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A Newly Mapped Magnetic Anomaly in the Imbrium Basin and its Paleomagnetic Pole Position

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Introduction

During the last year, more detailed mapping of Lunar Prospector and Kaguya magnetometer data at low altitudes within Imbrian-aged lunar impact basins has confirmed the existence of at least one moderately strong and isolated anomaly within the Imbrium basin [1]. This anomaly is located just northwest of Timocharis crater. It is relatively isolated and dominantly dipolar, making it a good candidate for modeling to estimate the bulk direction of magnetization of the source material. It is located well within the basin and most probably results from magnetization via slow cooling of subsurface impact melt rocks in the presence of a steady, long-lived magnetizing field, i.e., the former core dynamo field.

Assuming that the dynamo field was dominantly dipolar and centered in the Moon, the derived magnetization direction should yield a determination of the paleomagnetic pole position at the approximate time when Imbrium formed (~ 3.9 Gyr ago). Further assuming that the former lunar dynamo behaved as do most current planetary dynamos (e.g., Earth, Mercury, Jupiter, and Saturn), the paleomagnetic pole position would indicate the approximate location (within a few tens of degrees) of the paleorotational pole.

In this paper, we report results of modeling the Imbrium anomaly for the purpose of estimating its paleomagnetic pole position.

Data and Methods

DATA: Figure 1 (from [1]) shows contour plots of the radial field component and the field magnitude within the Imbrium basin at a constant altitude of 15 km. The contour interval is 0.4 nT. An equivalent source dipole technique was used to produce these plots using Lunar Prospector magnetometer data from April of 1999. The resulting mean field values within one-third by one-third degree bins were smoothed two-dimensionally using a 3 × 3 boxcar filter (i.e., 1° longitude by 1° latitude). The effective noise level of the map is ~ 0.4 nT so only the relatively strong isolated anomaly located about 100 km northwest of Timocharis crater is verified to be real in the interior of the basin. As seen in the lower panel, the smoothed field amplitude reaches a peak of ~ 1.8 nT at this altitude.

METHODS: Two independent methods for modeling the anomaly to derive an estimate for the bulk direction of source magnetization and the corresponding paleomagnetic pole position have been employed.

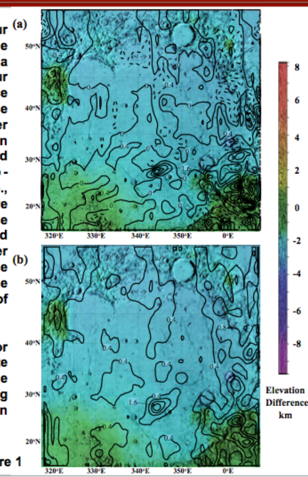

Figure 1

Method 1: Iterative Forward Modeling

METHOD 1: An iterative forward modeling method is applied in which the source of the anomaly is assumed to consist of a single uniformly magnetized body. The declination (defined as the angle measured clockwise between true north and the projection of the magnetization vector onto the horizontal plane) is first estimated as 151° E from the radial field component map by drawing a line from the negative anomaly maximum to the positive anomaly maximum, assuming that the magnetization direction is upward [2]. The inclination (defined as the angle between the magnetization vector and the downward side of the horizontal plane) is estimated by trial-and-error calculations with the declination held constant. An elliptical tabular source body with various locations, depths, and thicknesses is assumed. Figure 2 shows results for two assumed locations (red and black ellipses in the upper left diagram) and a series of possible depths and thicknesses. In general, these results suggest that the inclination ranges between about -29.8° and -31.8° and is minimally affected by variations in the source's position and thickness, provided that the declination is known.

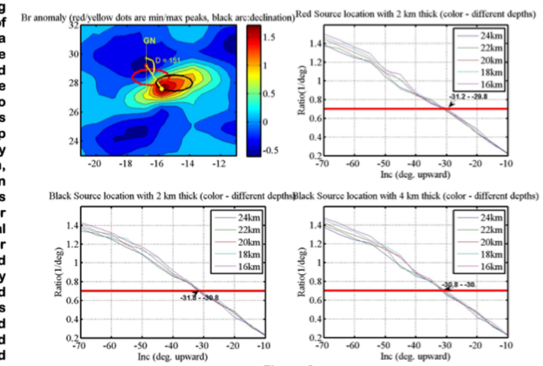

Figure 2

For either of the two source locations shown in the upper left diagram, the estimated declination of 151° E and inclination of -31° yield a paleopole location at about 61° N and 123° W (237°E).

