HIGH RESOLUTION MAPPING OF THE LUNAR CRUSTAL MAGNETIC FIELD. D. L. Mitchell, J. S. Halekas, R. P. Lin, K. A. Anderson, *Space Sciences Laboratory, Berkeley, CA 94720, USA*, M. H. Acuña, *NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*, A. Binder, *Lunar Research Institude, Gilroy, CA 95020, USA*

We present high resolution mapping of the large (~400 km) lunar crustal magnetic field anomaly filling the central part of the region antipodal to the Mare Crisium impact basin. There are strong magnetic fields of up to nearly a hundred nanotesla over much of the antipodal region, but there is also fine scale variation down to a scale of tens of kilometers or less. We also show several smaller anomalies of similar field strength, but only tens of kilometers to ~50 km in size, in the region north of the Crisium antipode.

The moon has no global dipole magnetic field [1]; however, lunar rocks were found to be magnetized, and measurements at the Apollo landing sites revealed magnetic patches in the crust with surface field strengths ranging from a few tenths of a nanotesla to hundreds of nanoteslas (1 nT = 10^{-5} Gauss) [2,3]. Measurements from orbit revealed that there were hundreds of these magnetic patches on the surface, ranging in size from <7 km, the resolution limit of the observations, to ~500 km [4]. Lunar rocks can be magnetized when they are heated or shocked in the presence of an ambient magnetic field. The observed crustal magnetization indicates that magnetic fields at the moon were much stronger in the past than they are today. Radioactive dating and magnetic testing of returned lunar samples indicates that strong (~0.1-1 Gauss) fields were present at the moon from ~3.9-3.6 billion years ago [5]. These fields may have been generated by an ancient (and now extinct) lunar dynamo.

The magnetometer and electron reflectometer (MAG/ER) on Lunar Prospector is designed to map crustal magnetic fields with high sensitivity (~0.01 nT) and spatial resolution (~4 km) over the entire lunar surface. Electron reflection magnetometry depends on the magnetic mirror effect, that is, the reflection of charged particles from regions of increased magnetic fields. The Sun and Earth's magnetosphere provide continuous fluxes of electrons with energies from a few electron volts (eV) to tens of keV. These fast moving electrons are guided in spiral paths by the interplanetary or Earth's magnetotail field lines, depending on which regime of space the Moon is situated in. The electron reflectometer (ER) compares the flux of electrons traveling along the magnetic field lines from the spacecraft to the Moon with the oppositely directed flux. If there is no crustal magnetic field, then the downward flux impacts the Moon and is absorbed. As the crustal field strength increases, more and more electrons are reflected before they can impact the surface. By measuring these reflected electrons we can remotely sense and map the lunar crustal magnetic field at high resolution.

Electron reflectometry has great advantages over other mapping techniques. Since we measure electrons that travel along magnetic field lines with minimal cross-field drift, our resolution is limited only by the gyroradius of the electrons, which is on the order of 5 km for 140 eV electrons. In comparison, mapping of the magnetic field by magnetometer from orbit has a resolution which is limited by the orbital altitude, about 100 km. Furthermore, the magnetometer can only detect crustal magnetic fields by measuring the small perturbations in the magnetic field detectable at orbital altitude, since magnetic fields drop off rapidly with distance. In effect, reflectometry overcomes this $1/r^3$ radial decrease in magnetic field strength and allows us to map the crustal fields with a high resolution from orbit.

We here present high resolution mapping of the region antipodal to the Crisium impact basin and northward. Crisium is a young (~3.85 billion years) large impact basin. There is a semicircular region of strong magnetic field approximately 300-500 km in diameter, with surface magnetic fields of up to about 80 nT, nearly directly antipodal to the center of the Crisium impact basin. The magnetic anomaly is strong enough to produce a 3 nT signal at the 88 km satellite altitude. Strong magnetic fields fill much of the inner antipode region (635 km radius); however, there are substantial variations in field strength within this region. While it is difficult to determine the longitudinal extent of small scale features since each consecutive orbit of the spacecraft is separated by ~30 km, we can determine the latitudinal extent of the fine scale structure down to our resolution limit of ~4 km. On virtually every orbit we see variations in magnetic field strength of up to tens of nanotesla over a range in latitude of only tens of kilometers. In some cases the crustal magnetic fields within the antipodal region appear to vary over a range as small or smaller than our resolution limit.

The correspondence of the surface magnetic fields with the Crisium antipodal zone strengthens the hypothesis that the crustal magnetization is associated with the formation of young large-impact basins. The hypervelocity (>10 km/s) impacts that form such large basins will produce a plasma cloud that expands around the moon in about five minutes, compressing and amplifying the pre-existing ambient magnetic field at the antipode [6]. The amplified field should remain for about a day before the cloud becomes too tenuous. Meanwhile, seismic energy from the impact is focused at the antipode, and basin ejecta arrives at the antipode within tens of minutes after the impact. The crust at the antipode is then shocked and magnetized in the amplified field. Paleomagnetic data from returned lunar samples imply a relatively stable 0.1-1 Gauss field around the Moon 3.9-3.6 billion years ago (perhaps from an ancient lunar dynamo), about the same time that the Crisium impact basin was formed.

The Crisium antipodal region is marked by swirl-like albedo markings, which have been observed to correlate with regions of strong surface magnetic field [7]. One hypothesis states that these albedo markings may result from magnetic deflection of the solar wind and, hence, depletion of the implanted solar wind hydrogen in the uppermost soil layers [8]. This hypothesis implicitly assumes that implanted hydrogen is a necessary component of the process that results in optical darkening of the lunar surface. If true, though, this hypothesis suggests that the magnetic field anomaly could be strong enough to deflect or even stand off the solar wind. This possibility is also supported by the discovery of magnetic field amplifications which may be associated with shocks from the deflection of the solar wind by crustal magnetic fields.

While perhaps not large enough to deflect the solar wind to any great extent, small anomalies of similar strength to the Crisium antipodal region have been discovered to the north of it. The largest of these is 100 km. across and lies northwest of the Crisium antipode at 5˚ s, 230˚ E. Its strength is comparable to the Crisium antipode, about 80 nT. Other anomalies with magnetic fields of ~50-100 nT and sizes of ~20-50 km across are located at 5˚. N, 250˚ E, 10˚ N, 245˚ E, and 25˚ N, 255˚ E. Other even smaller anomalies, most with field strengths on the order of tens of nanotesla or less, are scattered throughout the region to the north of the Crisium antipode. On a single orbit track it is sometimes possible to see up to ten or fifteen distinct magnetic field anomalies with strengths of a few nanotesla up to ~50 nT, and with an extent in latitude ranging from ~50 km down to our resolution limit of 5 km or possibly even less.

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