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A search for a crustal magnetization signature of variations in insolation at Mercury

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1. Introduction

Spatial variations in insolation on Mercury could give rise to long-wavelength variations in the depth to the Curie isotherm for a given magnetic mineral. Global-scale magnetic fields can result from remanent crustal magnetization in such an environment [1]. Magnetic field data from previous flybys and from the first 108 MESSENGER orbits around Mercury indicate that most of the signal can be explained by a dipole field of core origin and associated magnetospheric currents, rather than by a long-wavelength crustal field. Here we examine residual fields that remain after the removal of the main core and external fields and test for signatures of remanent crustal magnetization due to variations of insolation with latitude and longitude.

2. Approach

Large-scale longitudinal variations in near-surface temperatures arise from the combination of Mercury's high eccentricity with its 3:2 spin-orbit resonance. The Sun is directly overhead at longitudes 0° or 180° at perihelion and at longitudes 90° or 270° at aphelion. As a consequence, the average annual surface temperature at the equator is 130 K higher at longitudes 0° and 180° (hot poles) than at 90° and 270° (cold poles). Temperatures are symmetric about the equator, and about longitudes 0°, 90°, 180°, and 270°. These symmetries provide a distinctive signature and may have left an imprint in lithospheric properties [2] including magnetization [1]. Such an imprint may have been extensively altered by impact and volcanic processes.

We use a thermal model [3,4] previously developed for Mercury. We calculate near-surface thermal boundary conditions for models of Mercury's crust, after accounting for a surficial regolith of low thermal conductivity and low density (Fig. 1, left).

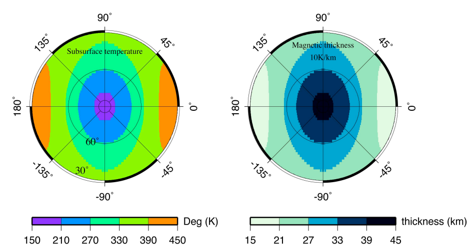

Figure 1. Modeled [4] average annual temperature below the attenuation depth of the surface temperature oscillation (left). Magnetized crustal thickness (right) determined from these thermal boundary conditions, an assumed magnetic carrier (magnetite), and a lithospheric thermal gradient of 10 K/km. Azimuthal equidistant polar projection.

This approach, coupled with an assumed vertical thermal gradient, predicts large-scale variations in the thickness of the layer (Fig. 1, right) capable of carrying a magnetic signature, either induced or remanent. Spherical harmonic expansions of these predicted large-scale thickness variations are dominated by (n,m) = (2,0), (2,2), and (4,0) terms. These map to dominant (n,m) = (1,0), (3,0), and (3,2) terms in the magnetic Gauss coefficients. The presence of a significant (1,0) term led to the suggestion that this process might explain Mercury's small global magnetic field [1]. To test this idea, a constrained least-squares solution was fit to flyby observations, using only these low-degree terms in the spherical harmonic expansion [5]. Regularized solutions were found for the internal field in which terms other than these were allowed but damped [6]. In both of these studies these Gauss coefficients were found to be inconsistent with the proposal that Mercury's global magnetic field is the result of such a mechanism.

3. Results

We confirm this earlier result with magnetic field observations collected through the first 54 days of MESSENGER's orbital phase, which now covers Mercury's entire northern hemisphere. The absence of features in the colatitudinal component at 60°N and the longitudinal symmetry of features in the radial component are inconsistent with predictions of the thermal model.

Further analysis of the magnetic field observations has been performed utilizing a magnetospheric model [7,8] of Mercury that describes the large-scale internal (offset dipole) and external (magnetopause and cross-tail currents) magnetic fields associated with the planetary system, as mediated by the solar wind. Given choices for the standoff distance to the magnetopause (1.35 R_M, where R_M is Mercury's radius) and the magnitude (-207 R_M nT^3) and offset (0.195 R_M northward) of the planetary dipole from other modelling efforts [e.g., 8, 9], we find residuals to this model that indicate the presence of systematic, unmodeled magnetic fields of internal origin. The character of these residuals is stable with respect to moderate changes in model parameters. Complete local time coverage and repeat coverage of the northern hemisphere, both of which will render the solutions more robust, must await completion of the first six months of orbital observations.

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