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

We present the first global maps of the lunar crustal magnetic field. These maps show the strong regions of crustal magnetic field in the regions antipodal to the young Imbrium, Serenitatis, and Crisium impact basins that were seen by the Apollo missions. In addition, they also show other magnetic anomalies seen by Apollo and some anomalies never before mapped.

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. Radiometric 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 the lunar 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. If magnetic anomalies are present on the surface, more electrons will be reflected back up the magnetic field lines from the surface. We detect these electrons at the spacecraft, allowing us to remotely sense the lunar surface magnetic field.

The polar orbit of the Lunar Prospector spacecraft allows us to survey the entire lunar surface, extending the mapping by the Apollo missions, which covered a belt of about 35 degrees latitude above and below the equator. Since the spacecraft is in a polar orbit, we map discrete tracks from south to north, and thus our resolution in latitude is the same as our resolution limit, ~4 km. However, adjacent orbit tracks are separated by ~30 km, and thus our longitudinal sampling is not as fine. Furthermore, we have not yet had the opportunity to map the entire lunar surface, so we have some gaps in our coverage. Therefore we bin our data into 5 degree by 5 degree bins, effectively reducing our resolution to ~150 km but improving our statistics. This lower resolution but higher sampling allows us to produce a smooth global map showing where the large scale regions of strong magnetic field are located.

The Apollo missions found the largest concentrations of strong crustal magnetic fields in regions antipodal to the Imbrium, Serenitatis, Crisium, and Orientale impact basins. We have mapped strong magnetic field regions antipodal to the first three of these impact basins. We have also begun mapping the Orientale antipode and have seen indications of strong crustal magnetic field, but have not yet completely surveyed it. The three large circular ringed basins whose antipodes we have mapped have ages between ~3.85 and 3.6 billion years, about the same as the most strongly magnetized returned samples. The impact basin antipodes are centered at 33˚S, 162˚E, 27˚S, 199˚E, and 18˚S, 239˚E respectively. The strong magnetic regions are large scale, ranging from hundreds of kilometers across for the Crisium region to over a thousand kilometers for Imbrium, and the magnetic fields in these regions vary from tens of nanoteslas to ~100 nT or more in the Imbrium region. By mapping the strong crustal magnetic fields in these three antipodal regions we have confirmed some of the main Apollo results. Furthermore, we have extended these results and shown that the regions of strong magnetic field in the Imbrium and Serenitatis antipodes extend southward of the Apollo mapping range and fill in the antipodal zones.

The correspondence of surface magnetic fields with the antipodal zones 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 could then possibly be 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 these impact basins were formed.

In addition to the three aforementioned areas, we have identified several other regions with strong magnetic fields. There is a region with magnetic fields of tens of nanoteslas antipodal to the Nectaris impact basin (a slightly older basin, ~3.92 billion years), centered at 16˚N, 214˚E. Southeast of the Imbrium and Serenitatis antipodes at around 55˚S, 180˚E, roughly antipodal to the Mare Frigoris impact basin, lies another region with magnetic fields comparable to the Imbrium and Serenitatis regions. Other regions with similar field strengths in the tens of nanotesla range which are not associated with
any impact basin antipodes are located at 70˚ N, 240˚ E, at 5˚ N, 310˚ E, north of the Imbrium antipode at 0˚ N, 160˚ E, and northwest of the Orientale antipode at 30˚ N, 60˚ E. The processes which may have formed these magnetic anomalies are not yet understood.

There are still regions of the lunar surface which we have not yet had an opportunity to map, and some regions where our sampling is not yet good enough to decisively resolve magnetic anomalies. As we get more data we anticipate being able to fill in the gaps in our global map and produce a truly global map of the lunar crustal magnetic field which will aid in determining how these magnetic anomalies were formed.

References