Method 2: Parker's Inversion Method

The second method is that of Parker [3], which was originally designed to study seamount magnetization on Earth. This method has recently been applied to model a series of mainly highland lunar magnetic anomalies by Oliveira and Wieczorek [4] using the global Tsunakawa et al. [5] vector crustal field maps at 30 km altitude. In this method, an array of equally spaced magnetic dipoles is placed over the region of interest, each with magnetic moment $M(s_i) = m\ m(s_i)$, where m is the direction of magnetization, and where $m(s_i)$ is the dipole moment at position s_i. The array is fixed at the surface and the dipole moment amplitudes and their uniform orientation are varied until a minimum rms misfit is obtained. An advantage of the method is that no assumptions are made about the geometry and location of the source body or bodies. It only assumes that the direction of crustal magnetization is constant in the region of interest.

Inversion results for the Imbrium anomaly are shown in Figure 3. The left panel shows the observed radial field component at 15 km altitude. The outer circle outlines the 3° radius region where observations are considered. The inner dashed circle outlines the region where dipole sources are assumed to exist. The second panel shows the model radial field component and the third panel shows the observations - model difference. The right panel shows the distribution of non-zero model dipole moments. The best fit direction of magnetization (Inc, Dec) is -56°, 156° and the paleomagnetic pole position is at 71°W, 67°N. The rms misfit of the model radial field component from the observed radial field component is 0.18 nT Figure 4 plots the RMS misfit versus (top) the pole position location; and (bottom) the inclination and declination of the magnetization vector. Both plots take into account an 0.4 nT estimated uncertainty of the magnetic field maps. Also shown for comparison in the top panel is the paleopole estimated by iterative forward modeling. The two paleopole estimates are in agreement within the uncertainties of the analysis.

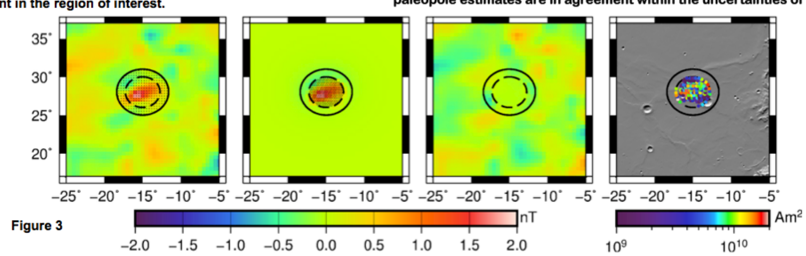

Figure 3

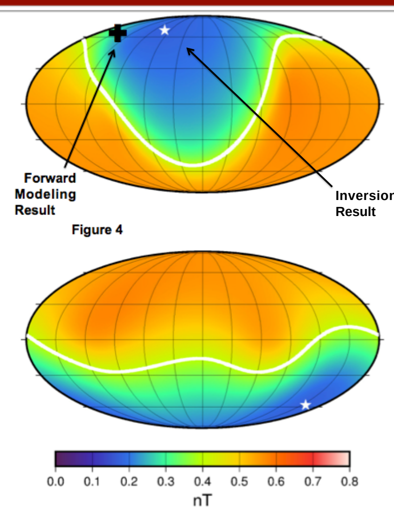

Figure 4

Conclusions

- Although the derived paleomagnetic pole position estimates have significant uncertainties, a high-latitude pole position is preferred by both iterative forward modeling and Parker's inversion method for the time of the Imbrium impact (~ 3.9 b. Y. ago).
- These magnetic anomaly modeling results therefore do not require any true polar wander since Imbrium formed or a dynamo field whose dipole moment was not aligned with the rotation axis when Imbrium formed.
- A dominantly dipolar and relatively isolated anomaly is most suitable for modeling to infer an accurate direction of magnetization.
- Future low-altitude measurements over this anomaly will allow more accurate crustal field maps and a more accurate inferred paleomagnetic pole.

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