However, uncertainties in the physics of the demagnetization process make it difficult to quantify the coherence scale. For example, a more gradual transition between complete demagnetization and pristine pre-impact magnetization results in a significant reduction in fringing fields. The demagnetization response of native iron carriers on the Moon is not well known, but laboratory experiments on magnetic minerals show a gradual increase in demagnetization with applied shock [7,8,9], arguing for a more gradual demagnetization model. Shock demagnetization measurements therefore provide crucial constraints for models.

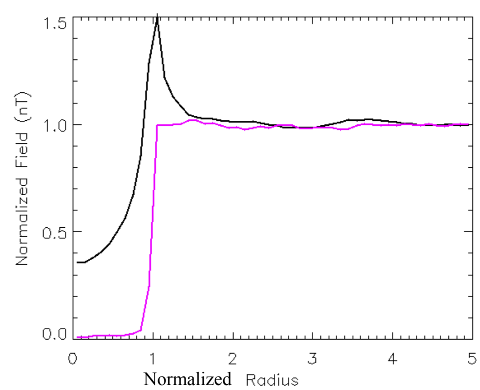

Figure 1. Average normalized radial profile of surface magnetic field for craters that demagnetized pre-existing magnetization with coherence scale twice the crater diameter (black) and coherence scale one eighth the crater diameter (pink).

Altitude variation: Though we normalized the profiles in Fig. 1, the field magnitude outside the demagnetized region can also help us determine magnetization properties if we have measurements at multiple altitudes. Fig. 2 shows how differently magnetic field magnitude varies with altitude for distributions of magnetization with different coherence scales.

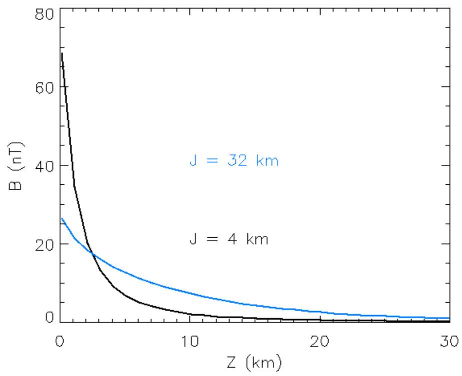

Figure 2: Average magnetic field B as a function of altitude Z for random distributions of magnetization with two different coherence scales J.

ER data: In order to determine the magnetic coherence scale, therefore, we want measurements close to the surface and at multiple altitudes. At the Moon, LP MAG and ER data provide just such constraints. However, the ER technique, rather than directly measuring the field like the MAG, uses measurements of electrons adiabatically reflected from crustal magnetic fields to infer the strength of the field at the surface. Therefore, we must understand the ER response to incoherent fields before we can use ER data to constrain the coherence scale. To achieve this end, we simulate millions of electron trajectories above regions with simple test magnetization distributions to determine how accurately the ER technique can measure the surface magnetic field, and show the results in Fig. 3.

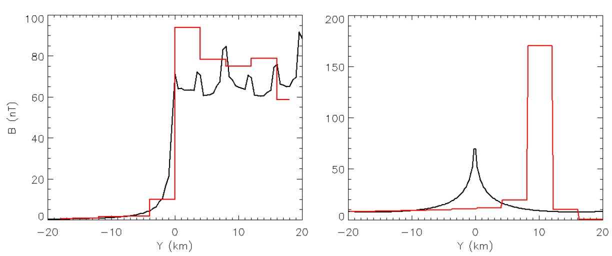

Figure 3: Simulated ER response across a boundary (at Y = 0) between two regions, with model surface field B in black and simulated ER data in red. Left panel shows a region with no magnetization next to a region with incoherent magnetization. Right panel shows a region with no magnetization next to a uniformly magnetized sheet.

For the cases we simulated, the ER technique infers surface fields which can differ by up to a factor of ~2-3 from the actual values. However, average fields in ~20-30 km bins generally correspond fairly closely, even for incoherent magnetization distributions (as in left panel of Fig. 3). For more coherent magnetization distributions, ER maps show some features offset from their true locations (as in right panel of Fig. 3) because of the large curvature of the field lines along which electrons travel. However, these discrepancies generally do not exceed a few tens of km. Given the ER intrinsic resolution (limited by electron gyrodiameter) of ~10 km, and the ER map resolution of >~30 km, we can accept these location errors. Our simulations suggest that we can safely use ER maps with data binned at resolutions of tens of km or larger.

Model/Data comparison: In order to fit the magnetic signatures of lunar basins, we specify the magnetic strength and coherence scale of the pre-impact magnetization, the shock demagnetization profile, and for some basins a form for the central magnetization. As an illustration, in Fig. 4 we show modeled and measured profiles for the multi-ring Nectaris basin (~860 km diameter), for a model with a magnetic coherence scale of ~50 km, gradually varying shock demagnetization, and a magnetized central uplift structure. This demonstrates that we can fit measurements rather well in some cases. However, we must now explore a much larger parameter space in order to determine the uniqueness of these models.

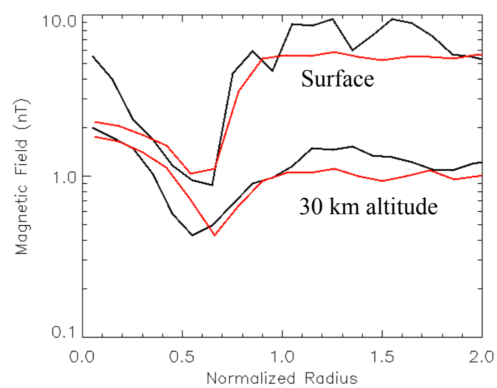

Figure 4: Modeled (red) and measured (black) average magnetic field radial profiles for the Nectaris basin, at the surface (ER data) and 30 km (MAG).

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