ORIGIN OF STRONG LUNAR MAGNETIC ANOMALIES: MORE DETAILED MAPPING AND EXAMINATIONS OF LROC IMAGERY IN REGIONS ANTIPODAL TO YOUNG LARGE BASINS. L. L. Hood[1], N. C. Richmond[2], and P. D. Spudis[3]. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, USA (lon@lpl.arizona.edu); [2]Pima College, Tucson, Arizona, USA; [3]Lunar and Planetary Institute, Houston, Texas, USA.

Introduction: Previous work has found evidence that the largest concentrations of strong lunar crustal magnetic fields are in regions antipodal (diametrically opposite) to four young large lunar basins: Orientale, Imbrium, Crisium, and Serenitatis (e.g., ref. 1). In at least two cases (Orientale and Imbrium), unusual ``grooved and mounded'' or ``hilly and furrowed'' terrain is found on imagery and geologic maps in the same regions. This terrain has been interpreted as an antipodal consequence of these young basin-forming impacts: i.e., shocking by converging ejecta impacts (2) or converging seismic waves (3). A model has also been proposed for the production of the antipodal magnetization signatures involving shock remanent magnetization (SRM) of impacting basin ejecta in the presence of a transient magnetic field amplified by the expanding ionized vapor-melt cloud (4). Current evidence indicates that the ambient magnetic field during the lunar basin-forming epoch was produced by a core dynamo (5,6).

Here, we investigate further the existence of magnetization signatures and landform modification antipodal to young lunar basins by (a) producing more detailed regional crustal magnetic field maps at low altitudes using Lunar Prospector (LP) magnetometer data; and (b) examining Lunar Reconnaissance Orbiter Wide Angle Camera imagery. In addition, we address recent suggestions that the anomalies antipodal to Imbrium and Serenitatis may actually be associated with the South Pole-Aitken (SPA) basin (7,8).

Magnetic Anomalies on the South-Central Far Side: We first consider a large area on the south-central far side extending from 140°E to 210°E and from 50°S to 10°S. This area includes part of the SPA basin and adjacent highland terrain and contains the largest group of strong anomalies on the Moon. Most of the latter can be interpreted as concentrated near the antipodes of the Imbrium and Serenitatis basins but they can also be described as concentrated along the northwest topographic rim of the SPA basin.

Figure 1 shows a contour map of the 2D filtered scalar field magnitude at ~ 25 km altitude (produced using a direct mapping method described in ref. 6) superposed onto a partial geologic map of the region. As seen in the figure, the strong anomalies are concentrated along the northern topographic rim of SPA (location indicated by the heavy dashed line). One hypothesis for their origin is therefore that they are associated in some way with SPA. For example, it has been proposed that they are a consequence of deposition of iron-rich ejecta from the SPA impactor (7) or that they are a consequence of subsurface dike swarms that fed mare basalt patches within the basin rim (8).

However, as indicated by the partial geologic map, an alternate hypothesis is that these anomalies are a consequence of antipodal effects of the Imbrium and Serenitatis impacts. The blue shaded unit represents unusual ``grooved and mounded'' terrain that has been interpreted by most analysts to be a probable antipodal consequence of these basin-forming impacts. The tendency for these strong anomalies to be concentrated near the unusual terrain leads to the alternate hypothesis that the magnetic anomaly sources formed at the times of the Imbrium and Serenitatis impacts (4).

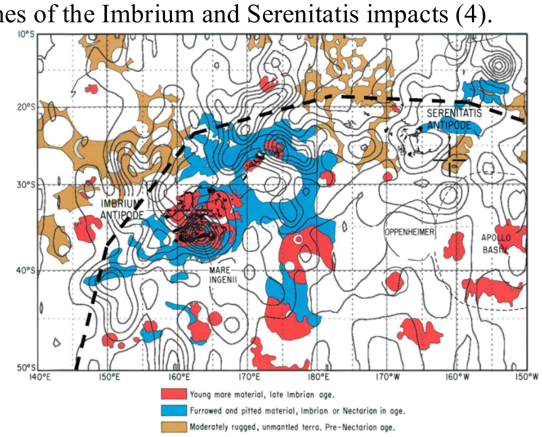

Figure 1

To distinguish between these two very different hypotheses, it is necessary to test further the antipodal magnetization mechanism by examining the antipodal regions of other young large basins as well as some isolated anomalies that are not antipodal to basins.

Basin Results: We consider here the eight youngest lunar basins according to Wilhelms (9). Of these, three do not show antipodal magnetic field or surface terrain signatures. However, the antipodal regions of two of these latter basins (Hertzsprung and Bailly) have been heavily modified by later events while the third (Sikorsky-Rittenhouse) is not clearly recognized as a basin. The remaining three basins (Orientale, Schrödinger, and Crisium) all have concentrations of strong anomalies near their antipodes. One of these (Orientale) has an extensive unit of ``furrowed and pitted'' terrain on geologic maps of the region that has been interpreted as being an antipodal consequence of the Orientale impact. A large concentration of strong anomalies is in the same area centered just southeast of the largest unit of unusual terrain.

