LUNAR MAGNETIC STUDIES WITHIN THE LUNAR ARCHITECTURE. Lon L. Hood, Lunar and Planetary Lab, University of Arizona, 1629 E. University Blvd., Tucson, Arizona 85721, lon@lpl.arizona.edu.

Introduction: According to the currently planned Global Exploration Strategy and lunar architecture (www.nasa.gov/mission_pages/exploration/mmb/), the next stage of U.S. lunar exploration will consist of a series of robotic missions followed by short manned missions beginning in 2020 and a permanent outpost or base by 2024. The first robotic mission is the Lunar Reconnaissance Orbiter and Lunar Crater Observation and Sensing Satellite, to be launched together in 2008. The currently favored site for a permanent outpost is one edge of Shackleton crater near the South Pole. The lunar base will serve as a precursor to future manned missions to Mars.

One of the six Lunar Exploration Themes that emerged from the GES discussions is "Scientific Knowledge: Pursue scientific activities that address fundamental questions about the history of Earth, the solar system and the universe – and about our place in them." In this paper, I will discuss three fundamental scientific questions that can be directly addressed by both further analysis of existing lunar field data and new magnetic field measurements at the Moon. These measurements can be obtained during the course of the next stage of U.S. lunar exploration within the framework of the current lunar architecture.

Scientific Questions: At least three basic scientific questions that can be addressed using existing and future lunar magnetic measurements are: (1) What is the size of a lunar metallic core and what are the implications for the early history of the Earth-Moon system? (2) Are large-scale impacts alone able to produce crustal magnetism on airless silicate bodies in the solar system? (3) What are the causes of optical maturation (darkening with time) of airless silicate body surfaces in the solar system? The existence and size of a metallic core is a basic constraint on lunar origin models and, indirectly, on the early history of the Earth. Answering the second question requires a better understanding of the magnetic effects of large-scale impacts and whether a former lunar core dynamo is needed to explain the observed crustal magnetism. If a core dynamo did exist, then a major constraint on planetary dynamo theory would be imposed. The third question relates to the origin of the Reiner Gamma-type albedo markings and whether they are caused, at least in part, by magnetic deflection of the solar wind ion flux.

Work Using Existing Data: The most complete set of magnetometer and electron reflection measurements of magnetic fields near the Moon was obtained during 1998 and 1999 by instruments on the polar orbiting Lunar Prospector spacecraft [1-5]. So far, these data have supported earlier results from Apollo data indicating that (a) the lunar metallic core is relatively small, representing no more than 3% of the lunar mass; (b) the largest concentrations of crustal magnetization occur antipodal to the four youngest large basins, suggesting an impact-related origin; and (c) the strongest individual anomalies, which are capable of deflecting the solar wind, correlate closely with unusual swirl-like albedo markings (e.g., Reiner Gamma).

Induced Dipole Moment Measurements. For several days each month, the Moon is exposed to a relatively steady, nearly uniform magnetic field as it traverses a lobe of the geomagnetic tail. The lunar induced dipole moment is a measure of the residual response of the interior to a sudden exposure to such a field in a near-vacuum environment. If it can be assumed that the induced moment is caused by the presence of a highly electrically conducting core, then the core radius can be inferred [6 and refs therein]. Initial measurements of the induced moment were reported using 21 orbits of LP magnetometer data occurring in April 1998 [7]. These measurements yielded an estimated core radius of 340 ± 90 km, which is comparable to that inferred from laser ranging data [8]. For an iron-rich composition, the core mass would be 1 to 3% of the lunar mass. Such a core mass suggests an influence of the Earth on lunar formation, e.g., the giant impact model. Although additional passages of the Moon through the geotail occurred during the LP mission, these later passages have not yet been analyzed in detail. Further work to test and confirm the initial LP measurements would therefore be very useful.

