REGIONAL MAPPING OF THE LUNAR CRUSTAL MAGNETIC FIELD: CORRELATION OF STRONG ANOMALIES WITH CURVILINEAR ALBEDO MARKINGS.

L. L. Hood, A. Yingst, A. Zakharian, *Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721-0092, USA*, R. P. Lin, D. L. Mitchell, J. Halekas, *Space Science Laboratory, University of California, Berkeley, CA 94720, USA*, M. H. Acuna, *NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*, A. B. Binder, *Lunar Research Institute, Tucson, AZ 85747, USA.*

During the last eight months of the Lunar Prospector (LP) mission (Dec. 1998 - July 1999), the spacecraft was placed in a relatively low-altitude (15-30 km periapsis), near-polar orbit that allowed higher-resolution mapping of lunar crustal magnetic fields. We present here initial results from regional mapping of the strongest crustal anomalies using the magnetometer (MAG) instrument. The MAG measures the crustal field directly and therefore provides an optimally accurate map at the low spacecraft altitude. Global maps produced by the electron reflection (ER) technique have shown that the large-scale distribution of lunar crustal fields is related to that of young large basins. Specifically, fields are relatively weak near these basins but are strong near their antipodes (1). In addition, some field anomalies are present peripheral to Imbrium that appear to be related to the distribution of ejecta associated with this basin-forming impact (2). The two largest anomalies peripheral to Imbrium, the Reiner Gamma anomaly and the Rima Sirsalis anomaly, are aligned nearly radial to the center of Imbrium.

Using the high-resolution regional MAG maps, we report here a close correlation of the strongest individual crustal anomalies with the locations of unusual curvilinear albedo markings (hereafter referred to as “swirls”). This correlation is known in the case of the nearside Reiner Gamma albedo marking from limited mapping of Apollo 16 subsatellite MAG data (3). However, the LP MAG data are more complete and include low-altitude coverage over several of the more extensive groups of both magnetic anomalies and swirls on the lunar far side. Figure 1 is a map of the field magnitude at the spacecraft altitude ($\sim$ 18 km) across a section of western Oceanus Procellarum containing the prototypical Reiner Gamma albedo marking. The resolution is limited by the $\sim$ 30 km orbit track spacing. For scale, the crater Reiner at right center is about 30 km in diameter. Within the accuracy and spatial resolution of the measurements, the two largest anomalies correlate closely with the main Reiner Gamma albedo marking and with the largest single secondary swirl 120 km to the northeast.

Much more extensive groups of anomalies comparable to or larger in amplitude than the Reiner Gamma anomaly were detected on the lunar far side by both the LP ER and MAG (1). These more extensive groups of anomalies are centered approximately antipodal (diametrically opposite) to young large impact basins including Imbrium, Orientale, Crisium, and Serenitatis (4). Regional maps of the Imbrium and Crisium antipode anomaly concentrations show that the strongest field maxima correlate well with the locations of prominent swirls. In the Imbrium antipode region (Figure 2), the strongest single anomaly has a smoothed amplitude of 23 nT at a mean altitude of about 19 km. The anomaly peak is centered approximately on a group of swirls visible in the

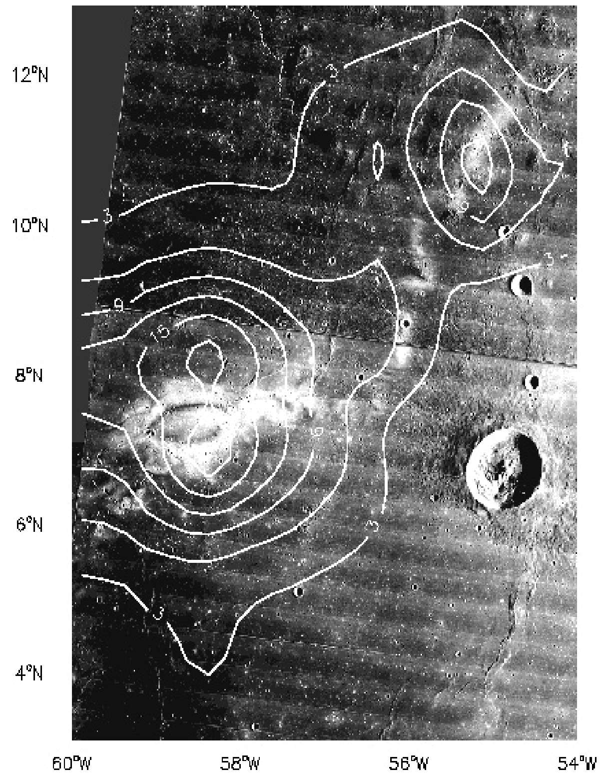

Figure 1: The Reiner Gamma Anomaly.

southern part of the Ingenii basin (5). An even stronger individual anomaly is present in the Crisium antipode region; it has a smoothed amplitude of 26 nT at an altitude of 24 km. Secondary anomalies with amplitudes of 18 and 16 nT are also nearby. This cluster of strong anomalies is centered approximately at 123°E, 23°S on a large group of swirls located on pre-Nectarian terrain just west of the main ejecta facies of the Orientale basin (5).

