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Testing the lunar dynamo hypothesis using global magnetic field data

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Abstract

We test the lunar dynamo hypothesis by modeling the magnetization directions of isolated crustal anomalies on the Moon. Although some of our modeled paleopole locations coincide with the current rotational axis of the Moon, the ensemble trace out a great circle from the north to south pole along 90°W and 90°E longitude. This behavior could be a result of a circulating dipole axis, true polar wander, or a predominantly quadrupolar field. We are currently implementing Parker's [1] method for calculating magnetization directions in order to assess the uniqueness of these paleopole positions.

1. Introduction

Although the Moon does not presently have a magnetic field generated by its core, it is possible that in early lunar history the core might have once powered a geodynamo. Such a field, if directionally stable, could have magnetized lavas and impact melt sheets at the surface and magmatic intrusions deep in the crust. However, some of the strongest magnetic anomalies appear to be correlated with the antipodes of large impact basins, and this has led to the alternative hypothesis that transient magnetic fields generated during impacts might be responsible for magnetizing portions of the lunar crust [see 2,3,4].

We have previously shown [5] that the magnitudes of the magnetic anomalies present in some Nectarian-aged impact basins require the presence of a few kilometers of uniformly magnetized metal-rich impact melts. The slow cooling timescales of such thick deposits require a stable magnetic field, which would most plausibly be generated by a core dynamo. In this work, we further test the dynamo hypothesis by modeling the magnetization directions of isolated crustal magnetic anomalies. From these directions, we determine the corresponding paloepole locations by assuming that the magnetizing field was dipolar and of internal origin. The dipole hypothesis is then assessed by comparing the calculated paleopole locations with the current rotational axis of the Moon.

2. Paleopole Modeling

Using the global magnetic field model of Puruker [6], we have identified 16 isolated magnetic anomalies that are predominantly dipolar in appearance. Our first approach was to model these anomalies as being the result of a uniformly magnetized cylindrical disk at the surface of the Moon. Fixing the disk to have a thickness of 1 km, a conjugate-gradient technique was used to determine the disk location, disk radius, and magnetization vector that best fit the observations. We have also performed inversions where we solved for the depth of the disk below the surface, as well as its thickness, but the magnetization directions were found to be unchanged for these calculations.

Assuming that the 16 magnetic anomalies were magnetized by a global dipolar field, we next calculated the paleopole locations that correspond to each magnetization direction. Given the plausibility that a lunar core dynamo, if present, would have reversed several times, we plot both the north and south magnetic poles in Figure 1, and consider each of these to be a possible paleopole location. This figure shows that our calculated paleopoles are decidedly non-uniformly distributed across the surface of the Moon. Though some paleopoles coincide with the current rotational axis of the Moon at the geographic north and south poles, the ensemble of paleopole locations appear to trace out a great circle from the north to south pole along 90°W and 90°E longitude.

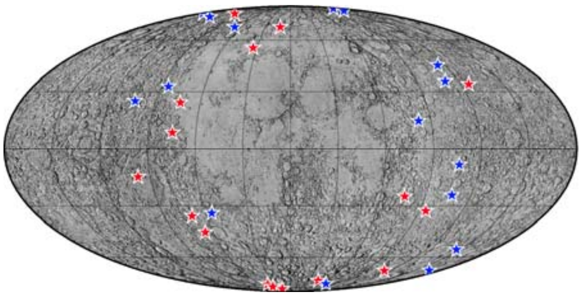

Figure 1. Paloepole locations of 16 isolated magnetic anomalies on the Moon, where the north magnetic poles are plotted in red and the corresponding south magnetic poles are plotted in blue. The base map is a shaded relief map displayed in a Mollweide projection centered on 0° longitude.

3. Interpretation

The non-uniform distribution of our calculated paleopole locations can be interpreted in several ways.

First, it is possible that the Moon once possessed a core dynamo that generated a dipolar field, but that the axis of this dipole was not fixed to the rotational axis. Dynamo simulations for the Moon that take into account possible hemispheric variations in heat flow out of the core indeed predict that the dipole axis would circulate along a single great circle path [7].

Second, it is possible that the early Moon once possessed an internally generated dipolar field that was aligned with the rotational axis, but the that solid portion of the Moon underwent a significant amount of true polar wander. This hypothesis was originally proposed by Runcorn [8] to explain his paleopole calculations that were based on the Apollo equatorial magnetic field data. For this hypothesis to hold, the Moon would need to undergo about 90 degrees of true polar wander, and this would be most easy to account for if temporal variations in the mass distribution of the Moon led to an interchange of its maximum and intermediate moments of inertia (a process known as inertial interchange true polar wander).

A third possibility is that the Moon once possessed a dynamo, but that the field was predominantly quadrupolar. For the case of a pure quadrupolar field, it can be shown that the crustal magnetization directions would give rise to "apparent" paleopole locations that would be distributed along a single great circle path.

4. Conclusions

The above interpretations are based upon the validity of our modeled magnetization directions, and these are currently being improved in several ways. First, we will redo our calculations using the improved global magnetic field model of Purucker and Nicholas [9]. Second, we will invert for the magnetization directions using an alternative method that was originally developed by Parker [1] for the interpretation of seamount magnetization. Instead of modeling the magnetic field data under the assumption of uniform magnetization with specified source geometry, Parker's [1] method assumes that the magnetization within each source region is unidirectional and can vary in intensity. For a specified magnetization direction, the magnetic intensities are solved for using a non-negative least squares inversion, and the best fitting magnetization direction is obtained by calculating the misfit between the model and observation for all possible directions. A benefit of this approach is that it can be applied not only to isolated magnetic anomalies, but also to complex regions such as those on the farside of the Moon. Furthermore, the calculation of confidence intervals on the paleopole directions is considerably more straightforward than our model that uses uniformly magnetized cylindrical disks.

References

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