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Testing the Axial Dipole Hypothesis for the Moon by Modeling the Direction of Crustal Magnetization

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Magnetic field maps of the Moon show that there are strong magnetic anomalies of crustal origin distributed heterogeneously across the lunar surface. However, the origin of the fields that magnetized the crust are not understood and could be the result of either a long-lived core generated dynamo or transient fields associated with large impact events. Core-dynamo models usually predict that the field would be predominantly dipolar, with the dipole axis aligned with the rotation axis. In this case, the direction of crustal magnetization would vary with planetary latitude, just as on Earth. We test this hypothesis by modeling the direction of crustal magnetization using spacecraft-derived magnetic field data. From the direction of magnetization, we calculate the corresponding paleopole, which we define as the north magnetic pole of a predominantly dipolar core-generated field when the anomaly was formed. The dipolar core field hypothesis will be confirmed if the paleopoles cluster in one or two regions. We use the Parker method, originally developed to study seamounts magnetism, to invert for the direction of crustal magnetization associated with isolated lunar magnetic anomalies. This method largely bypasses the non-uniqueness associated with specifying the geometry of the magnetic sources. The only assumption is that when the region acquired a remnant magnetization, the main field was constant in direction. In practice, unidirectional equivalent source dipoles are placed on the surface within a circle of specified radius over a region that encompasses an isolated anomaly. For an assumed direction of magnetization, we solve for the magnetic moments of the dipoles and determine the misfit between the model and observations using a non-negative least squares inversions approach. The inversion naturally finds those dipoles that are non-zero, as well as their intensities. For our inversions we use global gridded magnetic field maps at 30 km altitude with a resolution of 0.5°, based on Lunar Prospector and Kaguya magnetometer observations. The paleopoles are not randomly located on the surface, as might be expected for magnetizing fields associated with impact events. Though a few paleopoles are associated with the current geographic poles, several well constrained anomalies have paleopoles at equatorial latitudes. Several hypothesis exist for this distribution of paleopoles, but one of the more convincing is that the Moon possessed a long-lived dipolar field, but that the dipole axis was not fixed to the rotation axis as a result of large scale heat flow heterogeneities at the core-mantle boundary.