Two major models for the origin of the lunar swirls have been proposed since the discovery of the Reiner Gamma magnetic anomaly. The first model (6) argues that they represent regions of surface alteration by relatively recent cometary impacts; scouring (surficial mass removal) during such impacts is suggested to be the cause of their higher albedos and of their observed enhanced reflectivity at large solar illumination angles. According to this model, the associated strong magnetic anomalies are the result of magnetization of near-surface materials heated above the Curie temperature through hypervelocity gas collisions and micro-impacts. The second model (7) argues that the swirls represent exposed silicate materials

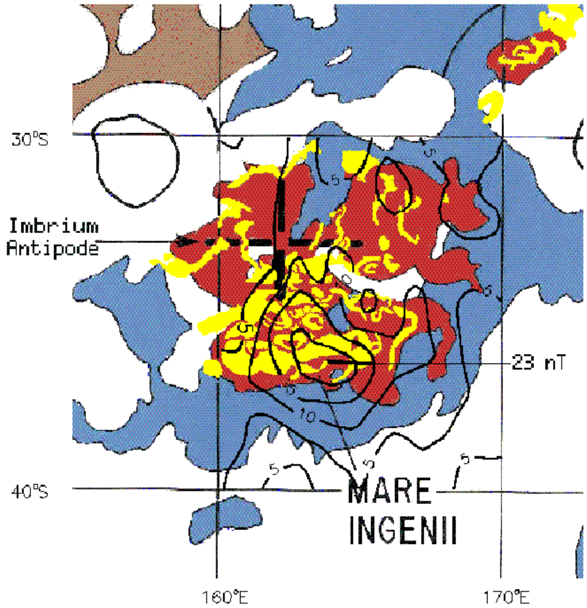

Figure 2: The Mare Ingenii Anomaly.

whose albedos have been selectively preserved via deflection of the solar wind ion bombardment by pre-existing strong crustal magnetic fields. According to this model, optical maturation or "space weathering" of exposed silicate surfaces in the inner solar system is at least partly a function of the solar wind ion bombardment.

Detailed spectral reflectance studies of Reiner Gamma, the only swirl accessible to ground-based optical remote sensing, have not clearly distinguished between the above models. These studies indicate that the surface composition of Reiner Gamma is a mixture of fresh highlands materials with much greater amounts of local mare basalt (8). No significant amounts of compositionally anomalous (i.e., cometary) materials are detectable. However, such anomalous materials may consist largely of volatiles that would have been lost as a result of solar heating and micrometeoroid impacts.

We suggest here that the LP MAG and ER data are more consistent with the solar wind deflection model than with the cometary impact model. First, energetic electron observations upstream of the Moon in the solar wind have shown that the strongest lunar magnetic anomalies are capable of deflecting the solar wind to form miniature ($\sim$ 100 km) magnetospheres (9). This is a necessary prerequisite for the validity of the deflection model. Second, the tendency for magnetic anomalies to be weak near young large impact basins and to be strong near their antipodes strongly indicates that basin-forming impacts occurring prior to 3.5 Gyr played a key role in determining the gross distribution of strong lunar fields. This tendency is difficult to explain via the cometary impact model, which would predict no relationship of strong anomalies (and associated swirls) with pre-existing surface geology. Physical models indicate that a basin-forming impact produces a dense, partially ionized vapor cloud that expands thermally around the Moon, forcing any ambient magnetic field outward and compressing it toward the antipode (10). The resulting field enhancement opposite to the impact point would then allow stronger magnetization to be acquired in these regions. The ambient magnetic field may have also been especially strong during the late basin-forming epoch ($\sim$ 3.6 – 3.9 Gyr) when lunar sample paleointensity data indicate the possible existence of an internal core dynamo (11). On the Moon, small metallic iron particles in the single domain size range (15–30 nm) are the main ferromagnetic carriers. These carriers are more prevalent in impact-generated breccias and fines (12). Strong magnetization of lunar crustal materials may therefore have occurred mainly by shock or rapid thermoremanence during ejecta deposition or as a result of the convergence of impact-generated seismic compressional waves (10).

The absence of a basin antipodal to Reiner Gamma, the strongest observed nearside anomaly, may appear to contradict the argument that basin-forming impacts determined the large-scale distribution of lunar crustal fields. However, ER maps (1) show that the Reiner Gamma anomaly is much smaller in combined amplitude and spatial scale than the farside anomaly concentrations that are antipodal to young large basins. As discussed in ref. 2, the Reiner Gamma anomaly is one of a series of anomalies located peripheral to this major young impact basin. A possible source for the Reiner Gamma anomaly is an unusually thick and/or strongly magnetized deposit of Imbrium basin ejecta lying beneath the visible younger mare surface.

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