The region around the Crisium antipode is marked by a large concentration of anomalies with relatively large amplitudes. The area is mostly overlain with ejecta from the Orientale basin, which is centered about 800 km to the east. Although examinations of LROC WAC imagery suggest that several craters may retain some evidence for grooved terrain in their walls, it is generally not possible to investigate whether any unusual (e.g., hilly and furrowed) terrain is present.

Schrödinger is one of the three youngest lunar basins but is smaller (310 km in diameter) than the other four basins with antipodal magnetic signatures. Mainly because of its south polar location, it has not previously been considered in this context. We have produced a contour map of the magnetic field at ~ 25 km altitude over the north polar region during the last year. This map shows only one large concentration of anomalies centered near 294^{o}E, 79^{o}N, or approximately 8^o of arc from the Schrödinger antipode. Examinations of LROC WAC imagery also yield evidence for possible antipodal landform modification in the same area where the magnetic anomalies are concentrated. In particular, possible grooved terrain is present in the walls of Froelich, which is located about 7^o of arc from the center of the group of strong magnetic anomalies.

Descartes Region: Although not antipodal to any lunar basin, the Descartes region near the Apollo 16 landing site is of special interest for two reasons: (a) It is the site of the strongest isolated magnetic anomaly on the Moon; and (b) it is characterized by unusual terrain (the Descartes Formation) that is similar to that present near the Orientale antipode. Crustal magnetic field maps of the region show that the isolated anomaly is centered over an area of higher albedo in the Descartes terrain just southeast of the landing site.

Previous (mainly photogeologic) investigations have established that the Descartes Formation consists primarily of basin ejecta materials from either the Imbrium event (e.g., ref. 13) or the Nectaris event (e.g., ref. 14). Examinations of LROC WAC imagery support this view. One recent study of radiometric ages and trace element compositions of Descartes breccias returned from the landing site has concluded that the Descartes terrain consists of Imbrium basin ejecta (12). Their trace element studies also indicated that ferroan anorthositic and KREEP-bearing rocks contributed to producing the breccia clasts, consistent with an origin in the Procellarum-KREEP terrane (PKT).

Conclusions and Discussion: Overall, the group of strong anomalies centered near the Schrödinger antipode and the unusual terrain in the same area provide further evidence of another antipodal magnetic and landform signature of a young lunar basin. This increases to five the number of young basins with probable antipodal signatures. While none of the five positive cases is individually convincing, the combination represents fairly compelling evidence that most strong lunar magnetic anomalies, including those near the northwest rim of SPA, originated as a consequence of antipodal effects of relatively young lunar basin-forming impacts. In view of evidence that other lunar anomalies (including the Descartes anomaly) have probable sources consisting of basin ejecta, the most probable mechanism for producing the antipodal anomalies is the deposition of converging ejecta, acquiring SRM in the presence of a magnetic field. It is possible that the antipodally converging ejecta was especially susceptible to strong magnetization because of shock-induced production of more single domain Fe-Ni remanence carriers, for example.

The numerical simulations of ref. 6 show that most ejecta impacting in the antipodal zone originate from the lower crust beneath the basin. The antipodal regions of young lunar basins should therefore show compositional anomalies as well as unusual terrain resulting from shock effects on the impacting ejecta. This expectation may be consistent with enhanced thorium abundances near the Imbrium antipode, as argued by Haskin (13), since the lower crust and upper mantle beneath Imbrium (the PKT) are known to be enriched in KREEP.

References: [1] Mitchell, D. L. et al. (2008) *Icarus*, 194, 401-409. [2] Moore, H. J. et al. (1974) *Proc. Lunar Sci. Conf. 5th*, 71-100. [3] Schultz, P. H., and D. E. Gault (1975) *The Moon,* 12, 159-177. [4] Hood L. L. and Artemieva N. A. (2008) *Icarus*, 193, 485-502. [5] Garrick-Bethell I. et al. (2009) *Science,* 323, 356-359. [6] Hood L. L. (2011) *Icarus,* 211, 1109-1128. [7] Wieczorek, M. A. et al. (2012) *Science,* 335, 1212-1215. [8] Purucker, M. E. et al. (2012) *J. Geophys. Res.,* 117, doi:10.1029/2011JE003922. [9] Wilhelms D. E. (1984) Chapter 6. *Moon, in The Geology of the Terrestrial Planets*, Michael H. Carr (editor), R. Stephen Saunders, Robert G. Strom, Don E. Wilhelms, NASA SP-469. [10] Muehlberger, W. R. et al. (1972), In: *Apollo 16 Preliminary Science Report,* NASA Spec. Publ. 315, pp. 6-1-6-81. [11] Spudis, P. D. (1993) *The Geology of Multi-Ring Impact Basins: The Moon and Other Planets,* Cambridge University Press, Cambridge, U.K., 263 pp. [12] Norman, M. D. et al. (2010) *Geochim. Cosmochim. Acta,* 74, 763-783. [13] Haskin, L. A. (1998) *J. Geophys. Res.,* 103, 1679-1689.