New Maps of the Crustal Field. Although the LP ER measurements have yielded near-global maps of the crustal field magnitude, the LP MAG data have so far only been used to produce regional maps of the vector field [2,4,5]. This is due mainly to the low amplitudes of the lunar fields, which require mapping only during selected times when there is little interference from the solar wind. More work is needed to produce maps with improved coverage from the existing data using better selection and altitude-normalization techniques. Preliminary new maps of this kind promise to yield first-order additions to existing knowledge. For example, recent low-altitude mapping on the lunar far side indicates that magnetic anomalies tend to be enhanced near the northern and western periphery of the South Pole-Aitken basin [9,10]. This new finding could provide basic insights into how and whether basin-forming impacts produce lunar crustal magnetization. Implications for the origin of geochemical anomalies in the northwest sector of SPA may also follow [10].

Estimated Directions of Magnetization. Improved mapping of the existing LP data can potentially allow an "inversion" of relatively isolated, dominantly dipolar anomalies to infer the bulk directions of magnetization of anomaly sources. This would, in turn, constrain the nature of the magnetizing field (dynamo field centered in the planet or transient fields generated by the interaction of impact vapor clouds with, e.g., a pre-existing solar wind field). Of special interest in this regard are magnetic anomalies located at the centers of some impact basins [11], which would constrain the nature of the magnetizing field at the impact point.

Associations With Swirls. Improved mapping of the existing LP data can also be applied to study further the detailed structure of magnetic anomalies associated with Reiner Gamma-type albedo markings. Using these data, it should be possible to test further the solar wind deflection model [12,13] for the origin of these surficial features and the nature of the anomaly sources (for a recent effort in this direction, see ref. [14]).

The Need for New Data: Although improved maps of the lunar crustal magnetic field can be constructed using existing LP MAG data, complete coverage of the Moon will not be possible without new orbital magnetometer measurements. This is because the LP spacecraft tended to pass over the same regions during successive lunations when the external plasma conditions were optimal for measuring weak crustal fields (i.e., mainly the geomagnetic tail lobes). The same may be true for future lunar orbital missions that are currently planned. In order to obtain full coverage, careful planning of orbital parameters in advance and a long mission duration (> 2 years with a low-altitude periapsis) to ensure a variety of orbit plane orientations, is necessary. To reduce external solar wind and magnetospheric disturbances, it would also help to carry out the mission during solar minimum conditions (e.g., ~2015-16). The result would be both improved maps of the lunar crustal field and refined estimates of the lunar induced moment in the geomagnetic tail (because of the reduced noise near solar minimum).

In addition to new orbital measurements, major advances in our understanding of the paleomagnetism and the nature of the Reiner Gamma-type swirls could be achieved through sample returns and surface measurements of magnetic fields and solar wind plasma fluxes. These measurements and sample retrievals could be done either during robotic missions or during manned missions, or both. On the near side, obvious targets include the Descartes mountains near the Apollo 16 landing site [4] or Reiner Gamma itself on western Oceanus Procellarum [2]. At the Descartes mountains location, the proposed source materials (basin ejecta) are directly exposed at the surface. At Reiner Gamma, they are buried beneath a relatively thin layer of mare basalt flows. Sample returns and surface magnetometer measurements at both sites would confirm the identity of the sources. Sample returns, surface magnetometer and solar wind spectrometer measurements would directly test the solar wind deflection model for the origin of the swirls.

New surface magnetometer measurements, combined with simultaneous orbital magnetometer data could also be used to electromagnetically sound the deep interior. This has previously been done using Apollo surface and Explorer 35 magnetometer data (e.g., [15]). However, a limitation of those studies was intercalibration errors between the magnetometers. Future measurements, using more accurately intercalibrated instruments would yield improved constraints on the lunar electrical conductivity profile. The latter profile, when combined with improved laboratory data, can be used to more accurately bound the present-day temperature profile (e.g., [16,17]).

Conclusion. Further analysis of existing Lunar Prospector magnetic field measurements and acquisition of future improved surface and orbital measurements as well as returned samples in preparation for the next phase of manned lunar exploration will help to resolve at least three fundamental solar system science issues. These issues relate directly to our understanding of the history of airless silicate bodies in the solar system (Moon, Mercury, asteroids) and, indirectly, to the earliest history of the Earth.

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